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Research Triangle Park, NC 27711

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Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations--Background Information for Proposed Standards

Volume I

NESHAP

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Volume I

U. S. Environmental Protection Agency
Office of Air and Radiation
Office of Air Quality Planning and Standards
Research Triangle Park, NC 27711

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ABBREVIATIONS USED IN THIS DOCUMENT

A	= ampere
acfm	= actual cubic feet per minute
acmm	= actual cubic meters per minute
Ah	= ampere-hour
ANSI	= American National Standards Institute
atm	= atmospheres
BACT	= best available control technology
BID	= background information document
CAA	= Clean Air Act
cm	= centimeter
cm^2	= square centimeter
cm^3	= cubic centimeter
°C	= degrees centigrade
Cr	= chromium
Cr^2	= chromium (II)
Cr^6	= hexavalent chromium
CrO_3	= chromium anhydride, commonly known as chromic acid
ΔP	= pressure drop
dscf	= dry standard cubic foot
dscfm	= dry standard cubic feet per minute
dscm	= dry standard cubic meter
EO	= Executive Order
°F	= degrees Fahrenheit
ft	= foot
ft^2	= square foot
ft^3	= cubic foot
g	= gram
GACT	= generally available control technology
gal	= gallon
gal/min	= gallons per minute
gr	= grain
hr	= hour
hp	= horsepower
in.	= inch

$in.^2$	= square inch
in. w.c.	= inches of water column
kg	= kilogram
kPa	= kilopascal
kW	= kilowatt
L	= liter
L/G	= liquid to gas [ratio]
LAER	= lowest achievable emission rate
lb	= pound
lb_f/ft	= pound force per foot
m	= meter
m^2	= square meter
m^3	= cubic meter
MACT	= maximum available control technology
mg	= milligram
Mg	= megagram
mil	= thousandth of an inch
min	= minute
MW	= megawatt
μg	= microgram
μm	= micrometer
NEPA	= National Environmental Policy Act
NESHAP	= national emission standards for hazardous air pollutants
ng	= nanogram
NSPS	= new source performance standard
OSHA	= Occupational Safety and Health Administration
oz	= ounce
P	= pressure
psi	= pounds per square inch
PVC	= polyvinyl chloride
RACT	= reasonably available control technology
RCRA	= Resource Conservation and Recovery Act
RFA	= Regulatory Flexibility Act
RIA	= Regulatory Impact Analysis
SIC	= Standard Industrial Classification (code)

TLV	= threshold limit value
V	= volt
wt	= weight
yr	= year

GLOSSARY OF ELECTROPLATING TERMS

Activation:	Process in which the conductivity of the part to be plated is increased.
Ampere:	Current flowing at a rate of one coulomb per second.
Anion:	A negatively charged ion.
Anode:	The electrode at which current enters or electrons leave the solution; also, the positive electrode at which negative ions are discharged, positive ions are formed, or at which other oxidizing reactions occur.
Anodizing:	A surface treatment of metals, particularly aluminum; the part to be plated serves as the anode and an oxide film is produced as an integral part of the base metal.
Baffle:	A device used to regulate the flow of gas by deflecting the gas.
Base metal:	The underlying metal or alloy system onto which the plated metal is deposited; for example, in the chromium electroplating of steel in the automotive industry, the steel is the base metal.
Brightener:	An agent added to electroplating baths that helps form a bright plate or improves the brightness of the deposit.
Bright plating:	Electroplating to provide a highly brilliant or polished-appearing surface; most decorative plating is done with brighteners.
Buffing:	Smoothing a surface using fine abrasive particles in liquid suspension, paste, or grease stick form.

Burnt deposit:	A rough, noncoherent, or otherwise unsatisfactory deposit produced by the application of excessive current density and usually containing oxides or other inclusions.
Bus (bus bar):	A rigid conducting section, usually copper, for carrying current to the anode and cathode bars.
Capture efficiency:	A measure of the effectiveness of a ventilation system to overcome opposing air currents and direct contaminated air from the process vessel into the ventilation hood.
Capture velocity:	Air velocity at any point in front of the ventilation hood or at the hood opening necessary to overcome opposing air currents and to capture the contaminated air at that point by causing it to flow into the hood.
Cathode:	The electrode through which current leaves or electrons enter the solution; the negative electrode. Also, the electrode at which positive ions are discharged, negative ions are formed, or other reducing reactions occur. In electroplating, the cathode typically is the workpiece to be plated.
Cathode efficiency:	The current efficiency of a specified cathodic process.
Cation:	A positively charged ion.
Chemical fume suppressants:	Surface-active compounds that reduce or suppress fumes at the surface of a solution.
Chromic acid:	The common name for chromium anhydride (CrO_3).
Cleaning:	The removal of grease or other foreign material from the surface of a part.

Alkaline:	Cleaning by means of an alkaline solution.
Anodic (reverse):	Electrolytic cleaning in which the workpiece is the anode.
Cathodic (direct):	Electrolytic cleaning in which the workpiece is the cathode.
Emulsion:	Cleaning by means of solutions containing organic solvents, water, and emulsifying agents.
Soak:	Alkaline cleaning without the use of current.
Solvent:	Cleaning by means of organic solvents.
Colloidal particle:	An electrically charged particle, generally smaller than 200 millimicrons, dispersed in a second phase.
Coloring (color buffing):	Light buffing of metal surfaces to produce a high luster.
Complexing agent:	A compound capable of forming a complex ion with a metal ion.
Conversion coating:	A coating produced by chemical or electrochemical treatment of a metallic surface that gives a superficial layer of a compound of the metal.
Correlation coefficient(r):	A measure of interdependence of two random variables that range in value from -1 to +1. The perfect negative correlation is indicated at -1, absence of correlation at 0, and perfect positive correlation at +1.
Coulomb:	The quantity of electricity which passes any section of an electric circuit in one second when the current in the circuit is one ampere.
Covering power:	The ability of a plating solution to produce a deposit at very low current densities.

Current density:	A measure of the flow of ionic species at the electrodes. Expressed as amperes per square foot, this is one of several important process parameters in the control of the overall electroplating operation. Current density is equal to the total current divided by the total area of the electrode in the solution.
Current efficiency:	Percentage of applied current used to deposit metal on a part being plated; remaining current is used in side reactions.
Decorative chromium plating:	Chromium plating for decorative purposes.
Degreasing:	The removal of grease and oils from a surface.
Solvent:	Degreasing by immersion in liquid organic solvents.
Vapor:	Degreasing by solvent vapors condensing on the parts being plated.
Desmut:	The removal of soil or grease films that cleaners and etchants leave behind.
Detergent:	A surface-active agent that can clean soiled surfaces.
Anionic:	A detergent that produces aggregates of negatively charged ions with colloidal properties.
Cationic:	A detergent that produces aggregates of positively charged ions with colloidal properties.
Nonionic:	A detergent that produces aggregates of electrically neutral molecules with colloidal properties.
Dielectric:	A material or medium that does not conduct electricity and that can sustain an electrical field.

Dielectric strength:	The maximum potential gradient that a dielectric material can withstand without rupture.
Direct interception:	Collection of particles, due to their size and relative velocity, by interception with a fluid boundary around the collection surface.
Drag-in:	The water or solution that adheres to objects introduced into a bath.
Drag-out:	The water or solution that adheres to objects removed from a bath.
Dummy:	A cathode in a plating tank that is used for working the solution but that is not to be used after plating.
Dummying:	Plating with dummy cathodes.
Effluent:	Liquid which flows away from a contained space or a main waterway.
Electrochemical equivalent:	The weight of an element, compound, radical, or ion involved in a specified electrochemical reaction during the passage of a unit quantity of electricity, such as a Faraday.
Electrochemistry:	The science that deals with the use of electrical energy to bring about a chemical reaction and the use of chemical action to generate electrical energy.
Electrodeposition:	The process of depositing a substance upon an electrode by electrolysis. Includes electroplating.
Electroless plating:	Depositing of a metallic coating by a controlled chemical reduction, which is catalyzed by the metal or alloy being deposited.

Electrolyte:	A conducting medium in which the flow of current is accompanied by movement of matter. Most often an aqueous solution of acids, bases, or salts but includes many other media such as fused salts, ionized gases, some solids, etc.
Electrolysis:	Production of chemical changes by the passage of current through an electrolyte.
Electroplating:	The electrodeposition of an adherent metallic coating upon an electrode (workpiece) to obtain a surface with properties or dimensions different from those of the base metal.
Face velocity:	The velocity of the gas stream across the face (front) of a given surface.
Faraday:	The number of coulombs (96,490) required for an electrochemical reaction involving one chemical equivalent.
Faraday's Law:	(1) The amount of any substance dissolved or deposited in electrolysis is proportional to the total electric charge passed. (2) The amounts of different substances dissolved or deposited by the passage of the same electric charge are proportioned to their equivalent weights.
Frequency distribution:	A function that measures the relative frequency or probability that a variable can take on a set of values.
Grinding:	The removal of metal by means of rotating rigid wheels containing abrasives.
Hard chromium plating:	Chromium plating for engineering or functional purposes rather than decorative applications.

Heat exchanger:	Any device that transfers heat from one fluid to another or to the environment.
Hexavalent chromium:	The form of chromium in a valence state of +6.
Horsepower:	The unit of power in the British engineering system equal to 550 foot-pounds per second, approximately 745.7 watts.
Inertial impaction:	Collection of particles by their collision with and adhesion to a stationary surface.
Influent:	A input stream of a fluid into a contained space or main waterway.
Inlet loading:	Uncontrolled concentration of the pollutant.
Ion:	An atom or group of atoms which has lost or gained one or more electrons, thereby acquiring a net electrical charge.
Kilowatt:	A unit of power equal to 1,000 watts.
Kilowatt-hour:	A unit of energy or work equal to 1,000 watt-hours.
Leveling action:	The ability of a plating solution to produce a smoother surface than that of a base metal.
Linear regression:	The straight line running among the points of a scatter diagram and about which the amount of scatter is smallest.
Liquid-to-gas ratio:	A design operating parameter for scrubbers that is set at a value to optimize performance. It is the amount of liquid flow compared to the gas flow, expressed in liters per minute to 1,000 cubic meters per minute.

Mist eliminator:	A device that removes liquid mist or droplets from a gas stream via impingement, flow-direction change, velocity change, centrifugal force, filters, or coalescing packs.
Oxidation:	A reaction in which electrons are removed from a reactant.
Packed bed:	A fixed layer of small particles or objects arranged in a vessel to promote intimate contact between gases, vapors, liquids, solids, or various combinations thereof.
Passivation:	The treatment of a metal to form a protective coating on its surface and reduce its chemical activity.
Periodic reverse:	A method of plating in which the current is reversed periodically.
Polishing:	Smoothing a metal surface with abrasive particles attached by adhesive to the surface of wheels or belts.
Polypropylene:	A crystalline, thermoplastic resin made by the polymerization of propylene. The product is hard and tough; resists moisture, oils, and solvents; and withstands temperatures up to 170 degrees centigrade.
Pressure drop:	The difference in pressure between two points in a flow system, usually caused by frictional resistance to a fluid or gas flowing through a conduit, filter media, or other flow-conducting system.
Rack:	A frame for suspending articles during plating and related operations.
Rectifier:	A device which converts alternating current into direct current by permitting appreciable flow of current in one direction.

Reduction:	A chemical reaction in which electrons are added to the reactant.
Reentrainment:	Reentry into the gas stream of previously collected particles.
Reentrainment velocity:	The velocity at which particle reentry occurs.
Scrubber:	A device that removes entrained liquid droplets, dust, or an undesired gas component from the process gas stream via impaction or direct interception.
Shield:	To alter the normal current distribution on an anode or cathode by the interposition of a nonconductor.
Slot velocity:	Air velocity through the openings in a slot-type hood. It is used primarily as a means of obtaining air distribution across the face of the hood.
Smut:	Anything that fouls or soils the external surface of the base metal in electroplating processes; removal of smut is a critical initial step in the electroplating process.
Strike:	A solution used to deposit a thin initial film of metal.
Surface active agent:	A soluble or colloidal substance that affects markedly the surface energy of solutions even when present in very low concentrations.
Surface tension:	The property, due to molecular forces, that exists in the surface film of all liquids and tends to prevent liquid from spreading.
Tarnish:	Dulling, staining, or discoloration of metals due to superficial corrosion.
Thermocouple:	A device that is used to measure temperature.

Throwing power:	The improvement of the coating distribution ratio over the primary current distribution ratio on an electrode. Also, a measure of the degree of uniformity with which metal is deposited on an irregularly shaped cathode.
Trivalent chromium:	The form of chromium in a valence state of +3.
Volt:	The electromotive force that will produce a current of one ampere through a resistance of one ohm.
Watt:	The unit of power in the metric system of units, equal to one joule per second.
Wetting agent:	A substance that reduces the surface tension of a liquid, thereby causing it to spread more readily on a solid surface.
Workload:	The amount of work in the process tank at a given time.
Workpiece:	The material being plated or otherwise finished.

1. SUMMARY

National emission standards for hazardous air pollutants (NESHAP) are established under Section 112 of the Clean Air Act (CAA) (P.L. 101-459), as amended in 1990. Section 112(b) contains a list of hazardous air pollutants (HAP's), which are the specific air toxics regulated by NESHAP. Section 112(c) directs the Administrator to use this pollutant list to develop and publish a list of source categories for which NESHAP will be developed. Chromium electroplating operations are included on this source category list and were selected by EPA for NESHAP development based on their "threat of adverse effects to health and the environment."

This background information document (BID) supports proposed standards for hard and decorative chromium electroplating and chromic acid anodizing operations. These operations are significant emitters of chromic acid, the principal constituent of chromium electroplating and anodizing baths. Chromic acid is a hexavalent chromium compound, and chromium compounds are included in the list of HAP's. Chromium electroplating and anodizing operations typically are located in or near industrial centers in areas of high population density.

1.1 CONTROL OPTIONS

Table 1-1 is a summary of the control options for chromium electroplating and chromic acid anodizing operations. Each control option represents a different level of emission control. The level of control assigned to each control technique is based on the percent emission reduction achievable by well-maintained units at average inlet loadings for each type of operation. For each type of operation, Option 1 is the "no action" or baseline

option. The "no action" option reflects the level of control achieved at existing operations in the absence of further regulation. The control options, together with the newer technologies described in the document Technical Assessment of Innovative Emission Control Technologies Used in the Chromium Electroplating Industry form the basis of the proposed regulatory alternatives for chromium electroplating and chromic acid anodizing operations.

1.2 ENVIRONMENTAL IMPACT

Tables 1-2, 1-3, and 1-4 summarize the environmental and economic impacts associated with the control options for the hard chromium electroplating, decorative chromium electroplating, and chromic acid anodizing source categories.

1.2.1 Hard Chromium Electroplating Operations

Control Option II for hard chromium electroplating operations would reduce nationwide chromium air emissions from the baseline level of 145 Mg/yr (160 tons/yr) to 18 Mg/yr (20 tons/yr). Control Options IIIa and IIIb would further reduce these emissions to 4.2 Mg/yr (4.7 tons/yr).

As shown in Table 1-2, the reduction in nationwide chromium emissions associated with either of the control options would result in minimal adverse environmental impacts. There would be a negligible increase in solid waste attributable to Control Options IIIa and IIIb. Control Option II, IIIa, or IIIb would cause a slight increase in energy consumption due to the additional energy requirements for fans, when chevron-blade mist eliminators are used, and fans and recirculation pumps, when packed-bed scrubbers are mesh-pad mist eliminators are used.

1.2.2 Decorative Chromium Electroplating Operations

Control Options IIa and IIb for decorative chromium electroplating operations would reduce nationwide chromium air emissions from the baseline level of 10 Mg/yr (11 tons/yr) to 1.7 Mg/yr (1.9 tons/yr). Control Option III would reduce chromium emissions to 0.29 Mg/yr (0.32 ton/yr). Control Option IV, which involves the substitution of a trivalent chromium plating bath for the conventional hexavalent chromium

plating bath, would eliminate hexavalent chromium emissions from these operations.

As can be seen in Table 1-3, the reduction in nationwide chromium emissions associated with Control Options IIa and IIb results in a negligible increase in solid waste. The slight increase in energy consumption is due to the additional fan and pump horsepower required to operate packed-bed scrubbers or mesh-pad mist eliminators. No environmental impacts are associated with the reduction in nationwide chromium emissions achieved under Control Option III. Control Option IV results in beneficial environmental impacts with decreases in solid waste and energy usage. Control Option IV has a beneficial impact on water pollution because the use of the more toxic hexavalent solution is eliminated.

1.2.3 Chromic Acid Anodizing Operations

Control Options IIa and IIb for chromic acid anodizing operations would reduce nationwide chromium air emissions from a baseline level of 3.6 Mg/yr (3.9 tons/yr) to 0.25 Mg/yr (0.28 ton/yr). Control Option III would further reduce chromium emissions to 0.04 Mg/yr (0.05 ton/yr).

As shown in Table 1-4, only minimal adverse environmental impacts are associated with Control Options IIa and IIb. There would be a negligible increase in solid waste and a slight increase in energy consumption (due to the increase in fan and pump horsepower requirements). No environmental impacts are associated with the reduction in nationwide chromium emissions attributable to Control Option III.

1.3 ECONOMIC IMPACT

An overview of the economic impacts of the control options for chromium electroplating and chromic acid anodizing operations is presented in Tables 1-2, 1-3, and 1-4. Table 1-5 shows the nationwide capital and net annualized costs associated with each of the control options. Analyses of the costs and economic impacts are presented in Chapters 7 and 8.

TABLE 1-1. SUMMARY OF CONTROL OPTIONS

Type of operation/ Control option	Control technique
Hard chromium plating	
Option I (no action)	Existing (baseline) level of control • 30 percent of operations uncontrolled • 30 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent • 40 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 97 percent
Option II	Chevron-blade mist eliminators that reduce uncontrolled emissions by 95 percent
Option III	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent
Decorative chromium plating	
Option I (no action)	Existing (baseline) level of control • 15 percent of operations uncontrolled • 40 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 40 percent of operations controlled by a combination of chemical fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent • 5 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent
Option IV	Trivalent chromium plating processes that reduce hexavalent chromium emissions by 100 percent (technology forcing)
Chromic acid anodizing	
Option I (no action)	Existing (baseline) level of control • 40 percent of operations uncontrolled • 30 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 10 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent • 20 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent.
Option II	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent

TABLE 1-2. ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC IMPACTS FOR EACH CONTROL OPTION CONSIDERED FOR HARD CHROMIUM ELECTROPLATING OPERATIONS

Administrative action	Air impact	Water impact	Solid waste impact	Energy impact	Noise impact	Economic impact
Control Option I Baseline	0	0	0	0	0	0
Control Option II Chevron-blade mist eliminators	+3**	0	0	-1**	0	-1**
Control Option IIIa Single packed-bed scrubbers	+4**	0	-1**	-1**	0	-1**
Control Option IIIb Mesh-pad mist eliminators	+4**	0	-1**	-1**	0	-1**
Delayed standards or No standards	0	0	0	0	0	0

KEY:
+ = beneficial impact
- = adverse impact
0 = no impact
1 = negligible impact
2 = small impact
3 = moderate impact
4 = large impact
* = short-term impact
** = long-term impact
*** = irreversible impact

TABLE 1-3. ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC IMPACTS FOR EACH CONTROL OPTION CONSIDERED FOR DECORATIVE CHROMIUM ELECTROPLATING OPERATIONS

Administrative action	Air impact	Water impact	Solid waste impact	Energy impact	Noise impact	Economic impact
Control Option I Baseline	0	0	0	0	0	0
Control Option IIa Single packed-bed scrubbers	+2**	0	-1**	-1**	0	-1**
Control Option IIb Mesh-pad mist eliminators	+2**	0	-1**	-1**	0	-1**
Control Option III Fume suppressants	+3**	0	0	0	0	0
Control Option IV Trivalent chromium process	+4**	+1**	+1**	+1**	0	0
Delayed standards or No standards	0	0	0	0	0	0

KEY:
+ = beneficial impact
- = adverse impact
0 = no impact
1 = negligible impact
2 = small impact
3 = moderate impact
4 = large impact
* = short-term impact
** = long-term impact
*** = irreversible impact

TABLE 1-4. ASSESSMENT OF ENVIRONMENTAL AND ECONOMIC IMPACTS FOR EACH CONTROL OPTION CONSIDERED FOR CHROMIC ACID ANODIZING OPERATIONS

Administrative action	Air impact	Water impact	Solid waste impact	Energy impact	Noise impact	Economic impact
Control Option I Baseline	0	0	0	0	0	0
Control Option IIa Single packed-bed scrubbers	+3**	0	-1**	-1**	0	-1**
Control Option IIb Mesh-pad mist eliminators	+3**	0	-1**	-1**	0	-1**
Control Option III Fume suppressants	+4**	0	0	0	0	0
Delayed standards or No standards	0	0	0	0	0	0

KEY:
+ = beneficial impact
- = adverse impact
0 = no impact
1 = negligible impact
2 = small impact
3 = moderate impact
4 = large impact
* = short-term impact
** = long-term impact
*** = irreversible impact

TABLE 1-5. NATIONWIDE CAPITAL AND NET ANNUALIZED COSTS OF THE CONTROL OPTIONS FOR CHROMIUM ELECTROPLATING AND CHROMIC ACID ANODIZING OPERATIONS
(November 1988 dollars)

Control option	Capital costs, ($ million)	Net annualized costs, ($ million/yr)
Hard Chromium Electroplating		
Control Option I Baseline	49.57	11.93
Control Option II Chevron-blade mist eliminators	71.86	16.83
Control Option IIIa Single packed-bed scrubbers	91.28	23.22
Control Option IIIb Mesh-pad mist eliminators	77.24	24.27
Decorative Chromium Electroplating		
Control Option I Baseline	58.73	21.76
Control Option IIa Single packed-bed scrubbers	78.31	27.36
Control Option IIb Mesh-pad mist eliminators	70.76	26.51
Control Option III Fume suppressants	55.37	21.99
Control Option IV Trivalent chromium process	285.26	(254.41) to 55.86

TABLE 1-5. (Continued)

Control option	Capital costs, ($ million)	Net annualized costs, ($ million/yr)
Chromic Acid Anodizing		
Control Option I Baseline	8.30	2.78
Control Option IIa Single packed-bed scrubbers	23.05	7.15
Control Option IIb Mesh-pad mist eliminators	20.48	7.88
Control Option III Fume suppressants	0.00	1.53

2. INTRODUCTION

2.1 BACKGROUND AND AUTHORITY FOR STANDARDS

According to industry estimates, more than 2.4 billion pounds of toxic pollutants were emitted to the atmosphere in 1988 (Implementation Strategy for the Clean Air Act Amendments of 1990, EPA Office of Air and Radiation, January 15, 1991). These emissions may result in a variety of adverse health effects, including cancer, reproductive effects, birth defects, and respiratory illnesses. Title III of the Clean Air Act Amendments of 1990 provides the tools for controlling emissions of these pollutants. Emissions from both large and small facilities that contribute to air toxics problems in urban and other areas will be regulated. The primary consideration in establishing national industry standards must be demonstrated technology. Before national emission standards for hazardous air pollutants (NESHAP) are proposed as Federal regulations, air pollution prevention and control methods are examined in detail with respect to their feasibility, environmental impacts, and costs. Various control options based on different technologies and degrees of efficiency are examined, and a determination is made regarding whether the various control options apply to each emissions source or if dissimilarities exist between the sources. In most cases, regulatory alternatives are subsequently developed that are then studied by EPA as a prospective basis for a standard. The alternatives are investigated in terms of their impacts on the environment, the economics and well-being of the industry, the national economy, and energy and other impacts. This document summarizes the information obtained through these studies so that

interested persons will be able to evaluate the information considered by EPA in developing the proposed standards.

National emission standards for hazardous air pollutants for new and existing sources are established under Section 112 of the Clean Air Act as amended in 1990 [42 U.S.C. 7401 et seq., as amended by PL 101-549, November 15, 1990], hereafter referred to as the Act. Section 112 directs the EPA Administrator to promulgate standards that "require the maximum degree of reduction in emissions of the hazardous air pollutants subject to this section (including a prohibition of such emissions, where achievable) that the Administrator, taking into consideration the cost of achieving such emission reductions, and any non-air quality health and environmental impacts and energy requirements, determines is achievable ... ." The Act allows the Administrator to set standards that "distinguish among classes, types, and sizes of sources within a category or subcategory."

The Act differentiates between major sources and area sources. A major source is defined as "any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit considering controls, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants." The Administrator, however, may establish a lesser quantity cutoff to distinguish between major and area sources. The level of the cutoff is based on the potency, persistence, or other characteristics or factors of the air pollutant. An area source is defined as "any stationary source of hazardous air pollutants that is not a major source." For new sources, the amendments state that the "maximum degree of reduction in emissions that is deemed achievable for new sources in a category or subcategory shall not be less stringent than the emission control that is achieved in practice by the best controlled similar source, as determined by the Administrator." Emission standards for existing sources:

may be less stringent than the standards for new sources in the same category or subcategory but shall not be less stringent, and may be more stringent than--

> (A) the average emission limitation achieved by the best performing 12 percent of the existing sources (for which the Administrator has emissions information), excluding those sources that have, within 18 months before the emission standard is proposed or within 30 months before such standard is promulgated, whichever is later, first achieved a level of emission rate or emission reduction which complies, or would comply if the source is not subject to such standard, with the lowest achievable emission rate (as defined by Section 171) applicable to the source category and prevailing at the time, in the category or subcategory for categories and subcategories with 30 or more sources, or
>
> (B) the average emission limitation achieved by the best performing five sources (for which the Administrator has or could reasonably obtain emissions information) in the category or subcategory for categories or subcategories with fewer than 30 sources.

The Federal standards are also known as "MACT" standards and are based on the maximum achievable control technology previously discussed. The MACT standards apply to both major and area sources, although the existing source standards may be less stringent than the new source standards, within the constraints presented above. The MACT is considered to be the basis for the standard, but the Administrator may promulgate more stringent standards than the MACT floor, which have several advantages. First, they may help achieve long-term cost savings by avoiding the need for more expensive retrofitting to meet possible future residual risk standards, which may be more stringent (discussed in Section 2.7). Second, Congress was clearly interested in providing incentives for improving technology. Finally, in the Clean Air Act Amendments of 1990, Congress gave EPA a clear mandate to reduce the health and environmental risk of air toxics emissions as quickly as possible.

For area sources, the Administrator may "elect to promulgate standards or requirements applicable to sources in such categories or subcategories which provide for the use of generally available control technologies or management practices by such sources to reduce emissions of hazardous air pollutants." These area source standards are also known as "GACT" (generally available control technology) standards, although MACT may be applied at the Administrator's discretion, as discussed previously.

The standards for hazardous air pollutants (HAP's), like the new source performance standards (NSPS) for criteria pollutants required by Section 111 of the Act (42 U.S.C. 7411), differ from other regulatory programs required by the Act (such as the new source review program and the prevention of significant deterioration program) in that NESHAP and NSPS are national in scope (versus site-specific). Congress intended for the NESHAP and NSPS programs to provide a degree of uniformity to State regulations to avoid situations where some States may attract industries by relaxing standards relative to other States. States are free under Section 116 of the Act to establish standards more stringent than Section 111 or 112 standards.

Although NESHAP are normally structured in terms of numerical emissions limits, alternative approaches are sometimes necessary. In some cases, physically measuring emissions from a source may be impossible or at least impracticable due to technological and economic limitations. Section 112(h) of the Act allows the Administrator to promulgate a design, equipment, work practice, or operational standard, or combination thereof, in those cases where it is not feasible to prescribe or enforce an emissions standard. For example, emissions of volatile organic compounds (many of which may be HAP's, such as benzene) from storage vessels for volatile organic liquids are greatest during tank filling. The nature of the emissions (i.e., high concentrations for short periods during filling and low concentrations for longer periods during storage) and the configuration of storage tanks make direct emission measurement

impractical. Therefore, the MACT or GACT standards may be based on equipment specifications.

Under Section 112(h)(3), the Act also allows the use of alternative equivalent technological systems: "If, after notice and opportunity for comment, the owner or operator of any source establishes to the satisfaction of the Administrator that an alternative means of emission limitation" will reduce emissions of any air pollutant at least as much as would be achieved under the design, equipment, work practice, or operational standard, the Administrator shall permit the use of the alternative means.

Efforts to achieve early environmental benefits are encouraged in Title III. For example, source owners and operators are encouraged to use the Section 112(i)(5) provisions, which allow a 6-year compliance extension of the MACT standard in exchange for the implementation of an early emission reduction program. The owner or operator of an existing source must demonstrate a 90 percent emission reduction of HAP's (or 95 percent if the HAP's are particulates) and meet an alternative emission limitation, established by permit, in lieu of the otherwise applicable MACT standard. This alternative limitation must reflect the 90 (95) percent reduction and is in effect for a period of 6 years from the compliance date for the otherwise applicable standard. The 90 (95) percent early emission reduction must be achieved before the otherwise applicable standard is first proposed, although the reduction may be achieved after the standard's proposal (but before January 1, 1994) if the source owner or operator makes an enforceable commitment before the proposal of the standard to achieve the reduction. The source must meet several criteria to qualify for the early reduction standard, and Section 112(i)(5)(A) provides that the State may require additional reductions.

2.2 SELECTION OF POLLUTANTS AND SOURCE CATEGORIES

As amended in 1990, the Act includes a list of 190 HAP's. Petitions to add or delete pollutants from this list may be submitted to EPA. Using this list of pollutants, EPA will publish a list of source categories (major and area sources) for

which emission standards will be developed. Within 2 years of enactment (November 1992), EPA will publish a schedule establishing dates for promulgating these standards. Petitions may also be submitted to EPA to remove source categories from the list. The schedule for standards for source categories will be determined according to the following criteria:

(A) The known or anticipated adverse effects of such pollutants on public health and the environment;

(B) The quantity and location of emissions or reasonably anticipated emissions of HAP's that each category or subcategory will emit; and

(C) The efficiency of grouping categories or subcategories according to the pollutants emitted or the processes or technologies used.

After the source category has been chosen, the types of facilities within the source category to which the standard will apply must be determined. A source category may have several facilities that cause air pollution, and emissions from these facilities may vary in magnitude and control cost. Economic studies of the source category and applicable control technology may show that air pollution control is better served by applying standards to the more severe pollution sources. For this reason, and because there is no adequately demonstrated system for controlling emissions from certain facilities, standards often do not apply to all facilities at a source. For the same reasons, the standards may not apply to all air pollutants emitted. Thus, although a source category may be selected to be covered by standards, the standards may not cover all pollutants or facilities within that source category.

2.3 PROCEDURE FOR DEVELOPMENT OF NESHAP

Standards for major and area sources must (1) realistically reflect MACT or GACT; (2) adequately consider the cost, the non-air quality health and environmental impacts, and the energy requirements of such control; (3) apply to new and existing sources; and (4) meet these conditions for all variations of industry operating conditions anywhere in the country.

The objective of the NESHAP program is to develop standards to protect the public health by requiring facilities to control emissions to the level achievable according to the MACT or GACT guidelines. The standard-setting process involves three principal phases of activity: (1) gathering information, (2) analyzing the information, and (3) developing the standards.

During the information-gathering phase, industries are questioned through telephone surveys, letters of inquiry, and plant visits by EPA representatives. Information is also gathered from other sources, such as a literature search. Based on the information acquired about the industry, EPA selects certain plants at which emissions tests are conducted to provide reliable data that characterize the HAP's emissions from well-controlled existing facilities.

In the second phase of a project, the information about the industry, the pollutants emitted, and the control options are used in analytical studies. Hypothetical "model plants" are defined to provide a common basis for analysis. The model plant definitions, national pollutant emissions data, and existing State regulations governing emissions from the source category are then used to establish regulatory alternatives. These regulatory alternatives may be different levels of emissions control or different degrees of applicability or both.

The EPA conducts studies to determine the cost, economic, environmental, and energy impacts of each regulatory alternative. From several alternatives, EPA selects the single most plausible regulatory alternative as the basis for the NESHAP for the source category under study.

In the third phase of a project, the selected regulatory alternative is translated into standards, which, in turn, are written in the form of a Federal regulation. The Federal regulation limits emissions to the levels indicated in the selected regulatory alternative.

As early as is practical in each standard-setting project, EPA representatives discuss the possibilities of a standard and the form it might take with members of the National Air Pollution

Control Techniques Advisory Committee, which is composed of representatives from industry, environmental groups, and State and local air pollution control agencies. Other interested parties also participate in these meetings.

The information acquired in the project is summarized in the background information document (BID). The BID, the proposed standards, and a preamble explaining the standards are widely circulated to the industry being considered for control, environmental groups, other government agencies, and offices within EPA. Through this extensive review process, the points of view of expert reviewers are taken into consideration as changes are made to the documentation.

A "proposal package" is assembled and sent through the offices of EPA Assistant Administrators for concurrence before the proposed standards are officially endorsed by the EPA Administrator. After being approved by the EPA Administrator, the preamble and the proposed regulation are published in the Federal Register.

The public is invited to participate in the standard-setting process as part of the Federal Register announcement of the proposed regulation. The EPA invites written comments on the proposal and also holds a public hearing to discuss the proposed standards with interested parties. All public comments are summarized and incorporated into a second volume of the BID. All information reviewed and generated in studies in support of the standards is available to the public in a "docket" on file in Washington, D.C. Comments from the public are evaluated, and the standards may be altered in response to the comments.

The significant comments and EPA's position on the issues raised are included in the preamble of a promulgation package, which also contains the draft of the final regulation. The regulation is then subjected to another round of internal EPA review and refinement until it is approved by the EPA Administrator. After the Administrator signs the regulation, it is published as a "final rule" in the Federal Register.

2.4 CONSIDERATION OF COSTS

The requirements and guidelines for the economic analysis of proposed NESHAP are prescribed by Presidential Executive Order 12291 (EO 12291) and the Regulatory Flexibility Act (RFA). The EO 12291 requires preparation of a Regulatory Impact Analysis (RIA) for all "major" economic impacts. An economic impact is considered to be major if it satisfies any of the following criteria:

1. An annual effect on the economy of $100 million or more;
2. A major increase in costs or prices for consumers; individual industries; Federal, State, or local government agencies; or geographic regions; or
3. Significant adverse effects on competition, employment, investment, productivity, innovation, or on the ability of United States-based enterprises to compete with foreign-based enterprises in domestic or export markets.

An RIA describes the potential benefits and costs of the proposed regulation and explores alternative regulatory and nonregulatory approaches to achieving the desired objectives. If the analysis identifies less costly alternatives, the RIA includes an explanation of the legal reasons why the less costly alternatives could not be adopted. In addition to requiring an analysis of the potential costs and benefits, EO 12291 specifies that EPA, to the extent allowed by the CAA and court orders, demonstrate that the benefits of the proposed standards outweigh the costs and that the net benefits are maximized.

The RFA requires Federal agencies to give special consideration to the impact of regulations on small businesses, small organizations, and small governmental units. If the proposed regulation is expected to have a significant impact on a substantial number of small entities, a regulatory flexibility analysis must be prepared. In preparing this analysis, EPA takes into consideration such factors as the availability of capital for small entities, possible closures among small entities, the increase in production costs due to compliance, and a comparison

of the relative compliance costs as a percent of sales for small versus large entities.

The prime objective of the cost analysis is to identify the incremental economic impacts associated with compliance with the standards based on each regulatory alternative compared to baseline. Other environmental regulatory costs may be factored into the analysis wherever appropriate. Air pollutant emissions may cause water pollution problems, and captured potential air pollutants may pose a solid waste disposal problem. The total environmental impact of an emission source must, therefore, be analyzed and the costs determined whenever possible.

A thorough study of the profitability and price-setting mechanisms of the industry is essential to the analysis so that an accurate estimate of potential adverse economic impacts can be made for proposed standards. It is also essential to know the capital requirements for pollution control systems already placed on plants so that the additional capital requirements necessitated by these Federal standards can be placed in proper perspective. Finally, it is necessary to assess the availability of capital to provide the additional control equipment needed to meet the standards.

2.5 CONSIDERATION OF ENVIRONMENTAL IMPACTS

Section 102(2)(C) of the National Environmental Policy Act (NEPA) of 1969 requires Federal agencies to prepare detailed environmental impact statements on proposals for legislation and other major Federal actions significantly affecting the quality of the human environment. The objective of NEPA is to build into the decision-making process of Federal agencies a careful consideration of all environmental aspects of proposed actions.

In a number of legal challenges to standards for various industries, the United States Court of Appeals for the District of Columbia Circuit has held that environmental impact statements need not be prepared by EPA for proposed actions under the Clean Air Act. Essentially, the Court of Appeals has determined that the best system of emissions reduction requires the Administrator to take into account counterproductive environmental effects of

proposed standards as well as economic costs to the industry. On this basis, therefore, the Courts established a narrow exemption from NEPA for EPA determinations.

In addition to these judicial determinations, the Energy Supply and Environmental Coordination Act of 1974 (PL-93-319) specifically exempted proposed actions under the Clean Air Act from NEPA requirements. According to Section 7(c)(1), "No action taken under the Clean Air Act shall be deemed a major Federal action significantly affecting the quality of the human environment within the meaning of the National Environmental Policy Act of 1969" (15 U.S.C. 793(c)(1)).

Nevertheless, EPA has concluded that preparing environmental impact statements could have beneficial effects on certain regulatory actions. Consequently, although not legally required to do so by Section 102(2)(C) of NEPA, EPA has adopted a policy requiring that environmental impact statements be prepared for various regulatory actions, including NESHAP developed under Section 112 of the Act. This voluntary preparation of environmental impact statements, however, in no way legally subjects the EPA to NEPA requirements.

To implement this policy, a separate section is included in this document that is devoted solely to an analysis of the potential environmental impacts associated with the proposed standards. Both adverse and beneficial impacts in such areas as air and water pollution, increased solid waste disposal, and increased energy consumption are discussed.

2.6 RESIDUAL RISK STANDARDS

Section 112 of the Act provides that 8 years after MACT standards are established (except for those standards established 2 years after enactment, which have 9 years), standards to protect against the residual health and environmental risks remaining must be promulgated, if necessary. The standards would be triggered if more than one source in a category or subcategory exceeds a maximum individual risk of cancer of 1 in 1 million. These residual risk regulations would be based on the concept of providing an "ample margin of safety to protect public health."

The Administrator may also consider whether a more stringent standard is necessary to prevent--considering costs, energy, safety, and other relevant factors--an adverse environmental effect. In the case of area sources controlled under GACT standards, the Administrator is not required to conduct a residual risk review.

3. CHROMIUM ELECTROPLATING AND CHROMIC ACID ANODIZING OPERATIONS

3.1 GENERAL

The source categories being evaluated include hard and decorative chromium electroplating and chromic acid anodizing. In hard plating, a relatively thick layer of chromium is deposited directly on a base metal (usually steel) to provide a surface with wear resistance, a low coefficient of friction, hardness, and corrosion resistance. Hard plating is used for items such as hydraulic cylinders and rods, industrial rolls, zinc die castings, plastic molds, engine components, and marine hardware. In decorative plating, the base material (e.g., brass, steel, aluminum, or plastic) generally is plated with a layer of nickel followed by a relatively thin layer of chromium to provide a bright surface with wear and tarnish resistance. Decorative plating is used for items such as automotive trim, metal furniture, bicycles, hand tools, and plumbing fixtures. In chromic acid anodizing, chromic acid is used to form an oxide layer on aluminum to provide corrosion resistance. Chromic acid anodizing is used primarily on aircraft parts and architectural structures that are subject to high stress and corrosive conditions. Although other types of operations performed at metal finishing plants involve chromium in some form, the source categories described in this document include only those processes that use chromic acid in an electrolytic cell to deposit chromium metal or to form an oxide film on a product.

There are an estimated 1,540 hard chromium electroplating and 2,800 decorative chromium electroplating operations in the United States.[1] There are an estimated 680 chromic acid

anodizing operations in the United States.[2] Plating operations range in size from small shops, with one or two small tanks that are operated only a few hours per week, to large shops, with several large tanks that are operated 24 hours per day, 7 days per week. Many plating operations are captive shops that perform chromium electroplating or chromic acid anodizing as one operation within or for a manufacturing facility, while others are job shops that provide custom plating or anodizing services for many different clients. Captive and job shops may perform hard or decorative chromium plating or chromic acid anodizing or any combination of these three operations. Electroplating and anodizing shops typically are located in or near industrial centers in areas of high population density. States with large numbers of chromium electroplaters include California, Illinois, Massachusetts, Michigan, New York, Ohio, and Pennsylvania.

3.2 PROCESS DESCRIPTION

3.2.1 Electrochemistry

A schematic of a typical electrolytic cell is presented in Figure 3-1.[3] An electrolytic cell consists of an electrolytic solution and an external electrical circuit. Electrolytic solutions are composed of chemicals, dissolved in a solvent (usually water), that are capable of conducting an electric current by the movement of dissociated positive and negative ions to the electrodes. The current flows toward a positively charged electrode, or anode, and is drawn from a negatively charged electrode, or cathode. The cathode is supplied with electrons from an external circuit, which usually consists of a rectifier that changes alternating current to direct current. The positively charged ions (cations) draw electrons from the cathode, neutralizing the positive charge; while the negatively charged ions (anions) simultaneously release an equal number of electrons to the anode, neutralizing their negative charge. Gain of electrons by the cations at the cathode is called reduction, and loss of electrons by the anions at the anode is called oxidation. The current then flows from the anode to the cathode

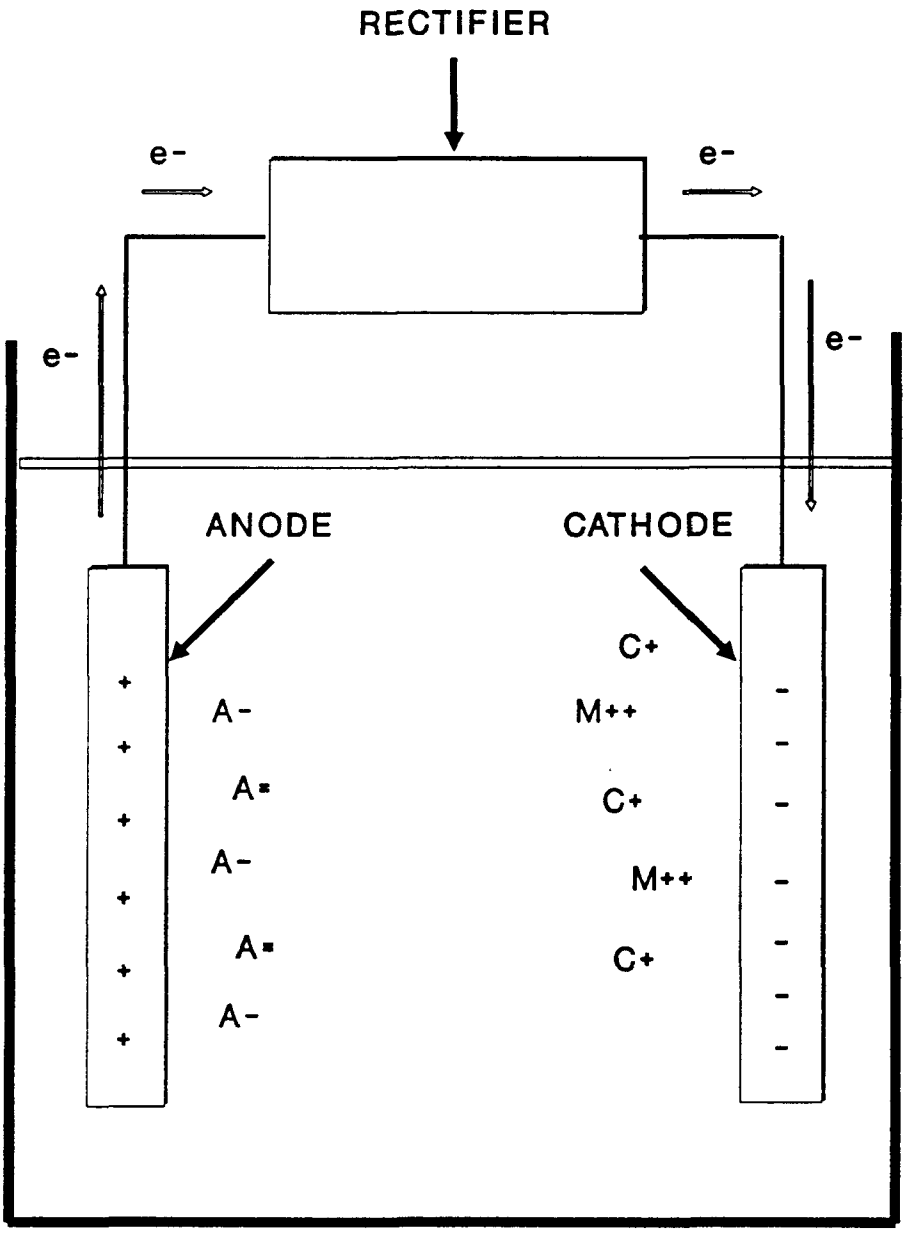


Figure 3-1. Schematic of a typical electrolytic cell.

by way of the rectifier, which acts as a pump to transfer electrons.

In electroplating, the metal that will form the plate is supplied to the plating solution either as a metal salt in solution or as a soluble anode. The positively charged metal ion is drawn to the negatively charged cathode and undergoes reduction, resulting in the deposit of the metal on the cathode (substrate). Water is the principal solvent used in electroplating solutions. Depending upon the efficiency of the electroplating process used, substantial quantities of hydrogen and oxygen gas may be generated due to the dissociation of water into hydrogen (H+) and hydroxyl (OH-) ions. The hydrogen ion is drawn to the cathode where it is reduced to form hydrogen (H_2) gas. The hydroxyl ion is drawn to the anode and reacts to form oxygen (O_2) and water.

3.2.2 Hard Chromium Electroplating of Metals

Hard chromium plating provides the following desirable combination of physical and mechanical properties:

1. Low coefficient of friction;
2. High hardness factor--Vickers 800+;
3. Good corrosion resistance;
4. High heat resistance; and
5. Antigalling (antichafing) surface.[4]

Figure 3-2 presents a schematic of a typical electroplating tank. Tanks used for hard chromium electroplating usually are constructed of steel and lined with a polyvinyl chloride sheet or plastisol. The anodes, which are insoluble, are made of a lead alloy that contains either tin or antimony. The part to be plated, the cathode, is suspended from a rack that is connected to the cathode bar of the rectifier. The plating rack may be loaded in the tank by hand, manually by a hoist, or by an automatically controlled hoist system.

Plating tanks typically are equipped with some type of heat exchanger. Before initial startup, the bath is heated to normal plating temperatures (49° to 66°C [120° to 150°F]). Mechanical agitators or compressed air supplied through pipes on the tank

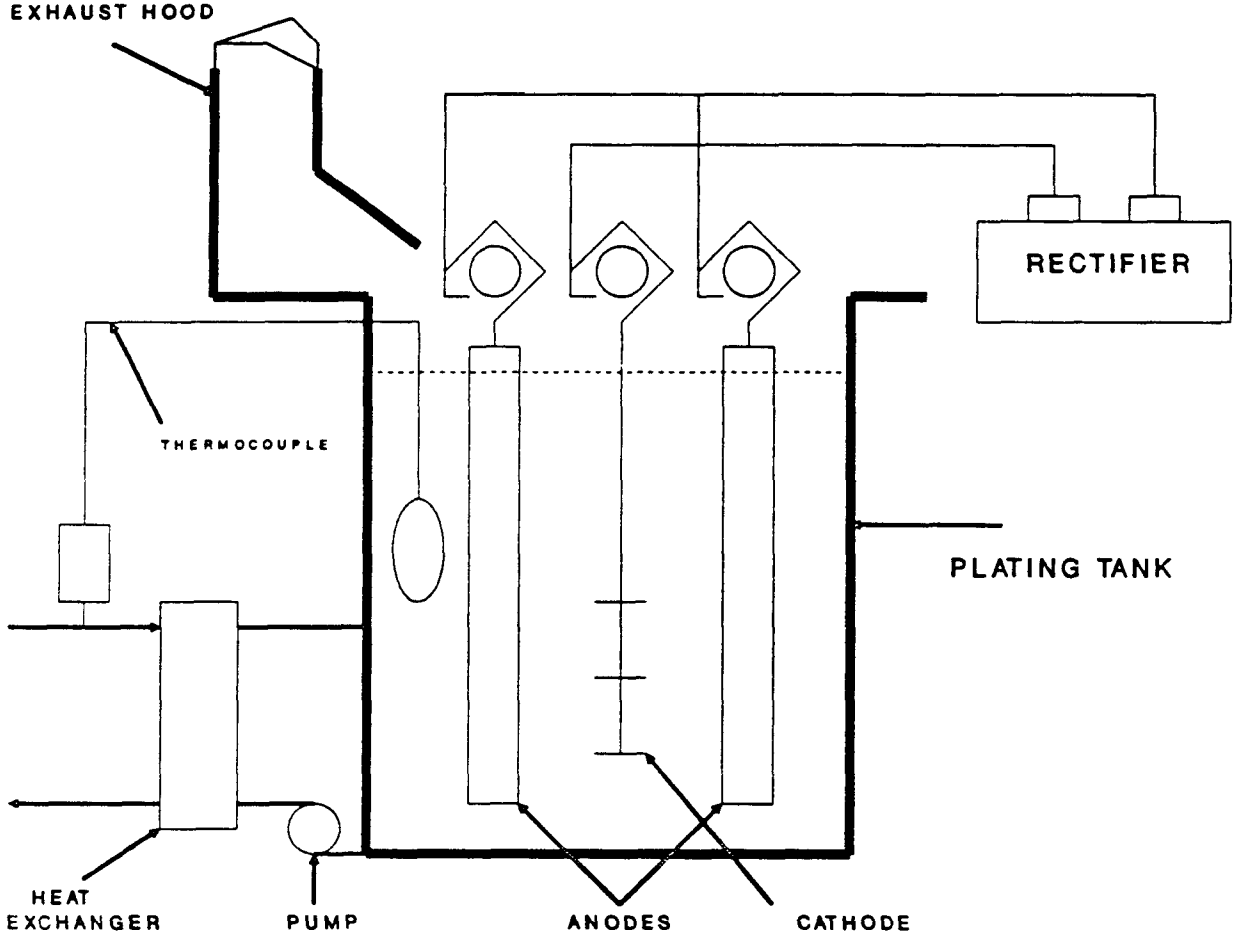


Figure 3-2. Basic components of chromium electroplating equipment.

bottom may be used to provide uniform bath temperature and composition. Frequent cooling is required during operation because of the heat produced by the high current load. Metal coils and external shell-and-tube heat exchangers typically are used to heat or cool plating solutions. Metal coils are hung on the tank sidewall and convey either steam or coolant. In shell-and-tube heat exchangers, plating solution is pumped from the tank through the tube side of the heat exchanger and returned to the tank while steam or coolant is added to the shell side of the heat exchanger. A thermocouple is used to control the flow of steam or coolant into the heat exchanger.

A flow diagram for a typical hard chromium plating process is presented in Figure 3-3. The process consists of the following steps:

1. Pretreatment (polishing, grinding, degreasing);
2. Alkaline cleaning and acid dipping (optional);
3. Chromic acid anodic treatment (optional); and
4. Chromium electroplating.

The part being plated is rinsed after each step in the process to prevent carry-over of solution that may contaminate the baths used in successive process steps. Either hot or cold water may be used in rinse tanks, but hot water is more efficient than cold water for removing contaminants. Softened, distilled, or deionized water may be required for final rinses.

Pretreatment steps include polishing, grinding, and/or degreasing the metal part to prepare the surface for plating. Polishing and grinding are performed to smooth the surface of the part. Degreasing is performed either by dipping the part in organic solvents or by vapor degreasing the part using organic solvents. Vapor degreasing is typically used when the surface loading of oil or grease is excessive. The two organic solvents most commonly used in dipping solutions or for vapor degreasing are trichloroethylene and perchloroethylene. In vapor degreasing, the solvent is boiled in a tank and the vapor condenses on the part and removes the oil and grease from its surface. Vapor degreasers must be fitted with a local

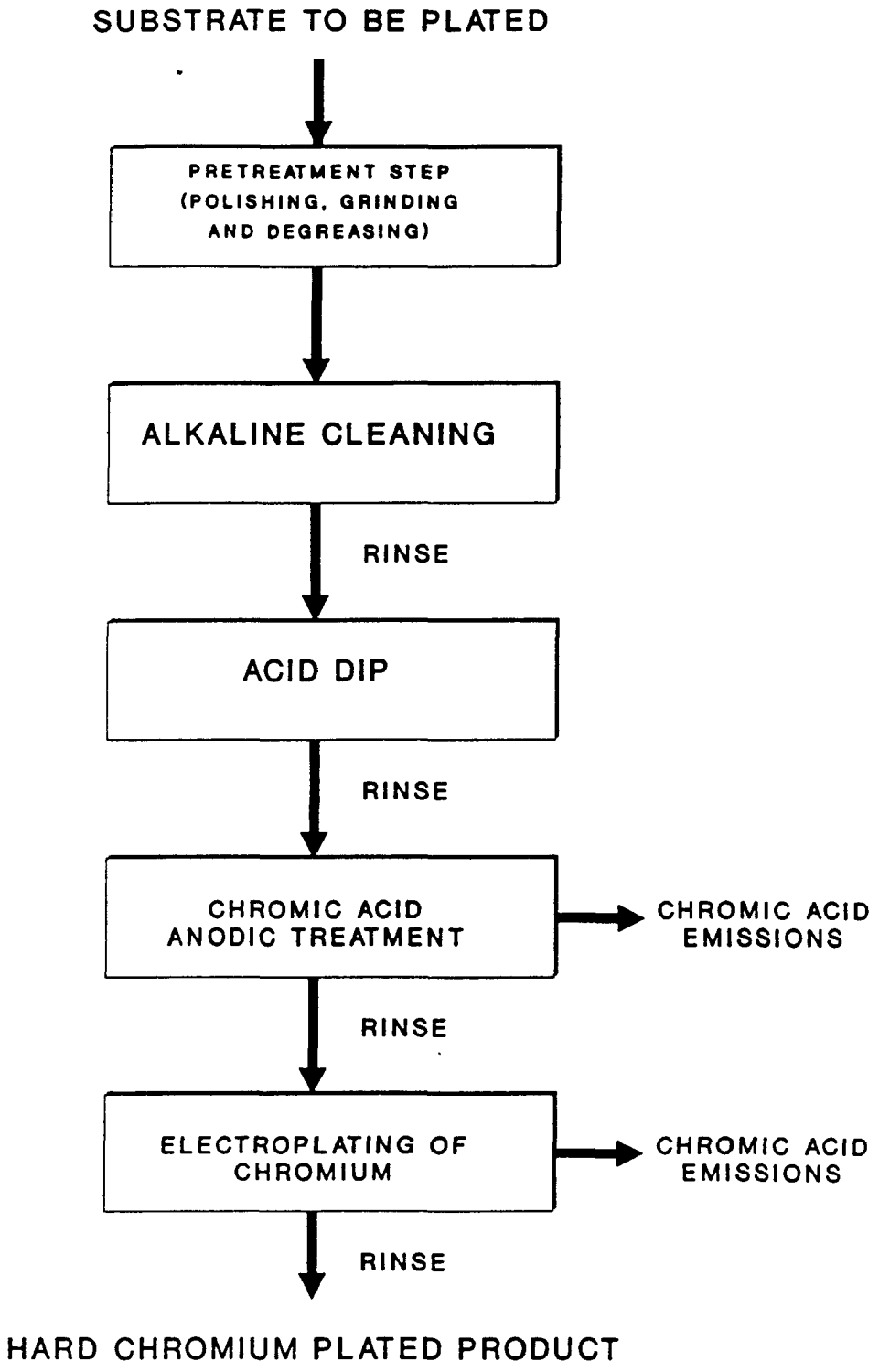


Figure 3-3. Flow diagram for a typical hard chromium plating process.

ventilation system designed to pick up solvent vapors escaping from the tanks without pulling vapor from the machine itself. Vapor degreasers should also be installed with a safety thermostat in the freeboard zone just above the normal vapor level to shut off the heat as the vapor level rises above the condensing surface (part) for any reason.[5]

Alkaline cleaning is sometimes used to dislodge surface soil and prevent it from settling back onto the metal. These cleaning solutions are typically made up of compounds such as sodium carbonate, sodium phosphate, and sodium hydroxide and usually contain a surfactant.[6] Alkaline cleaning techniques include soaking and cathodic and anodic cleaning. In soaking, the metal is placed in an alkaline bath that is agitated mildly. In cathodic cleaning, the metal is placed in an alkaline bath and direct current is applied. The part acts as the cathode; therefore, when current is applied, hydrogen gas evolves, enhancing the detergent action of the solution. Two disadvantages of cathodic cleaning are that impurities in the cleaning solution may be deposited on the metal and hydrogen may embrittle the metal. In anodic cleaning, the part is placed in an alkaline bath and reverse current is applied. The part then acts as the anode so that when the current is applied, oxygen gas is evolved. One disadvantage of anodic cleaning is that oxides may form on the surface of the metal. Also, anodic cleaning is less efficient than cathodic cleaning because oxygen gas is liberated at one-half the rate that hydrogen gas is liberated during cathodic cleaning.[7] During alkaline cleaning, an alkaline mist can be released at a fairly high rate because of the hydrogen and oxygen gases entrapping the solution and releasing it as the bubbles burst at the surface; therefore, adequate ventilation should be provided.[8]

Acid dips may be used to remove any tarnish or oxide films formed in the alkaline cleaning step and to neutralize the alkaline film. Acid dip solutions typically contain from 10 to 30 percent by volume hydrochloric or sulfuric acid in water. Because of the release of hydrogen and oxygen gases, an acid mist

is generated from the dip tanks at varying rates and, as with alkaline cleaning, proper ventilation should be provided.[8]

A chromic acid anodic treatment step is sometimes included. This treatment cleans the metal surface, with the evolution of oxygen gas scouring the metal. The chromic acid also activates the surface, which enhances the adhesion of chromium in the electroplating step. A typical bath contains chromic acid in a concentration that ranges from 120 to 240 g/L (16 to 32 oz/gal) at temperatures ranging from 49° to 66°C (120° to 150°F).[9] Satisfactory cleaning and activation of the surface are usually obtained at 6 V and a current density ranging from 1,550 to 4,650 A/m^2 (140 to 430 A/ft^2) for 1 to 3 minutes.[10] Anodic treatment is typically accomplished by applying reverse current in the hard chromium plating tank.[11] The anodic treatment also adds a protective oxide layer to the metal so that the chromium can be plated without applying an undercoating of nickel.

The final step of the process is the chromium electroplating operation. Chromium electroplating requires constant control of the plating bath temperature, current density, plating time, and bath composition. Typical operating parameters are given in Table 3-1.[12]

TABLE 3-1. TYPICAL OPERATING PARAMETERS FOR HARD CHROMIUM ELECTROPLATING

Plating thickness, μm (mil)	1.3-762 (0.05-30)
Plating time, min	20-2,160
Chromic acid concentration, g/L (oz/gal)	225-375 (30-50)
Sulfuric acid concentration, g/L (oz/gal)	2.25-3.75 (0.3-0.5)
Temperature of solution, °C (°F)	49-66 (120-150)
Voltage, V	a
Current, A	b
Current density, A/m^2 (A/ft^2)	1,600-6,500 (150-600)

[a]Depends on the distance between the anodes and the items being plated.
[b]Depends on the amount of surface area plated.

Chromic acid plating baths are most widely used for depositing chromium on metal. Chromium anhydride (CrO_3) is the hexavalent compound of chromium used to make up the plating bath. By common usage, CrO_3 is widely known as chromic acid. Therefore, in this document CrO_3 will be referred to as chromic acid. The baths typically contain chromic acid in a concentration of 225 to 375 g/L (30 to 50 oz/gal of water). In addition, small amounts of sulfuric acid (2.25 to 3.75 g/L [0.3 to 0.5 oz/gal]) are added as a bath catalyst. As CrO_3 is added to water, it reacts with the water to form a compound (H_2CrO_4), which is correctly called chromic acid. As more CrO_3 is added to the plating bath, the H_2CrO_4 molecules combine to form dichromic acid ($H_2Cr_2O_7$) and water. As dichromic acid forms, it readily ionizes to form dichromate ions ($Cr_2O_7^{=}$) and hydrogen ions (H^+). The dichromate ions are then used in the chromium deposition reaction as discussed below.

The cathode reactions take place at the surface of the part to be plated. These are the deposition reaction and two side reactions:[13]

1. $Cr_2O_7^{=} + 14H^+ + 12(e) \rightarrow 2Cr^{\circ} + 7H_2O$
2. $2H^+ + 2(e) \rightarrow H_2\uparrow$
3. $Cr_2O_7^{=} + 14H^+ + 6(e) \rightarrow 2Cr^{+3} + 7H_2O$

The first reaction deposits the chromium metal on the part to be plated. In this reaction, the dichromate ion reacts with hydrogen ions and electrons to form chromium metal and water. This reaction takes place in the presence of a catalyst, the sulfate ion. In addition to this deposition reaction, two side reactions also take place. In the first side reaction, two hydrogen ions combine with two electrons to form hydrogen gas. The evolution of hydrogen gas consumes 80 to 90 percent of the power supplied to the bath, leaving the remaining 10 to 20 percent for the deposition reaction. When the hydrogen gas evolves, it entrains chromic acid and causes misting at the surface of the plating bath. In the second side reaction, the dichromate ion combines with hydrogen ions and electrons to form water and trivalent chromium, which is detrimental to the bath.

The trivalent chromium is reoxidized to chromic acid at the anode. The anode area is always larger than the cathode area to ensure that most of the trivalent chromium formed at the cathode will react at the anode to form chromic acid. This technique does not always ensure, however, that the concentration of trivalent chromium will not build up to a level that will contaminate the bath.

The preferred anode material for chromium electroplating is lead alloyed with tin or antimony. The following reactions take place at the anode during chromium electroplating:[14]

1. $4OH^- - 4(e) \rightarrow 2H_2O + O_2\uparrow$
2. $Pb + 4OH^- - 4(e) \rightarrow PbO_2 + 2H_2O$
3. $2Cr^{+3} + 3O_2\uparrow - 6(e) \rightarrow 2CrO_3$

Most of the energy from the electric current is consumed in the first reaction. The second reaction (lead and hydroxyl ions) allows the third reaction to take place due to the coating of lead peroxide. The third reaction (trivalent chromium with oxygen) reoxidizes trivalent chromium to chromic acid. This reaction purifies the bath by keeping the number of trivalent chromium ions low.

3.2.3 Decorative Chromium Electroplating of Metals

The purpose of decorative chromium plating is to achieve a unique combination of surface properties. Decorative chromium plate is characterized by a blue-white color. It has a high reflectivity that endures long use because of the excellent tarnish resistance of chromium. It is highly resistant to corrosion and exhibits good wear and scratch resistance.[15]

The decorative chromium plating process consists of a series of plating operations. Figure 3-4 presents a process flow diagram for the decorative chromium plating of metals (i.e., brass, steel, and aluminum). The process consists of the following steps:

1. Pretreatment (polishing, grinding, degreasing);
2. Alkaline cleaning;
3. Acid dipping;
4. Strike plating of copper;

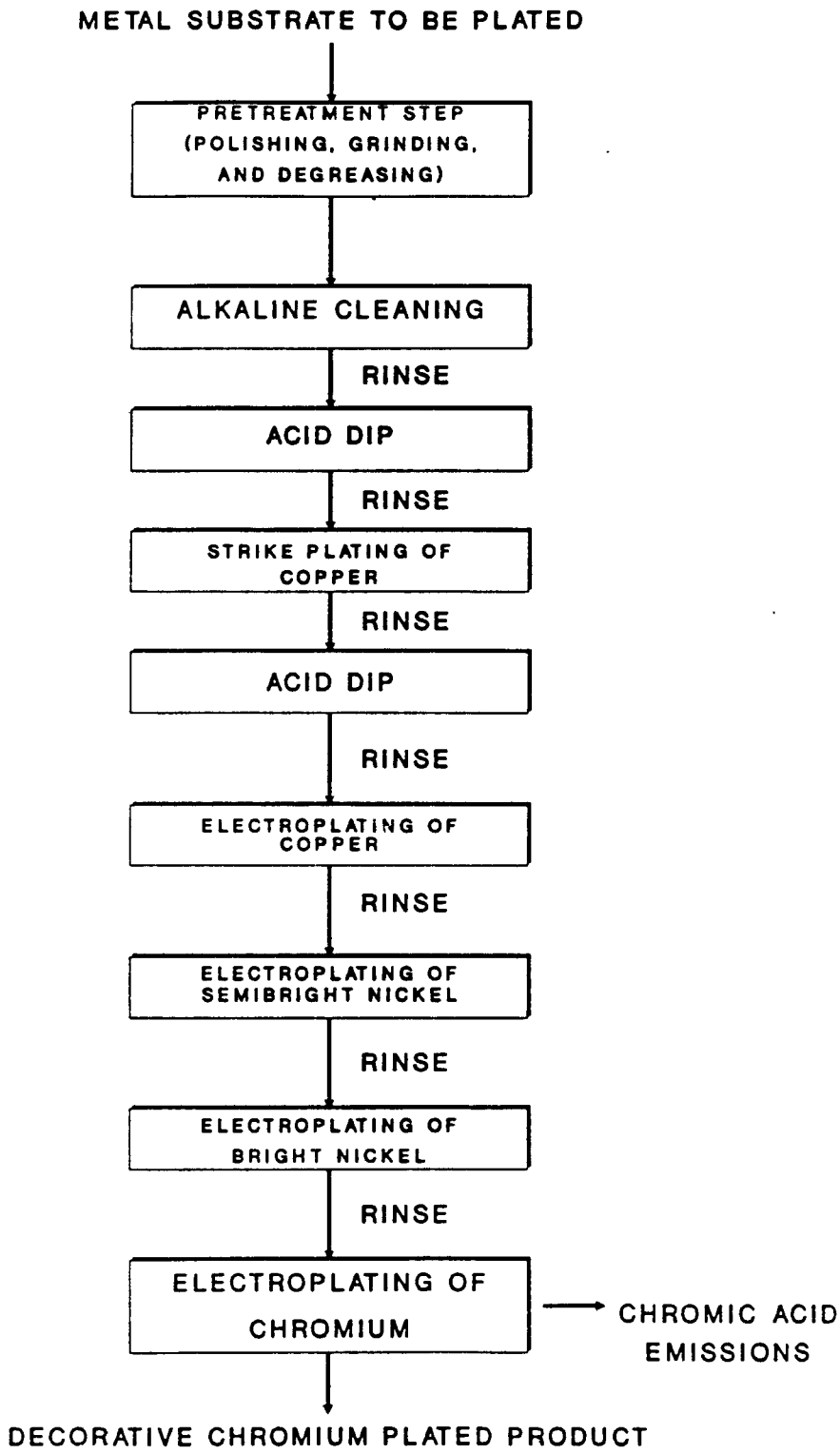


Figure 3-4. Flow diagram for decorative chromium plating on a metal substrate.

5. Electroplating of copper;
6. Electroplating of nickel; and
7. Electroplating of chromium.

As with hard chromium plating, the part being plated is rinsed after each step in the process to prevent carry-over of solution that may contaminate the baths used in successive process steps. Either hot or cold water may be used in the rinse tanks, but hot water is more efficient than cold water for removing contaminants. Softened, distilled, or deionized water may be required for final rinses.

Decorative electroplating baths operate on the same principle as that described for the hard chromium plating process: The part to be plated is immersed in a plating solution, and direct current is passed from the anode through the plating solution causing the desired metal (copper, nickel, chromium) to deposit out of the solution onto the surface of the part to be plated (cathode).

Pretreatment steps include polishing, grinding, and/or degreasing the part to prepare for plating. Polishing and grinding are performed to smooth the surface of the part. Alkaline cleaning may be used to dislodge surface soil and prevent it from settling back onto the metal. Acid dipping is sometimes used to remove tarnish or oxide films formed in the alkaline cleaning step. Acid dips are also typically used following strike plating of copper. These steps are described in more detail in Section 3.2.2 for hard chromium plating.

The first step following pretreatment is a copper strike, which consists of applying a thin layer of copper to enhance the conductive properties of the base metal and to protect the part from attack by the acidic copper sulfate baths. The plating bath is typically a copper cyanide solution.[16] The plating time (0.5 to 2.0 min) is limited to that necessary for complete coverage of a thin layer (2.5 μm [0.1 mil]) over the entire surface of the part.[17] Strike plating of copper typically is followed by an acid dip.

The part is then usually electroplated with an undercoat of copper to improve the corrosion resistance and to cover scratch marks and other defects. Copper deposits in the recesses of the part more readily than nickel or chromium, and this enhances the corrosion resistance of the part.[18] The baths used for copper electroplating are either alkaline (cyanides or pyrophosphates) or acid copper solutions. Copper cyanide solution is used most often; however, use of an acid copper bath is growing, due mainly to the low chemical cost and simplified effluent treatment.[19] The acid copper bath requires a copper strike plate for steel substrates before electroplating because the copper cannot be applied directly to steel; however, copper cyanide baths can be directly applied to the steel substrate.[20] Copper cyanide baths are composed of copper cyanide, potassium or sodium cyanide, potassium or sodium hydroxide, potassium or sodium carbonate, and a Rochelle salt. Acid copper baths are usually composed of copper sulfate, sulfuric acid, chloride, and thiourea. Another commonly used acid plating formulation contains copper fluoborate (instead of copper sulfate) as the active component. Table 3-2 presents the operating parameters for typical copper plating baths.[21,22] Copper may be deposited as a matte finish, or brightening agents may be added to the bath to produce a semibright or bright surface.

TABLE 3-2. TYPICAL OPERATING PARAMETERS FOR COPPER PLATING BATHS

	Copper cyanide	Acid copper
Plating bath temperature, °C (°F)	24-66 (75-140)	24-32 (75-90)
Current density, A/m^2 (A/ft^2)	54-430 (5-40)	215-860 (20-80)
Plating time, min	3-5	4-5
Cathode efficiency, percent	30-99	95-100

When a cyanide bath is used for strike copper plating or copper electroplating, both cyanide and alkaline mist are released from the bath. The potential for release of significant

concentrations of these materials into the workroom atmosphere is great enough to warrant the use of local exhaust ventilation.[23] Acid copper plating solutions are capable of releasing the copper salt and sulfuric acid mist into the atmosphere, but because of the generally high electrode efficiencies, acid mist generation is minimal. However, when high current densities or agitation is used, mist generation can increase and local exhaust ventilation must be provided.[24]

Nickel plating improves the corrosion resistance and strength of the metal substrate and activates the surface of the metal for chromium plating. The nickel is plated on the surface of the part in two layers. The first layer is semibright (sulfur-free) nickel, and the second layer is bright (sulfur-containing) nickel. Pits that form in the outer (bright) layer cannot continue through the inner (semibright) layer because of the difference in the electromagnetic properties of the two layers.[25] Semibright nickel and bright nickel baths are both variations of the Watts bath, and the constituents are nickel sulfate (or nickel sulfamate), nickel chloride, and boric acid. The semibright nickel additives are coumarin or other proprietary materials that act as leveling agents to hide surface defects, a brightener, and a wetting agent. The bright nickel bath is a high-chloride version of the Watts bath, which also contains a brightener and a wetting agent. Nickel plating baths typically operate at 45° to 65°C (110° to 150°F) with current densities ranging from 270 to 1,075 A/m^2 (25 to 100 A/ft^2).[26]

Generally, gassing from the nickel plating solutions containing sulfate and/or chloride baths is low because the baths are operated at moderate temperatures and low to moderate current densities and have high cathode efficiencies (95 to 98 percent). The need for local exhaust ventilation under such conditions may be minimal.[27]

The final step in the decorative chromium plating process is the plating of chromium itself. Typical operating parameters for this step are presented in Table 3-3.[28] As can be seen when comparing these parameters with those for hard chromium plating

(Table 3-1), decorative chromium deposits are considerably thinner than those associated with the functional hard chromium plating process. The current densities required for decorative chromium plating are about one-third lower than those required for hard chromium plating, and, therefore, the operating temperatures are lower for the decorative process. Plating times required for decorative chromium plating are much shorter than the times required for hard chromium plating.

TABLE 3-3. TYPICAL OPERATING PARAMETERS FOR DECORATIVE CHROMIUM PLATING

Plating thickness, μm (mil)	0.003-2.5 (0.0001-0.1)
Plating time, min	0.5-5
Chromic acid concentration, g/L (oz/gal)	225-375 (30-50)
Sulfuric acid concentration, g/L (oz/gal)	2.25-3.75 (0.3-0.5)
Temperature of solution, °C (°F)	38-46 (100-115)
Voltage, V	a
Current, A	b
Current density, A/m^2 (A/ft^2)	540-2,400 (50-220)

[a]Depends on the distance between the anodes and the items being plated.
[b]Depends on the amount of surface area being plated.

Each of the operating parameters must be carefully monitored during the plating process. The chemistry of the bath affects plating speed, covering power, and operating voltage requirements. The plating speed is the rate of film growth and is typically expressed in microinches per minute. Covering power is the ability of a plating solution to produce a deposit at very low current densities. The bath temperature has an effect on plating speed and current density. Current density also affects plating speed as well as the covering power and plating thickness.

The composition of the plating bath and the deposition reactions for decorative chromium electroplating are the same as

those described for hard chromium plating. Some decorative chromium plating operations use fluoride catalysts instead of sulfuric acid because fluoride catalysts, such as fluosilicate or fluoborate, have been found to produce higher bath efficiencies.[29]

3.2.4 Decorative Chromium Electroplating of Plastics

Most plastics that are electroplated with chromium are formed from the polymer composed of acrylonitrile, butadiene, and styrene (ABS).[30] The process for chromium electroplating of ABS plastics consists of the following steps:

1. Chromic acid/sulfuric acid etch;
2. Dilute hydrochloric acid dip;
3. Collodial palladium activation;
4. Dilute hydrochloric acid dip;
5. Electroless nickel plating or copper plating; and
6. Chromium electroplating.

After each process step, the plastic is rinsed with water to prevent carry-over of solution from one bath to another. The chromic acid/sulfuric acid etch solution (see Table 3-4) renders the ABS surface hydrophilic and modifies the surface to provide adhesion for the metal coating.[31] The dilute hydrochloric acid dips are used to clean the surface and remove palladium metal from the plating rack, which is insulated with a coating of polyvinyl chloride. The colloidal palladium activation solution (see Table 3-5) deposits a thin layer of metallic palladium over the plastic surface.[32] The metallic palladium induces the deposition of copper or nickel, which will not deposit directly onto plastic. Electroless nickel or copper plate is applied to impart electrical conductivity to the part; otherwise, the insulating surface of the plastic could not be electroplated with chromium. The electroless nickel plating or copper electroplating baths develop a film on the plastic about 1.0 μm (0.039 mil) thick. The plating time for electroless nickel plating and electroless copper plating ranges from 10 to 15 minutes and 15 to 30 minutes, respectively, at temperatures ranging from 25° to 35°C (77° to 95°F). The components of the

plating baths include the metal salt (nickel or copper), a reducing agent, a complexing agent, a stabilizer, and a pH buffer system.[33] The decorative chromium electroplating cycle is the same as that described above in Section 3.2.3.

TABLE 3-4. CHROMIC ACID/SULFURIC ACID ETCH SOLUTION

Concentrated sulfuric acid, g/L (oz/gal)	172 (23)
Chromic acid, g/L (oz/gal)	430 (57)
Temperature, °C (°F)	60-65 (140-149)
Immersion time, min	3-10

TABLE 3-5. COLLOIDAL PALLADIUM ACTIVATING SOLUTION

Palladium chloride, g/L (oz/gal)	0.007 (9.0×10^{-4})
Stannous chloride, g/L (oz/gal)	35.0 (4.7)
Stannic chloride, g/L (oz/gal)	4.0 (0.53)
Concentrated hydrochloric acid, g/L (oz/gal)	480 (64)
Temperature, °C (°F)	25-30 (77-86)
Immersion time, min	3-6

3.2.5 Chromic Acid Anodizing of Aluminum

Anodizing is the process of forming a film of surface oxide electrolytically. Used primarily for aluminum and its alloys, anodizing improves resistance to corrosion, provides electrical insulation, and enhances the ease of coloring. There are several types of anodizing, of which sulfuric acid processes are the most commercially important. However, where parts may be subjected to considerable stress (e.g., aircraft parts), the potential retention of corrosive sulfuric acid in crevices and recesses of anodized parts could cause problems. Chromic acid, on the other hand, is a recognized corrosion inhibitor, so its retention in crevices and joints does not present a problem. This makes chromic acid the preferred (and specified) anodizing process for

aircraft parts, as well as for other assemblies with overlapping joints, recesses, or crevices. Another advantage of chromic acid anodic coatings is their very high resistance to salt spray corrosion as compared to sulfuric acid coatings of the same thickness.[34]

There are four primary differences between the equipment used for chromic acid anodizing and that used for chromium electroplating: (1) rectifiers must be fitted with a rheostat or other control mechanism to permit voltage adjustments; (2) the tank rather than the part is the cathode in the electrical circuit; (3) the part acts as the anode; and (4) sidewall shields are used instead of a tank liner to minimize short circuits and to decrease the effective cathode area.[35]

Figure 3-5 presents a flow diagram for a typical chromic acid anodizing process. The process consists of pretreatment operations, the actual chromic acid anodizing step, and postanodizing operations that include sealing and air-drying.

The following pretreatment steps are typically used to clean the aluminum before anodizing:

1. Alkaline soak;
2. Etching;
3. Desmutting; and
4. Vapor degreasing.

The pretreatment steps used for a particular aluminum substrate depend upon the amount of smut and the composition of the aluminum. The aluminum substrate is rinsed between pretreatment steps to remove cleaners. The use of water rinsing following cleaning and all subsequent treatments is critical, and the use of rinse tanks common to all process steps is avoided.

The alkaline soak is the primary preparatory step in cleaning the aluminum; its purpose is to dislodge soil from the aluminum surface. The solutions for alkaline cleaning are typically made up of compounds such as sodium carbonate, sodium phosphate, and sodium hydroxide and usually contain a small amount of silicate to prevent metal attack.[36] The alkaline soak

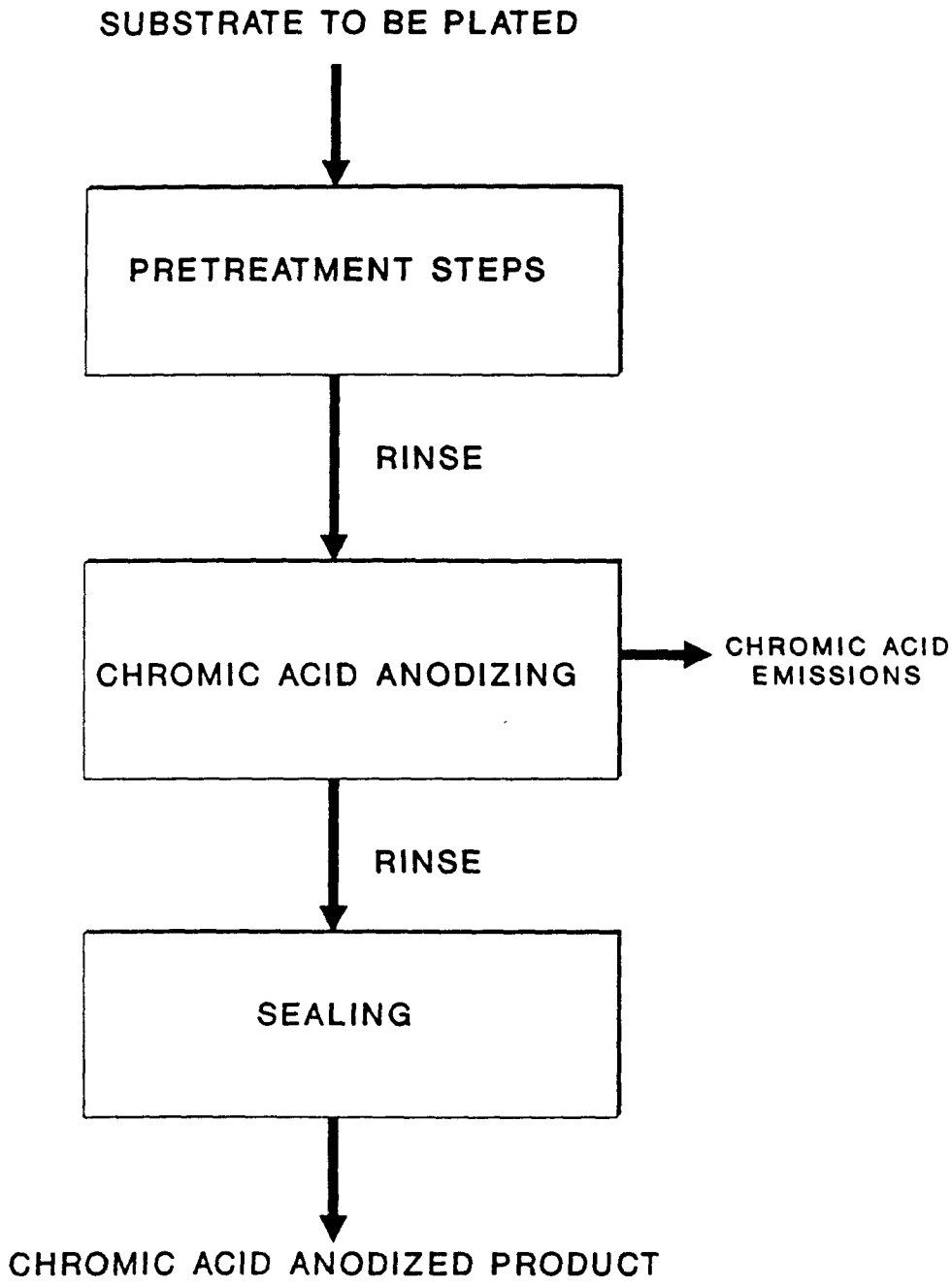


Figure 3-5. Flow diagram for a typical chromic acid anodizing process.

step consists of immersing the metal in the alkaline solution, which is mildly agitated with air.

When a dull finish is desired, the aluminum is etched before anodizing. Etching baths consist of dilute solutions of soda ash, caustic soda, or nitric acid.[37] When soda ash or caustic soda is used, aluminum parts are rinsed with water, dipped in concentrated nitric acid for a few seconds, and rinsed with water again. The degree of etching desired and the composition of the aluminum being treated determine the concentration of the etch solution, temperature of the bath, and duration of the etch.

Another pretreatment step is desmutting, which removes soil or grease films that cleaners and etchants leave behind. Desmutting baths typically consist of a cold nitric acid solution mixed with water at a concentration ranging from 5 to 50 percent acid by volume. The nitric acid bath is also used either as a bleaching treatment to remove dyes from faulty coatings or as part of the technique of producing multicolor coatings.[38] Other desmutting treatments use combinations of chromic, phosphoric, and sulfuric acids depending upon the amount of smut to be removed or the aluminum composition of the part.

Vapor degreasing typically is used when the surface loading of oil or grease is excessive. The two organic solvents most commonly used in dipping solutions or for vapor degreasing are trichloroethylene and perchloroethylene. In vapor degreasing, the solvent is boiled in a tank, and the vapor condenses on the part and removes the oil and grease from the surface of the part.

The next step in the process is the actual anodizing. Typical operating parameters for chromic acid anodizing baths are presented in Table 3-6.[39,40] The voltage is applied step-wise (5 V per minute) from 0 to 20 or 40 V and maintained at the desired voltage for the remainder of the anodizing time.[41] The total anodizing time is typically 30 to 60 minutes. A low starting voltage (e.g., 5 V) minimizes current surge that may cause "burning" at contact points between supporting racks and aluminum parts being anodized. The process is effective over a wide range of voltages, temperatures, and anodizing times. In

general, high voltages tend to produce bright transparent films, and lower voltages tend to produce opaque films.[42] Raising the bath temperature increases current density to produce thicker films in a given time period. Temperatures up to 49°C (120°F) typically are used to produce films that are to be colored by dyeing.[43] The amount of current applied varies depending on the size of the aluminum part(s). Typical current densities range from 1,550 to 7,750 A/m^2 (144 to 720 A/ft^2).

TABLE 3-6. TYPICAL OPERATING PARAMETERS FOR CHROMIC ACID ANODIZING

Chromic acid concentration, g/L (oz/gal)	50-100 (6.67-13.3)
Temperature, °C (°F)	32-35 (90-95)
Anodizing time, min	30-60
pH	0.5-0.85
Current density, A/m^2 (A/ft^2)	1,550-7,750 (144-720)
Voltage (step-wise), V	20 or 40
Film thickness, μm (mil)	0.15-1.27 (0.02-0.05)

When the current is applied, chromic acid breaks down in the bath resulting in the liberation of oxygen and hydrogen. The oxygen is evolved at the surface of the aluminum part where it reacts with the substrate to form an aluminum oxide layer. At the same time, chromic and dichromic acids contained in the bath react with the aluminum oxide film in a dissolving action.[44] This action results in the formation of very fine pores, enhancing the continuation of current flow to the metal surface. Competition between the oxide film growth and oxide dissolution regulates the anodic film properties. As the film thickens, the growth rate decreases until it is equal to the oxide dissolution rate, at which point the film thickness reaches a limiting value dependent on the current density. This process usually takes 30 to 40 minutes. About half of the oxidized aluminum is retained as anodic film, and the remainder goes into solution to form

alumina-chromic acid compounds.[45] The relationship between the cathode and the shape or relative location of the anode is not critical in chromic acid anodizing.[46]

After the anodizing is complete, the anodized parts undergo several postanodizing steps. These include sealing and air drying. Sealing causes hydration of the aluminum oxide and fills the pores in the aluminum surface. As a result, the elasticity of the oxide film increases but the hardness and wear resistance decrease.[47] Sealing is performed by immersing aluminum in a water bath at 88° to 99°C (190° to 210°F) for a minimum of 15 minutes.[48] Chromic acid or other chromates may be added to the solution to help improve corrosion resistance. The aluminum is allowed to air dry after it is sealed.

3.2.6 Other Plating and Metal Treatment Processes Involving Chromium

3.2.6.1 Trivalent Chromium Plating. Trivalent chromium electroplating baths were developed primarily as an alternative to hexavalent chromium plating baths for decorative chromium plating. Development of a trivalent chromium plating process has been difficult due to the tendency of trivalent chromium to solvate in water to form complex stable ions that do not release chromium readily. State-of-the-art trivalent chromium baths that have been developed are complex in chemistry and are generally considered proprietary by suppliers.

The first trivalent chromium plating bath was developed in the mid-1800's, but the process did not become commercially successful until 1975. There are two types of trivalent chromium processes available for decorative chromium plating: the single-cell and the double-cell. In the single-cell process, anodes are in direct contact with the plating solution. In the double-cell process, anodes are encased in boxes that are lined with a permeable (ion-selective) membrane and that contain a dilute solution of sulfuric acid. This membrane allows the passage of hydrogen ions but not other positively charged ions (such as the trivalent chromium species present in the plating solution). This mechanism prevents undesirable side reactions (such as

oxidation of trivalent chromium to hexavalent chromium) from occurring at the anode. The use of a weak solution of sulfuric acid, contained within the box, facilitates hydrogen ion transport through the membrane (away from the anode) to compensate for hydrogen gas evolution at the cathode.[49]

The advantages of the trivalent chromium processes over the hexavalent chromium process are (1) fewer environmental concerns, (2) higher productivity, and (3) lower operating costs. In the trivalent chromium process, chromic acid is not present in the plating solution. Furthermore, hexavalent chromium is regarded as a plating bath contaminant in this process. Trivalent chromium is much less toxic than hexavalent chromium and is not presently listed as a potential human carcinogen, as is hexavalent chromium. The total chromium concentration in trivalent chromium solutions is approximately one-fifth that in hexavalent chromium solutions.[50] As a result of the trivalent chromium bath chemistry, the surface tension of the plating solution is approximately 40 dynes/cm (2.7×10^{-3} lb_f/ft). At this low surface tension, any hydrogen gas that is evolved at the cathode will not burst at the surface of the solution to produce a chromium mist. Based on visual observation made during site visits to trivalent chromium plating facilities, no detectable misting is observed at the surface of the solution, and because of this most plants do not ventilate the plating tank. Use of trivalent chromium also reduces waste disposal problems and the associated costs. Waste treatment of hexavalent chromium is a two-stage process. The hexavalent chromium is first reduced to the trivalent chromium ion; then it can be precipitated as chromium hydroxide. Trivalent chromium plating solution wastewaters are already in the reduced trivalent state and require only the chromium hydroxide-precipitation step.

An advantage of the trivalent chromium process is that it has better covering and throwing power than the hexavalent chromium process. Throwing power is the ability to form electrodeposited films of such uniform thickness that even the most recessed areas of a part are covered. Better throwing and

covering power results in increased productivity because less stripping and replating of parts is required, more parts can be placed on a rack, and more racks can be placed on a workbar.[51] Chromium color buffing is also eliminated when using most trivalent chromium processes. The gray "burnt" areas caused by the high current densities used in the hexavalent chromium process must be buffed to restore the bright and shiny appearance of the plated surface. Because the trivalent chromium processes use cathode current densities that are about half those used for the hexavalent process, burning does not occur.

Two disadvantages of the trivalent chromium process, as compared with the hexavalent chromium process, are that the trivalent chromium process is more sensitive to contamination, and it cannot plate the full range of plate thicknesses.[52] Because it is sensitive to contamination, the trivalent chromium process requires more thorough rinsing and tighter laboratory control (more frequent analyses of bath composition). Trivalent chromium baths can plate thicknesses ranging from 0.13 to 25 μm (0.005 to 1.0 mils) thick.[53] The hexavalent chromium process is able to plate up to 762 μm (30 mils) thick. Therefore, trivalent chromium solutions cannot be used for most hard chromium plating applications.

Special precautions must be taken when the trivalent chromium process is used with brass, zinc, and tubular (hollow) steel parts. The copper, zinc, and lead metals found in these parts can contaminate the trivalent chromium solution if the parts fall off the racks and the metals dissolve in the solution or if there is insufficient coverage in the nickel bath and the base metals are exposed and dissolve in the solution. Tubular (hollow) brass or steel parts present unique problems because the throwing power in the nickel plating process is not sufficient to cover the internal surfaces of tubular parts. This can result in lead or copper contamination of the trivalent chromium solution.[54]

The plating efficiency of a trivalent chromium bath, approximately 20 to 25 percent, is slightly higher than that of a

hexavalent chromium plating bath.[55] The color, hardness, and corrosion resistance of trivalent chromium deposits are comparable to those of hexavalent chromium deposits.[56] However, the composition of the trivalent chromium deposit is significantly different from that of the hexavalent chromium deposit as shown in Table 3-7.[57]

TABLE 3-7. HEXAVALENT AND TRIVALENT CHROMIUM DEPOSIT COMPOSITIONS

Chromium deposit	Carbon, percent wt	Oxygen, percent wt	Chromium, percent wt
Hexavalent	0.0	0.4	99+
Trivalent	2.9	1.6	95+

3.2.6.2 Chromating. Chromating refers to the application of chromate conversion coatings on metals. The coatings are produced by chemical or electrochemical treatment involving mixtures of hexavalent chromium and certain other compounds. Film formation requires the presence of certain anions (activators). These include acetate, formate, sulfate, chloride, fluoride, nitrate, phosphate, and sulfamate ions. Chromate film properties and rate of formation are dependent on the particular activator and its concentration. Therefore, many formulations have been developed on a proprietary basis. The concentration of hexavalent chromium can vary widely. One important factor in controlling the formation of the film is the pH of the treatment solution. The optimum pH value varies with different metal/chromate systems. The rates of metal dissolution and metal formation are determined by the pH of the solution.[58]

Chromating is usually done by immersion, although spraying, brushing, swabbing, or electrolytic methods may be used.[59] The chromating process involves oxidation of the metal surface in the chromating solution with simultaneous transition of the basis metal ions to the solution and evolution of hydrogen. The

liberated hydrogen reduces a certain amount of hexavalent chromium to trivalent chromium.[59] The solution then contains a complex mixture of chromates and oxides of both chromium and the basis metal. Therefore, the film consists of indefinite proportions of materials involved in the process. The properties of chromate coatings depend upon the chemical makeup, pH, and temperature of the chromating solution and the contact time of the solution and metal, which can vary from 1 second to 1 hour.[58]

3.3 UNCONTROLLED EMISSIONS

Plating operations generate mists due to the evolution of hydrogen and oxygen gas. The gases are formed in the process tanks on the surface of the submerged part or on anodes or cathodes. As these gas bubbles rise to the surface, they escape into the air and may carry considerable liquid with them in the form of a fine mist. The rate of gassing is a function of the chemical or electrochemical activity in the tank and increases with the amount of work in the tank, the strength and temperature of the solution, and the current densities in plating tanks.[60]

Emissions are also generated from surface preparation steps (alkaline cleaning, acid dipping, and vapor degreasing). These emissions are in the form of alkaline and acid mists and solvent vapors. (Solvent [volatile organic compounds] emissions from vapor degreasing operations are currently the subject of a regulation being developed by EPA.)

The extent of acid misting from the plating processes (copper, nickel, and chromium) depends mainly on the efficiency of the plating bath. Both copper and nickel plating baths have high cathode efficiencies so that the generation of mist is minimal. However, the cathode efficiency of chromium plating baths is very low (10 to 20 percent), and a substantial quantity of chromic acid mist is generated.

The focus of this study is on chromic acid emissions from chromium plating baths because of the adverse health affects of hexavalent chromium and the significant quantity of chromium emitted. The other plating processes discussed above are not significant emitters of toxic pollutants, or they are common to

numerous metal finishing operations other than chromium electroplating processes.

Emissions of chromic acid mist from the electrodeposition of chromium in chromic acid plating baths occur because of the inefficiency of the hexavalent chromium plating process; only about 10 to 20 percent of the current applied actually is used to deposit chromium on the item plated. Eighty to 90 percent of the current applied is consumed by the evolution of hydrogen gas at the cathode with the resultant liberation of gas bubbles. Additional bubbles are formed at the anode due to the evolution of oxygen. As the bubbles burst at the surface of the plating solution, a substantial amount of fine chromic acid mist is formed.

3.3.1 Hard and Decorative Chromium Plating Operations

A source test program was established to quantify uncontrolled hexavalent chromium emissions from hard and decorative chromium electroplating operations. The following sections present a description of the facilities tested, the source test method and procedures used to quantify uncontrolled emissions, the uncontrolled hexavalent chromium emissions data, factors affecting the uncontrolled emissions, and the development of process emission factors.

3.3.1.1 Facility Descriptions. Facilities selected for emissions testing were representative of typical hard and decorative chromium plating shops based on the size of the plating tanks, the types of parts plated, and the plating bath operating parameters. The operating parameters examined at each facility were the current, voltage, plating time, temperature, and chromic acid concentration of the plating bath. Nine hard chromium plating operations and two decorative chromium plating operations were selected for emissions testing. Tables 3-8 and 3-9 present the key operating parameters monitored during the emissions tests. Voltages, chromic acid concentrations, and temperatures did not vary significantly among the hard or the decorative chromium plating operations tested. These monitored parameters are representative of typical operating values for

TABLE 3-8. TANK PARAMETERS AND PROCESS OPERATING PARAMETERS MONITORED DURING HARD CHROMIUM PLATING TESTS

Plant	Tank parameters[a]			Ventilation rate, acmm/m^2 (acfm/ft^2)[b]	Type of parts plated	Average process parameters monitored			
	No. of tank(s)	Total tank surface area, m^2 (ft^2)	Total tank capacity, L (gal)			Current, amperes	Voltage, volts	Chromic acid concentration, g/L (oz/gal)	Bath temp., °C (°F)
Plant A[61]	1	5.8 (63)	9,800 (2,590)	39 (126)	Textile, hydraulic components	6,220	9.0	254 (34)	52 (125)
Plant B[62]	2	2.5 (27)	4,130 (1,090)	61 (200)	Industrial rolls	1,610	12.3	242 (32)	62 (145)
Plant D[63]	1	5.2 (56)	15,100 (3,890)	34 (112)	Industrial rolls	8,390	7.4	156 (21)	52 (125)
Plant E[64]	1	3.4 (37)	9,270 (2,450)	56 (180)	Industrial rolls	4,970	7.0	244 (33)	54 (130)
Plant F[65]	1	1.8 (20)	4,810 (1,270)	71 (227)	Hydraulic cylinders	2,640	4.9	195 (26)	56 (133)
Plant G[66]	1	1.4 (15)	5,720 (1,510)	68 (224)	Industrial rolls	3,480	4.9	210 (28)	55 (131)
Plant I[67]	2	9.0 (99)	9,840 (2,600)	32 (104)	Industrial rolls	1,140	7.7	225 (30)	59 (138)
Plant K[68]	3	6.6 (71)	5,150 (1,360)	78 (255)	Textile loom parts	1,150	6.1	173 (23)	49 (120)
Plant L[69]	1	10.0 (110)	10,400 (2,750)	58 (184)	Crankshafts	3,090	5.9	222 (30)	53 (127)

[a]Tank parameters are not indicative of the actual size of the plating shop. The parameters presented represent the values for all tanks tested at each shop.
[b]acmm = actual cubic meters per minute; acfm = actual cubic feet per minute.

TABLE 3-9. TANK PARAMETERS AND PROCESS OPERATING PARAMETERS MONITORED DURING DECORATIVE CHROMIUM PLATING TESTS

Plant	Tank parameters[a]			Ventilation rate, acmm/m^2 (acfm/ft^2)[b]	Type of parts plated	Average process parameters monitored			
	No. of tank(s)	Total tank surface area, m^2 (ft^2)	Total tank capacity, L (gal)			Current, amperes	Voltage, volts	Chromic acid concentration, g/L (oz/gal)	Bath temp., °C (°F)
Plant M[70]	1	22.6 (240)	61,170 (16,160)	30 (100)	Bumpers	21,320	22.4	300 (40)	54 (130)
Plant N[71]	1	2.9 (31)	3,940 (1,040)	24 (80)	Small automotive parts	2,700	5.1	241 (32)	48 (119)

[a]Tank parameters are not indicative of the actual size of the plating shop. The parameters presented represent the values for all tanks tested at each shop.
[b]acmm = actual cubic meters per minute; acfm = actual cubic feet per minute.

conventional hard and decorative chromium plating baths. However, the amount of current supplied to the plating baths during the emissions tests varied considerably among facilities because of differences in the sizes and quantities of parts plated and the thicknesses of chromium applied. The types of parts that were plated at the hard chromium plating facilities during testing were typical hard chromium plated parts such as industrial rolls, hydraulic cylinders, and crankshafts. The types of parts (automotive) that were plated at the decorative chromium plating facilities during testing were representative of typical parts that are decorative chromium plated. Appendix C presents a more detailed description of the facilities tested.

3.3.1.2 Source Test Method. Mass emission sampling was conducted using an isokinetic sampling train. A minimum of three mass emission test runs were conducted at each test facility. Each test run was typically 2 to 3 hours in duration. The sample location at each facility was downstream of the hood in an area of the duct preceding any air pollution control device and where flow disturbances were minimal or nonexistent. Prior to sampling, velocity, static pressure, molecular weight, moisture content, and temperature of the gas stream were measured to determine the sampling rate and nozzle size. The duct area is sampled by traversing across two perpendicular diameters. The number of traverse points or sampling points along one diameter is determined based on the size of the duct. Traversing of the duct is necessary because the distribution of chromium in the duct is not uniform. Following sample collection and recovery, the hexavalent chromium content of the sample was determined by spectrophotometry. For a more detailed discussion of the test methods and subsequent analyses, refer to Appendix D.

3.3.1.3 Uncontrolled Emission Data. Tables 3-10 and 3-11 present the uncontrolled hexavalent chromium emissions data collected at each of the hard and decorative chromium plating operations tested. As shown in Table 3-10, the average uncontrolled hexavalent chromium emission concentration at the hard chromium plating operations ranged from 697×10^{-3} to

TABLE 3-10. UNCONTROLLED HEXAVALENT CHROMIUM EMISSION DATA FROM HARD CHROMIUM PLATING OPERATIONS

Plant	No. of test runs	Ampere-hours[a]	Actual gas flow rate, m^3/min (ft^3/min)	Concentration, mg/dscm (gr/dscf) (10^{-3})	Mass emission rate, kg/hr (lb/hr)	Process Cr^{+6} emission rate, mg/Ah (gr/Ah)
Plant A[61]	4	12,200	226 (7,970)	2,030 (0.885)	0.026 (0.057)	4.5 (0.07)
Plant B[62]	3	14,400	152 (5,390)	1,760 (0.771)	0.015 (0.033)	3.2 (0.05)
Plant D[63]	3	19,600	177 (6,260)	7,960 (3.47)	0.076 (0.168)	9.2 (0.14)
Plant E[64]	3	12,100	190 (6,670)	3,070 (1.34)	0.031 (0.069)	6.2 (0.10)
Plant F[65]	5	12,200	128 (4,540)	11,400 (4.98)	0.083 (0.183)	16.3 (0.25)
Plant G[66]	3	8,800	95 (3,360)	4,410 (1.93)	0.024 (0.053)	6.6 (0.10)
Plant I[67]	11	8,530	290 (10,300)	5,510 (2.41)	0.090 (0.199)	22.5 (0.35)
Plant K[68]	3	8,790	512 (18,100)	1,670 (0.729)	0.046 (0.102)	15.5 (0.24)
Plant L[69]	8	6,900	575 (20,300)	697 (0.305)	0.023 (0.050)	7.4 (0.11)
Average						10.2 (0.16)

[a]Ampere-hour is a unit of electrical energy. Ampere-hours measure the amount of current supplied to the plating tank over any given time frame. (Here, the time frame represents the duration of sampling.)

TABLE 3-11. UNCONTROLLED HEXAVALENT CHROMIUM EMISSION DATA FROM DECORATIVE CHROMIUM PLATING OPERATIONS

Plant	No. of test runs	Ampere-hours[a]	Actual gas flow rate, m^3/min (ft^3/min)	Concentration, mg/dscm (gr/dscf) (10^{-3})	Mass emission rate, kg/hr (lb/hr)	Process Cr^{+6} emission rate, mg/Ah (gr/Ah)
Plant M[70]	3	97,000	683 (24,100)	1,600 (0.699)	0.066 (0.145)	2.0 (0.03)
Plant N[71]	3	6,500	70 (2,470)	916 (0.400)	0.004 (0.008)	1.3 (0.02)
Average						1.7 (0.03)

[a]Ampere-hour is a unit of electrical energy. Ampere-hours measure the amount of current supplied to the plating tank over any given time frame. (Here, the time frame represents the duration of sampling.)

11,400 x 10^{-3} mg/dscm (3.05 x 10^{-4} to 4.98 x 10^{-3} gr/dscf), and the hexavalent chromium mass emission rate varied from 0.015 to 0.090 kg/hr (0.033 to 0.199 lb/hr). The range of mass emission rates for the hard chromium plating operations is narrower than the range in the concentration data, this is because the mass emission rate is normalized based on the varying ventilation rates at each facility. As shown in Table 3-11, the average uncontrolled hexavalent chromium emission concentration at decorative chromium plating operations varied from 916 x 10^{-3} to 1,600 x 10^{-3} mg/dscm (4.0 x 10^{-4} to 6.99 x 10^{-4} gr/dscf), and the hexavalent chromium mass emission rate varied from 0.004 to 0.066 kg/hr (0.008 to 0.145 lb/hr).

3.3.1.4 Factors Affecting Emissions. Numerous factors cause the variability in the emission data. These factors include:

1. Current density applied;
2. Surface area of the part plated;
3. Plate thickness; and
4. Plating time.

These factors are all interrelated and are determined by using the electrochemical equivalent of chromium, which is:

$$\frac{\text{(Current, amperes) (Plating time, hr)}}{\text{(Thickness, mil) (Surface area of part, ft}^2\text{)}} = 51.8$$

The electrochemical equivalent is derived from Faraday's law. The equation above is based on a cathode efficiency of 100 percent and means that 51.8 Ah are required to deposit 25 μm (1 mil) of chromium per square foot of part surface area. As discussed previously, the cathode efficiency for actual chromium plating baths is only 10 to 20 percent. The known variables in the equation above for all platers are the surface area of the part and the minimum plate thickness. The unknowns are then calculated by modifying the equation to account for the actual cathode efficiency. In the majority of cases, the plating time is the factor that is adjusted to account for the lower cathode efficiency. It is a common practice to set the current based on

a current density of 3,100 A/m^2 (2 $A/in.^2$) for hard chromium plating and approximately 1,500 A/m^2 (1 $A/in.^2$) for decorative chromium plating. The low cathode efficiency means that 80 to 90 percent of the current supplied to the bath goes to form hydrogen gas, which entraps the chromium solution. The amount of misting then becomes directly proportional to the amount of current supplied over a given time period.

Other factors that affect the amount of emissions are:

1. Type of parts plated;
2. The orientation of the parts within the tank;
3. The chromic acid concentration; and
4. The surface tension of the plating bath.

The type of part plated affects emissions because of its shape. For example, if two similar parts (parts with the same surface area plated) are plated to equal minimum thicknesses, but one part has a smooth surface and the other part has many recessed areas, the part with the recessed areas will require more current than the part with the smooth surface. The poor throwing power of chromium plating baths results in thicker deposits in the high current density range and thinner deposits in the low current density range. The current densities vary across the surface of recessed parts because of the varying distances from the anode. The orientation of the part within the tank also affects the amount of emissions. For example, if the same part is plated in a shallow horizontal tank, more chromium will be emitted than if the part is plated in a deep vertical tank. In a shallow tank, the hydrogen gas is evolved closer to the surface of the solution and the agitation effect is much greater than with the hydrogen gas generated in a deeper tank. The chromic acid concentration affects emissions generation because the higher the concentration of the solution that is entrapped in the hydrogen gas bubbles, the more chromium will be emitted when the bubbles burst to form the mist. The surface tension of the plating solution is another factor that affects the emissions. Common hexavalent chromium plating baths have a surface tension of 70 dynes/cm (4.8×10^{-3} lb_f/ft). However, surfactants can be added to the

plating bath to reduce the surface tension below 40 dynes/cm (2.7×10^{-3} lb_f/ft). At the lower surface tension, the hydrogen gas bubbles will not burst at the surface of the solution and the misting is substantially reduced. It should be noted that the facilities tested did not use surfactants during the tests because of the need to measure actual uncontrolled emissions. However, the ability of wetting agents to reduce uncontrolled emissions was determined and is discussed in Chapter 4.

There are two other factors that do not affect the quantity of emissions generated but that do affect the measurement of those emissions. These factors are the ventilation rate and the sample location in the duct. The ventilation rate must be adequate to capture the chromium mist. If the mist is not captured, then it cannot be measured accurately. In addition, the required ventilation rate is determined based on the surface area of the tank. Therefore, two tanks with the same capacities but different surface areas will be vented at different rates. If the two tanks are plating identical parts, the tank with the higher ventilation rate will have a lower concentration of chromium than the tank with a lower ventilation rate. The sample location will also affect the quantity of emissions measured because chromic acid mist will impinge on the duct walls and will lower the amount of chromium measured. For example, if a plating tank was tested with sample locations directly following the hood and 15 m (50 ft) downstream of the hood, the emissions measured at the hood would be higher than those measured 15 m (50 ft) downstream.

The variability in the emission data for hard and decorative plating operations is a direct measure of the variability in the factors discussed above. The only factors that were relatively constant among the facilities tested were the chromic acid concentration, plating bath temperature, and surface tension of the plating bath. As shown in part in Tables 3-8 and 3-9, the current, voltage, ventilation rate, type and surface area of parts plated, physical tank parameters, and location of the sample varied from plant to plant because of differences in the

process operation and the layout of the plant. However, there is less variability in the data among individual test runs at a given facility because the factors that affect emissions are fairly constant. For example, at Plant G, there was little to no variation in the bath operating parameters, the type and surface area of parts plated, or the current and voltage applied during each test run. The difference in uncontrolled mass emission rates between the highest and lowest values among the three test runs at Plant G was only 0.0085 kg/hr (0.0188 lb/hr). In contrast, the mass emission rate for individual test runs at Plant I varied from 0.072 kg/hr (0.158 lb/hr) to 0.117 kg/hr (0.259 lb/hr). At Plant I, values of the above parameters were constant, except for minor variations in the workload and current applied. As expected, the lowest mass emission rate (0.072 kg/hr [0.158 lb/hr]) was measured during the test run that also had the lowest current (5,470 Ah), and the highest mass emission rate (0.117 kg/hr [0.259 lb/hr]) was measured during the test run which had the second highest current (13,000 Ah). This suggests that the key operating parameter that affects emissions at any given plant would be the current applied, which is an indicator of the variation in the type and surface area of parts plated.

3.3.1.5 Emission Factor Development. Correlation analyses were used to evaluate the relationship between chromium emissions from hard chromium plating operations and key process operating parameters. Although small positive correlations were observed between total hexavalent chromium emissions and both energy input in ampere-hours and tank surface area, no statistically significant relationships were found. Based on engineering judgment, total energy input (ampere-hours) was selected as the best measure of process rate for electroplating operations because (1) emission generating mechanisms are related directly to energy input, and (2) energy input can be measured accurately. Emission data were normalized for different process rates and expressed in units of milligrams of chromium per ampere-hour (mg/Ah). Subsequent analyses of the test data indicated that the variability in process emission rates between plants was much

greater than the variability in process emission rates for different test runs at the same plant. These results suggest that operating differences between plants have a greater impact on emissions than does normal process measurement variability. Consequently, the best measure of typical chromium emission rates is the average plant-specific process emission rate. The average hexavalent chromium emission factors presented in Tables 3-10 and 3-11 for each source test were calculated by the following equation:

$$\text{Emission factor, mg/Ah} = \frac{\text{(Emission rate, kg/hr)(Sample time, hr)}}{\text{(Current, Ah)}} \times 10^6$$

Based on the existing data, an uncontrolled emission factor of 10 mg/Ah (0.15 gr/Ah) is considered to be representative of uncontrolled hexavalent chromium emissions from a hard chromium electroplating operation and an uncontrolled hexavalent chromium emission factor of 2 mg/Ah (0.03 gr/Ah) is considered to be representative of uncontrolled emissions from a decorative chromium electroplating operation.

3.3.2 Chromic Acid Anodizing Operation

Data on uncontrolled hexavalent chromium emissions from chromic acid anodizing operations based on direct measurement are currently not available. However, an uncontrolled emission estimate was developed based on a mass balance around a once-through scrubber system used to control emissions from a chromic acid anodizing operation. The mass balance procedure is described in the following sections.

The chromic acid anodizing facility examined was a small job shop that performs chromic acid anodizing of aircraft and electronic parts. The chromic acid anodizing tank was 3.5 m (11.5 ft) long, 0.61 m (2.0 ft) wide, and 0.91 m (3.0 ft) deep. The tank capacity was approximately 1,890 L (500 gal). The anodizing solution in the tank contained chromic acid in a concentration of approximately 60 to 75 g/L (8 to 10 oz/gal) of water. The operating temperature ranged from 35° to 38°C (95° to

100°F). The voltage was applied step-wise until a level of 40 volts was reached. This level was maintained for the remainder of the anodizing time. The current typically ranged from 200 to 300 amperes and the anodizing time was approximately 1 hour. For a more detailed description of the facility, Plant O, refer to Appendix C.

3.3.2.1 Sampling Procedures. Composite samples representative of the scrubber influent, scrubber effluent, and anodizing solution were obtained for each of four 1-hour anodizing cycles. Each sample consisted of four grab samples that were collected approximately 15, 30, 45, and 60 minutes into each anodizing cycle. The composite samples obtained during the tests were analyzed for both hexavalent and total chromium.

The scrubber water flow rate was also measured periodically by placing a 19-L (5-gal) container into the outlet stream and recording the amount of time required to fill the container. The temperature, operating voltage, and operating current of the anodizing solution; the number and types of parts anodized during each anodizing cycle; and the outlet water flow rate of the scrubber were recorded during each anodizing cycle. The average values for each of these parameters is shown in Table 3-12.

TABLE 3-12. PROCESS OPERATING PARAMETERS MONITORED DURING SAMPLING AT THE CHROMIC ACID ANODIZING FACILITY

Run No.	Anodizing bath temperature, °C (°F)	Current, amperes	Voltage, volts	Outlet water flow rate, L/min (gal/min)
1	35 (95)	80-100	35	7.5 (2.0)
2	35 (95)	20-40	36	7.2 (1.9)
3	35 (95)	20	37	7.2 (1.9)
4	35 (95)	100	36	7.5 (2.0)
Average	35 (95)	20-100	36	7.5 (2.0)

3.3.2.2 Results of Mass Balance. The results of the sample analyses were used to perform a chromium mass balance around the scrubber to estimate uncontrolled chromium emissions. The following equation was used to solve for the uncontrolled chromium mass emission rate:

$$M = [(Q_w)(C_w)]/E$$

where:

M = uncontrolled chromium mass emission rate, kg/hr (lb/hr);

Q_w = outlet water flow rate of scrubber, L/hr (gal/hr);

C_w = chromium concentration of outlet water stream, kg/L (lb/gal); and

E = efficiency of the scrubber, 90 percent.

The estimated uncontrolled chromium emission rates and workload descriptions for each test run are presented in Table 3-13. The uncontrolled chromium emission rate ranged from 1.5×10^{-4} kg/hr (3.3×10^{-4} lb/hr) to 2.5×10^{-3} kg/hr (5.5×10^{-3} lb/hr). The variation in the estimated uncontrolled chromium emission rates is directly related to the total surface area and configuration of the parts anodized during each test run. The same type of aircraft parts were anodized during run Nos. 2 and 3 with 22 parts anodized during run No. 2 and 16 parts anodized during run No. 3. The workload decreased 27 percent from run No. 2 to run No. 3 with a corresponding decrease of 61 percent in the uncontrolled emission rate. The types of parts anodized during both run Nos. 1 and 4 were similar and consisted of racks of small aircraft and electronic parts, with 14 racks of parts anodized during run No. 1 and 17 racks of parts anodized during run No. 4. The workload increased 18 percent from run No. 1 to run No. 4 with a corresponding increase of 24 percent in the uncontrolled chromium emission rate.

The average uncontrolled emission rate for run Nos. 2 and 3 is 2.7×10^{-4} kg/hr (5.9×10^{-4} lb/hr), and the average uncontrolled emission rate for run Nos. 1 and 4 is 2.2×10^{-3} kg/hr (4.9×10^{-3} lb/hr). The average of run Nos. 2 and 3 is only 12 percent of the average of run Nos. 1 and 4,

which suggests that both total surface area and configuration of parts substantially affect the amount of uncontrolled chromium emissions.

TABLE 3-13. UNCONTROLLED CHROMIUM MASS EMISSION RATES BASED ON HEXAVALENT AND TOTAL CHROMIUM CONCENTRATION OF OUTLET SCRUBBER WATER AT THE CHROMIC ACID ANODIZING FACILITY

Run No.	Uncontrolled chromium emission rate at scrubber efficiency of 90 percent, kg/hr (lb/hr)[a]	No. of parts or racks anodized	Type of part anodized
1	0.0019 (0.0042)	14 racks	Small aircraft and electronic parts
2	0.00039 (0.00086)	22 parts	Aircraft parts
3	0.00015 (0.00033)	16 parts	Aircraft parts
4	0.0025 (0.0055)	17 racks	Small aircraft and electronic parts
Average	0.0012 (0.0026)		

[a]Total and hexavalent chromium concentrations in scrubber water were equal.

The average uncontrolled chromium emission rate for all runs was 1.2×10^{-3} kg/hr (2.6×10^{-3} lb/hr). Even though the data show a wide range of uncontrolled emission rates due to the different workloads during each run, it is reasonable to average the estimated emissions because workload variations are common in the industry.

3.3.2.3 Emission Factor Development. The factors that affect the hexavalent chromium emission rate from chromic acid anodizing tanks are the types and surface area of parts anodized, surface area of the anodizing tank, orientation of parts within the anodizing tank, plating bath temperature, chromic acid concentration, and surface tension of the anodizing solution. These factors affect emissions in the same manner as they affect emissions from plating baths (see Section 3.3.1.4). However, a key difference between chromium plating and anodizing is the effect of the current applied on emission generation. In plating, the current does not vary across the plating time and, therefore, the chromium mist is generated at a constant rate. In

anodizing, the current varies because the oxide layer that is built up on the anodized part is resistant to current flow, so that the current peaks at the beginning of the anodizing cycle and decreases as the thickness of the oxide layer (or resistance) builds up. Therefore, the amount of hydrogen gassing or chromium misting decreases over the anodizing time as the current decreases. Because of the current fluctuations in anodizing, the average current supplied to the anodizing tank is difficult to determine, which in turn makes it difficult to develop an emission factor based on energy input.

The other predominant factors that affect emissions from chromic acid anodizing operations are the type and surface area of parts anodized, the surface area of the anodizing tank, and the chromic acid concentration. The chromic acid concentration is fairly constant for all anodizing baths and does not account for variations in the process load. The surface area of the parts is probably the best measure of emissions; however, the surface area may or may not be known and is difficult to quantify. Therefore, tank surface area was selected as the best measure of emissions because (1) energy input for anodizing operations cannot be accurately measured, and (2) tank surface area is a constraint on the workload, which is related to emission-generating mechanisms. Based on the results of the mass balance presented previously, the uncontrolled hexavalent chromium emission factor of 6.0×10^{-4} kg/hr/m^2 of tank surface area (1.2×10^{-4} lb/hr/ft^2 of tank surface area) can be used to characterize emissions from this type of operation.

3.4 EXISTING STATE REGULATIONS

Many States use their air toxics programs as a basis for establishing policy or guidelines for limiting chromium emissions. In other States, chromium emission sources are subject only to permit requirements. Fourteen States have adopted or proposed regulations for the control of chromium emissions to the atmosphere. The regulations for these States are discussed below.

3.4.1 California

The State of California has historically been a leader in developing and adopting regulations for the control of airborne toxics. Because of this, a detailed account of the California Air Resources Board's (CARB's) adopted regulations for hexavalent chromium emissions is presented. Their control measure applies to chromium plating and chromic acid anodizing operations. California has determined that, in California, large hard chromium plating and chromic acid anodizing facilities are responsible for 50 percent of all chromium plating emissions; medium hard chromium plating and chromic acid anodizing facilities are responsible for 46 percent; and small hard chromium plating and chromic acid anodizing shops and all decorative chromium plating shops are responsible for 4 percent. The levels of control required are based on the type of plating done and the amount of hexavalent chromium emitted.[72]

Hard chromium plating and chromic acid anodizing facilities emitting up to 0.91 kg/yr (2 lb/yr) (small shops) and all decorative chromium plating shops are required to achieve a level of control (95 percent) that is less stringent than BACT. Medium hard chromium plating and chromic acid anodizing shops--those emitting more than 0.91 kg/yr (2 lb/yr) but less than 4.5 kg/yr (10 lb/yr)--must achieve a 99 percent control efficiency, equivalent to that believed to be attainable by BACT. Large hard chromium platers and chromic acid anodizers (emitting 4.5 kg/yr [10 lb/yr] or more) must achieve a level of control (99.8 percent), which is beyond currently demonstrated BACT. This control efficiency has been demonstrated for control of acid mists in other industries.[72]

As alternatives to control efficiency requirements, CARB has set emission limits that correspond to each control efficiency level. These are based on milligrams of hexavalent chromium emitted per ampere-hour of electrical current use. For the 95 percent control level, the corresponding emission limit is 0.15 mg/Ah (0.002 gr/Ah). The emission levels corresponding to

99 and 99.8 percent control are 0.03 and 0.006 mg/Ah (0.0005 and 0.00009 gr/Ah), respectively.

There are 41 local districts in California. When an airborne toxic control measure (regulation) is adopted by CARB, all local districts must propose and adopt the measure or an equally effective or more stringent measure. The CARB regulation for controlling hexavalent chromium emissions from chromium plating and anodizing operations was adopted in February 1988 and approved by California's Office of Administrative Law (OAL) in December 1988. The effective date of the measure was 30 days following OAL's approval, and the districts had to adopt a measure at least as stringent by July 1989.[73]

3.4.2 Connecticut

A chromium regulation has been adopted by Connecticut and applies to new and existing facilities. The emission limit for hexavalent chromium is 0.25 $\mu g/m^3$ (1.1×10^{-7} gr/ft^3) as chromium (8-hour average). The point of compliance is usually at the property line. If the distance to the property line is very short, then the point of compliance may be up to 10 m (33 ft) beyond the property line. Sources exceeding the emissions limit must install control technology that will enable them to comply with the regulation.[74]

3.4.3 Kentucky

Kentucky's chromium regulations specify that existing sources emitting Cr^{+6} must use reasonably available control technology (RACT). The BACT is required for new and modified sources with Cr^{+6} emissions. Other chromium compounds are regulated only for new and modified sources. The ambient air concentration limit is based on the threshold ambient limit (TAL) for chromium compounds. For sources operating 40 hours per week or less, the emission limit is equal to the TAL for that compound divided by 100. For sources operating 168 hours per week, the limit is equal to the TAL divided by 42. Mathematical interpolation is used to determine limits for sources operating between these limits. The limits apply to the maximum ambient ground level concentration outside the property line.[75,76]

3.4.4 Maine

The regulations for this State have been adopted. The maximum 24-hour concentration for total chromium must not exceed 0.3 $\mu g/m^3$ (1.3×10^{-7} gr/ft^3), and the annual geometric mean must not exceed 0.05 $\mu g/m^3$ (2.2×10^{-8} gr/ft^3). The maximum 24-hour concentration for hexavalent chromium must not exceed the minimum detection level of an acceptable analytical procedure for measuring hexavalent chromium in the ambient air, or 1.0 ng/m^3 (4.4×10^{-10} gr/ft^3), whichever is greater.[77]

3.4.5 Maryland

Maryland has promulgated a regulation that includes total chromium and hexavalent chromium emissions. The regulation is based on EPA's unit risk factor for chromium and employs a screening level (vs. minimum acceptable level). The screening level for total chromium and hexavalent chromium is 5 $\mu g/m^3$ (2.2×10^{-6} gr/ft^3) (8-hour average). Offsite concentrations of hexavalent chromium cannot exceed 0.0008 $\mu g/m^3$ (3.5×10^{-10} gr/ft^3) (annual average). For total chromium, there is no annual average level. If sources cannot meet the level for hexavalent chromium, they must get a special permit that requires them to (1) perform a source-specific risk assessment, (2) demonstrate that all hexavalent chromium emission sources on the premises are controlled using BACT for toxic air pollutants, and (3) advertise in the newspaper to provide an opportunity for a public hearing. These procedures enable the State to make decisions on a case-by-case basis.[78]

3.4.6 Nevada

Emissions of all chromium compounds and chromium valence states for which a TLV exists are regulated. The regulations apply to new sources now and to existing sources as their operating permits are renewed. The ambient concentration limit is the TLV divided by 42 for each of these compounds. The point of compliance is the plant property line. If the concentrations are exceeded, control technology that has been proposed by the applicant and approved by the agency director must be installed at the plant.[79]

3.4.7 New Hampshire

This State's proposed regulation for hexavalent chromium would limit emissions to 0.12 $\mu g/m^3$ (5.2×10^{-8} gr/ft^3) (24-hour average) with the concentrations measured at the plant boundary. The regulation would first apply to new sources only, and existing sources will eventually be regulated.[80]

3.4.8 North Carolina

This State has proposed regulations for the control of emissions of hexavalent chromium. The regulations apply to new and existing sources and would limit the ambient concentration to an annual average of 8.3×10^{-8} mg/m^3 (3.6×10^{-11} gr/ft^3) determined at the property line.[81]

3.4.9 Rhode Island

The adopted regulation applies to new and existing sources. A total chromium emission level of 9.0×10^{-5} $\mu g/m^3$ (3.9×10^{-11} gr/ft^3) is considered acceptable under any conditions. If the level of emissions reaches 9.0×10^{-4} $\mu g/m^3$ (3.9×10^{-10} gr/ft^3), the source must apply lowest achievable emission rate (LAER) technology. Emissions are determined by modeling at the point of maximum impact off the property. If the source is not able to speciate chromium emissions, they are assumed by the State to be all hexavalent chromium.[82]

3.4.10 South Carolina

This State's proposed regulation would apply to new sources only and would limit chromium emissions to the TLV divided by 200, with the concentrations determined at the plant property line.[83]

3.4.11 Utah

Utah has existing regulations stating that any new or modified source of chromium emissions is required to install BACT.[84]

3.4.12 Vermont

This State has adopted a regulation for total chromium emissions. It specifies that sources emitting total chromium must meet a threshold level of 3.2×10^{-6} kg/8 hr (7.1×10^{-6} lb/8 hr) of chromium emissions before they are

subject to the regulation. Sources exceeding this action level must install hazardous most stringent emission rate (HMSER) control technology and are subject to the ambient air quality standard of 8.5×10^{-5} $\mu g/m^3$ (3.7×10^{-11} gr/ft^3), determined at the point of maximum impact.[85]

3.4.13 Virginia

This State's adopted regulations apply to new and existing sources. For chromium with valence states listed as carcinogenic, the 24-hour average emission limit is the TLV divided by 100; for valence states not listed as carcinogenic, the 24-hour average emission limit is the TLV divided by 60. The point of compliance is the fenceline.[86]

3.4.14 Wisconsin

Water-soluble hexavalent chromium is regulated as a toxic air pollutant for new and existing sources. The point of compliance is the property line. The de minimis level for sources with stack heights of less than 25 ft is 0.019 kg/hr (4.08×10^{-2} lb/hr) (24-hour average) and 0.077 kg/hr (17.04×10^{-2} lb/hr) (24-hour average) for stack heights of greater than 25 ft. The acceptable ambient concentration for water-soluble hexavalent chromium is 1.2 $\mu g/m^3$ (5.2×10^{-7} gr/ft^3). Water-insoluble hexavalent chromium is regulated as a known human carcinogen for new and existing sources. The de minimis level for new sources (and existing sources, eventually) is 0.91 kg/yr (2 lb/yr). If this level is exceeded, the source must apply LAER technology.[87]

3.5 REFERENCES FOR CHAPTER 3

1. Memo from Hester, C., MRI, to Smith, A., EPA/ISB. Bases of Risk Assessment Inputs for Chromium Electroplating Operations. June 10, 1988. p. 10.

2. Memo from Hester, C., MRI, to Smith, A., EPA/ISB. Bases of Risk Assessment Inputs for Chromic Acid Anodizing Operations. June 10, 1988. p. 9.

3. Decorative Chromium Plating. American Electroplaters Society, Inc. 1980. p. 4.

4. Logozzo, A. W., and M. Schwartz. Hard Chromium Plating. American Electroplaters Society, Inc. 1984. p. 9.

5. Graham, K. A. Electroplating Engineering Handbook (3rd ed.). New York, Van Nostrand Reinhold Co, 1971. p. 138.

6. Graham, K. A. Electroplating Engineering Handbook. New York, Reinhold Book Co. 1962. p. 162.

7. Reference 6, pp. 162-163.

8. Reference 5, p. 684.

9. Reference 4, p. 13.

10. Reference 4, p. 13.

11. Allen, W. Hard Chromium Plating: How Difficult? Products Finishing. March 1988. p. 69.

12. Chromium Emissions from Chromium Electroplating Operations--Technical Report. November 1, 1985. p. 3.

13. Reference 3, p. 7.

14. Reference 3, p. 8.

15. Reference 3, p. 2.

16. Lowenhein, F. A. Electroplating. New York, McGraw-Hill Book Co. 1978. p. 196.

17. Mackey, R. W. and D. A., Swalheim. Cyanide Copper Plating. American Electroplaters Society, Inc. 1969. pp. 7, 14.

18. Reference 17, p. 4.

19. Reference 16, pp. 201-202.

20. Reference 16, p. 202.

21. Metal Finishing. Guidebook and Directory Issue. 88(1A). January 1990. p. 203.

22. Olsen, Alan E. Bright Acid Sulfate Copper Plating. American Electroplaters Society, Inc. 1970. p. 3.

23. Soule, R. D. Electroplating. In: Industrial Hygiene Aspects of Plant Operations, Vol. 2, Unit Operations and Product Fabrication, Cralley, L. V. and L. J. Cralley (eds.). New York, Macmillan Publishing Company. 1984. p. 81.

24. Reference 23, p. 79.

25. Dennis, J. K., and T. E. Such. Nickel and Chromium Plating (2nd ed.). London, England Butterworth and Company. 1986. p. 232.

26. Reference 23, p. 84.

27. DiBari, G. A., and J. Horner. Nickel Plating. American Electroplaters Society, Inc. 1985. p. 4.

28. Reference 12. p. 3.

29. Reference 25, p. 179.

30. Reference 25, p. 287.

31. Reference 25, p. 289.

32. Reference 25, p. 290.

33. Reference 25, pp. 272, 294-295.

34. Schwartz, M. Anodizing Aluminum and Its Alloys. American Electroplaters Society. 1985. p. 15.

35. Reference 6, p. 432.

36. Reference 6, pp. 162, 427.

37. Darrin, M., and L. G. Tubbs. Dyeing Chromic Acid Anodized Aluminum. Metal Finishing. September 1943. p. 550.

38. Brace, A. W. The Technology of Anodizing Aluminum. Teddington, Robert Draper, Ltd. 1968. p. 54.

39. Reference 34, p. 17.

40. Wernick, S., and R. Pinner, Surface Treatment and Finishing of Light Metals, Metal Finishing. June 1955. p. 92.

41. Telecon. Cassidy, M., MRI, with Kellett, J., Boeing Commercial Airplane Company. February 27, 1989. Information on chromic acid anodizing process.

42. Reference 6, p. 429.

43. Reference 6, p. 429.

44. Mozley, P. P. The Chromic Acid Anodizing Process. Metal Finishing. June 1941. p. 302.

45. Prelinger, H. A. The Chromic Acid Anodizing Bath and Its Control. Metal Finishing. November 1960. p. 59.

46. Reference 6, p. 433.

47. Brimi, M. A., and J. R. Luck. Electrofinishing. New York, American Elsevier Publishing Co. 1965. p. 77.

48. Reference 6, p. 430.

49. Smart, D., T. E. Such, and S. J. Wake. A Novel Trivalent Chromium Electroplating Bath. Bulletin of the Institute of Metal Finishing. 61:106 p. 106.

50. Snyder, D. Trivalent Chromium Plating: The Second Decade. Product Finishing. March 1988. p. 59-60.

51. Reference 50, p. 63.

52. Reference 50, pp. 64-65.

53. Reference 50, p. 65.

54. Letter from Vervaert, A., EPA/ISB, to Masarik, D., Englehard Corporation. November 17, 1988. Trip report for Englehard Corporation, Beachwood and Cleveland, Ohio. p. 3.

55. Cost Enclosure for Decorative Chromium Electroplating Processes: Harshaw/Filtrol Partnership. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina, by Dennis Masarik, Manager of Technical Services. June 22, 1987. p. 3.

56. Tomaszewski, T., and R. Fischer. Trivalent Chromium: A Commercially Viable Alternative. Occidental Chemical Corp. p. 5.

57. Reference 56, pp. 5-6.

58. Eppensteiner, F., and M. Jenkins. Chromate Conversion Coatings. In: Metal Finishing, Guidebook and Directory Issue 1990. 88(1A):433-441.

59. Biestek, T., and J. Weber. Electrolytic and Chemical Conversion Coatings. Warsaw, Portcullis Press Ltd. 1976. p. 10.

60. Reference 5, pp. 682-686.

61. Chromium Electroplaters Test Report: Greensboro Industrial Platers, Greensboro, North Carolina. Entropy Environmentalists, Inc., Research Triangle Park, North Carolina. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-1. March 1986.

62. Chromium Electroplaters Test Report: Consolidated Engravers Corporation, Charlotte, North Carolina. Peer Consultants, Inc., Rockville, Maryland. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 87-CEP-9. May 1987.

63. Chromium Electroplaters Test Report: Able Machine Company, Taylors, South Carolina. PEI Associates, Inc., Cincinnati, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-3. June 1986.

64. Emission Test Report: Roll Technology Corporation, Greenville, South Carolina. Peer Consultants, Inc., Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-13. August 1988.

65. Chromium Electroplaters Test Report: Precision Machine and Hydraulic, Inc., Worthington, West Virginia. Peer Consultants, Inc., Dayton, Ohio. Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-14. September 1988.

66. Chromium Electroplaters Test Report: Hard Chrome Specialists, York, Pennsylvania. Peer Consultants, Inc., Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 89-CEP-15. February 1989.

67. Chromium Electroplaters Test Report: Piedmont Industrial Platers, Statesville, North Carolina. Entropy Environmentalists, Inc., Research Triangle Park, North Carolina. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-4. August 1986.

68. Chromium Electroplaters Test Report: Steel Heddle, Inc., Greenville, South Carolina. PEI Associates, Inc., Cincinnati, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-2. June 1986.

69. Chromium Electroplaters Test Report: Fusion, Inc., Houston, Texas. Peer Consultants, Inc., Dayton, Ohio. Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 89-CEP-16. May 1989.

70. Chromium Electroplaters Test Report: GMC Delco Products Division, Livonia, Michigan. Peer Consultants, Inc., Rockville, Maryland. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 87-CEP-7. March 1987.

71. Chromium Electroplaters Test Report: Automatic Die Casting, St. Clair Shores, Michigan. Peer Consultants, Inc., Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-11. April 1988.

72. State of California Air Resources Board. Staff Report: Initial Statement of Reasons for Proposed Rulemaking. Proposed Airborne Toxic Control Measure for Emissions of Hexavalent Chromium from Chrome Plating and Chromic Acid Anodizing Operations. January 1988.

73. Telecon. Cassidy, M., MRI, with Holiday, K., California Air Resources Board. February 24, 1989. Information on California's control measure for emissions of hexavalent chromium from chrome plating and chromic acid anodizing operations.

74. Telecon. Cassidy, M., MRI, with Gove, J., Connecticut Department of Environmental Protection Air Compliance Unit. March 14, 1989. Information on Connecticut's State regulation for chromium.

75. Telecon. Barker, R., MRI, with Saaid, H., Kentucky Resource and Environmental Protection Cabinet, Division of Air Pollution Control. October 2, 1986. Information on Kentucky's State regulation for chromium.

76. State of Kentucky Natural Resources and Environmental Protection Cabinet, Department of Environmental Protection, Division of Air Pollution--Regulations 401 KAR 63:021 and 401 KAR 63:022.

77. Telecon. Cassidy, M., MRI, with Severance, R., Maine Department of Environmental Protection, Bureau of Air Quality Control. August 28, 1986. Information on Maine's State regulation for chromium.

78. Telecon. Cassidy, M., MRI, with Aburn, T., Maryland Department of Health and Mental Hygiene, Air Management Administration. March 14, 1989. Information on Maryland's State regulation for chromium.

79. Telecon. Cassidy, M., MRI, with Shifley, L., Nevada Department of Conservation and Water Resources, Air Quality Bureau. March 14, 1989. Information on Nevada's State - regulation for chromium.

80. Telecon. Barker, R., MRI, with Andrews, R., New Hampshire Air Resources Agency. October 2, 1986. Information on New Hampshire's State regulation for chromium.

81. Telecon. Cassidy, M., MRI, with Hageman, R., North Carolina Department NRCD, Division of Environmental Management. March 14, 1989. Information on North Carolina's State regulation for chromium.

82. Telecon. Cassidy, M., MRI, with Morin, B., Rhode Island Department of Environmental Management, Division of Air and Hazardous Materials. March 13, 1989. Information on Rhode Island's State regulation for chromium.

83. Telecon. Cassidy, M., MRI, with Pearson, O., South Carolina Department of Health and Environmental Control, Bureau of Air Quality Control. August 26, 1986. Information on South Carolina's State regulation for chromium.

84. Telecon. Barker, R., MRI, with McNeil, D., Utah Department of Health, Bureau of Air Quality. October 7, 1986. Information on Utah's State regulation for chromium.

85. Telecon. Cassidy, M., MRI, with Garabedian H., Vermont Agency of Environmental Conservation, Air Pollution Control Division. March 10, 1989. Information on Vermont's State regulation for chromium.

86. Telecon. Cassidy, M., MRI, with Holmes, C., Virginia Air Pollution Control Board. August 28, 1986. Information on Virginia's State regulation for chromium.

87. Telecon. Cassidy, M., MRI, with Rudell, V., Wisconsin Department of Natural Resources, Bureau of Air Management. March 13, 1989. Information on Wisconsin's State regulation for chromium.

4. EMISSION CAPTURE AND CONTROL TECHNIQUES

This chapter presents a description of the techniques typically used to capture and control emissions of chromic acid mist from decorative and hard chromium electroplating and chromic acid anodizing baths.

4.1 EMISSION CAPTURE TECHNIQUES

Local exhaust ventilation is the most common method used to capture chromic acid mist from chromium plating and chromic acid anodizing baths. General ventilation, the exhausting of large volumes of air from a building or room, is not normally used because of the toxicity of chromic acid and the need to remove contaminated air that would accumulate close to the source.

4.1.1 Local Ventilation

Local exhaust ventilation equipment typically used to capture chromic acid mist from chromium plating and chromic acid anodizing operations includes lateral (slot) and push-pull exhaust hoods. Canopy hoods and enclosures are normally not used because they restrict access to the plating or anodizing tank. For tanks located where there are no room cross drafts, the recommended minimum capture air velocity across the liquid surface of the tank is 46 m/min (150 ft/min) for contaminants with high hazard potential and a high rate of mist evolution such as chromic acid.[1,2] Capture velocity is the velocity required to overcome opposing air currents and cause the contaminated air to flow into the hood. Where room cross drafts occur at the tank level, the capture velocity should be increased, and baffles should be installed to mitigate the effects of the cross drafts.

The design ventilation rate for a particular tank is based on the hood type selected, the capture or control velocity

selected, and on the aspect (width-to-length) ratio of the tank. Table 4-1 presents minimum recommended ventilation rates for tanks with aspect ratios less than 2.0. Ventilating parallel to the long dimension of a tank with an aspect ratio that exceeds 2.0 is not practicable.[1,2]

4.1.2 Lateral Exhaust Systems

All tanks exhausted by means of hoods that do not project over the entire tank, and in which the direction of air movement into the hood or hoods is substantially horizontal, are said to be laterally exhausted. Lateral exhaust systems typically applied to control chromic acid mist from open-surface tanks include both single- and double-sided slot hoods. The slot velocity affects the uniformity of airflow distribution along the length of the hood. Slot velocities of 610 m/min (2,000 ft/min) are recommended unless takeoffs (openings where emissions are exhausted to the duct) are provided. With well-designed, tapered takeoffs, lower velocities may be used. Multiple takeoffs are recommended for tanks at least 1.8 m (6.0 ft) in length and are necessary for tanks at least 3.0 m (10 ft) in length to maintain good capture efficiency.

An example of each type of slot hood is shown in Figures 4-1 and 4-2. Single-sided hoods have a maximum reach across the width of the tank of about 76 cm (30 in.) while double-sided hoods have a maximum reach of about 152 cm (60 in.). The advantage of a lateral slot hood is that it minimizes the space occupied by the hood when air distribution over a large surface is needed; the disadvantage is that the high slot velocities result in a relatively high static pressure loss at the hood entry.[1,2]

Push-pull ventilation is recommended for tanks greater than 107 cm (42 in.) in width.[1] A diagram of a push-pull system is presented in Figure 4-3. Push air supplied through slots, orifices, or nozzles is blown across the width of the tank to direct contaminated air toward an exhaust hood located on the opposite side of the tank. The major advantage of push-pull systems over lateral exhaust systems is that they provide the

TABLE 4-1. MINIMUM VENTILATION RATES FOR VENTILATION HOODS USED TO CAPTURE EMISSIONS OF CHROMIC ACID MIST FROM CHROMIUM PLATING AND CHROMIC ACID ANODIZING TANKS[a,1]

Tank width-to-length ratio	Hood along one side or two parallel sides of tank when tank is against a wall or baffled		Hood along one side or two parallel sides of free-standing tank not against wall or baffled	
	Lateral hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)[b c]	Push-pull hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)	Lateral hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)[b c]	Push-pull hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)
0.0-0.09	46 (150)	23 (75)	69 (225)	35 (115)
0.1-0.24	58 (190)	26 (95)	76 (250)	38 (125)
0.25-0.49	69 (225)	35 (115)	76 (250)	38 (125)
0.5-0.99	76 (250)	38 (125)	76 (250)	38 (125)
1.0-2.0	76 (250)	38 (125)	76 (250)	38 (125)

[a]Ventilation rates are based on the minimum control velocity of 46 m/min (150 ft/min) recommended for chromic acid mist.
[b]For lateral hoods along centerline or two parallel sides of tank, tank width-to-length ratio equals tank width ÷ 2.
[c]Although a ventilation rate of 76 $m^3/min/m^2$ (250 $ft^3/min/ft^2$) may not produce a control velocity of 46 m/min (150 ft/min) at all aspect ratios, the ventilation rate is considered adequate for control.

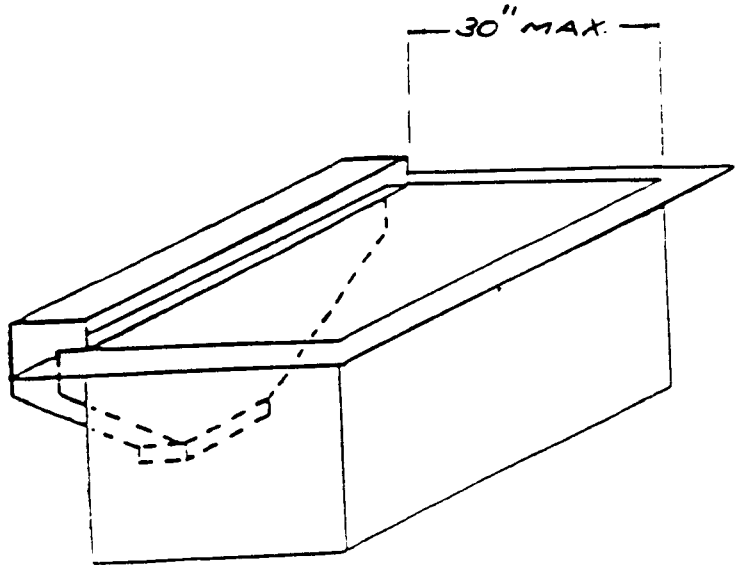


Figure 4-1. Example of a single-sided lateral exhaust hood.[3]

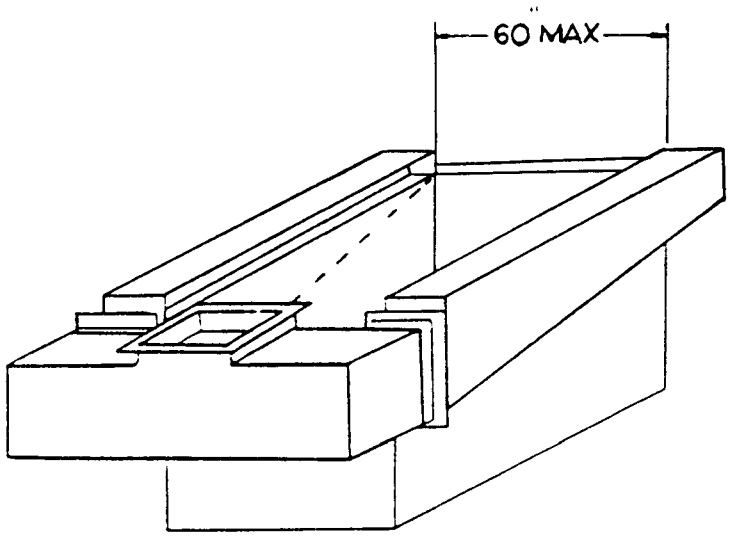


Figure 4-2. Example of a double-sided lateral exhaust hood.[4]

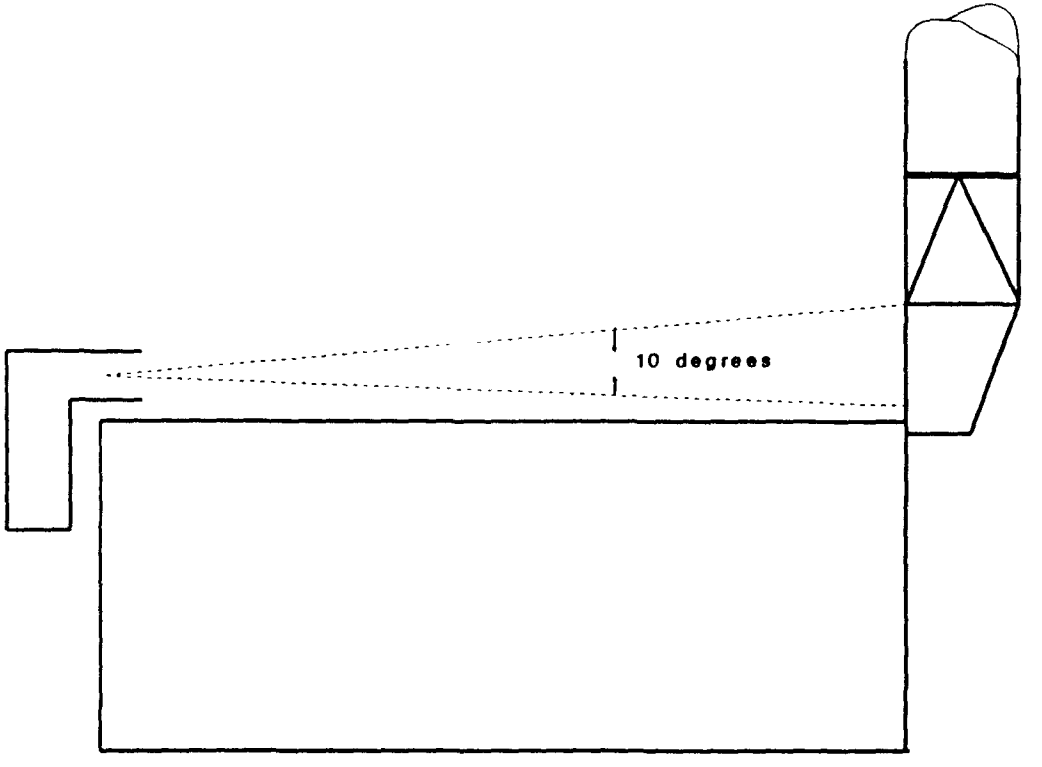


Figure 4-3. Diagram of a push-pull ventilation system.[5]

same ventilation efficiency while using only about one-half the volume of air. This efficiency results in smaller air handling equipment (ductwork and fans) and lower utility and makeup air requirements. However, push-pull ventilation cannot be used when plating racks, anode bars, or other obstructions that interfere with the flow of push air across the tank are present.

4.1.3 Factors Affecting Performance of Local Exhaust Ventilation

Maintaining an adequate ventilation rate is one of the major factors affecting the performance of ventilation systems. The ventilation rate must be maintained at a level sufficient to produce a uniform, horizontal movement of air (across the surface of the tank) that is capable of capturing and conveying the contaminated air to the exhaust hood. The capture velocity must be sufficiently high to compensate for air disturbances across the tank due to cross drafts in the room. Baffles can be added to lessen the effects of severe cross drafts.

Another key factor affecting the performance of local exhaust ventilation is the adequacy of the makeup air supply. Sufficient makeup air must be introduced to offset or replace air exhausted from the building. Without sufficient makeup air, exhaust systems have to work against an increased static pressure because buildings are under negative pressure, or suction. Regardless of the types of exhaust fans employed, actual exhaust rates and capture velocities can be reduced significantly. The main factors affecting the volumetric flow of makeup air in a shop include the layout and siting of heat sources and the physical layout of the building relative to the location of the tank.

In addition to the factors discussed above, other factors that affect the performance of a push-pull system include the amount of push air supplied, the size of the exhaust hood installed, and the extent to which obstructions are present in the push air stream path. Too much push air volume or pressure can result in airflows exceeding the exhaust rate. The exhaust hood opening must be large enough to intercept the entire cross

section of the air stream directed to it. Obstructions in the path of the air stream must be limited to avoid interference.

4.2 EMISSION CONTROL TECHNIQUES

The principal techniques used to control emissions of chromic acid mist from decorative and hard chromium plating and chromic acid anodizing operations include add-on control devices that treat ventilation air and methods, such as the addition of chemical fume suppressants, that affect the amount of mist released from the tank. Control devices applied most frequently include mist eliminators and wet scrubbers. Because of the corrosiveness of chromic acid, ventilation systems and control devices are typically made of PVC plastic or fiberglass.

Chemical fume suppressants are typically added to decorative chromium plating and chromic acid anodizing baths to inhibit chromic acid misting. Although the use of fume suppressants alone can be effective, many plants use them in conjunction with add-on control devices. Polypropylene balls are sometimes added to hard chromium plating baths to reduce heat loss and evaporation of the plating solution and, to a limited extent, to reduce chromic acid misting.

The two major control mechanisms by which contaminants such as chromic acid mist are removed from ventilation air are inertial impaction and direct interception. Collection by inertial impaction involves the collision of large particles with a stationary surface to which they adhere. In direct interception, particles attempt to follow the streamline around the collection surface, but, due to their size and relative velocity, they are intercepted by the fluid layer that surrounds the collection surface. Collected liquid droplets drain to the bottom of the collection device due to gravity. Particles that have been wetted increase in mass and are more easily removed from the gas stream than are smaller particles. Wetted particles may be separated from the gas stream by impingement against surfaces placed in the path of the gas flow, by centrifugal action's throwing particles to the outer walls of the collector, or by simple gravitational settling. Most control devices are

flushed with water on a periodic or continual basis to clean the collection surfaces.

4.2.1 Mist Eliminators

The types of mist eliminators most frequently used at chromium electroplating and anodizing facilities include chevron-blade and mesh-pad units. Inertial impaction and direct interception are the principal control mechanisms by which both types of mist eliminators collect chromic acid droplets from gas streams. Mist eliminators are usually operated as dry units that are periodically washed with water to clean the impaction media.

4.2.1.1 Chevron-Blade Mist Eliminators. Chevron-blade mist eliminators consist of one or more sets of parallel, chevron-shaped baffles (blades) arranged in a horizontal-flow configuration. Horizontal-flow chevron-blade mist eliminators typically are used to control chromic acid mist because the horizontal-flow configuration is more effective than the vertical-flow configuration for the high inlet velocities and pollutant loadings common for chromium plating operations. Diagrams of typical units with single and double sets of blades are presented in Figures 4-4 and 4-5, respectively. Each blade changes the direction of the gas flow four times, which causes chromic acid droplets to impinge on the surface of the blades as a result of inertial force. Water sprays mounted at the inlet of the mist eliminator and directed toward the blades are activated periodically to wash off the chromic acid that has built up on the blades. During washing, the fan should be turned off to prevent water droplets from being drawn through the stack and discharged to the atmosphere. In most instances, the wash water is drained to the plating tank to make up for evaporative losses of plating solution and to recover chromic acid. Otherwise, the wash water is drained to a wastewater treatment system.

Two blade designs commonly used are overlapping and sinusoidal wave. A schematic of each design is shown in Figure 4-6. The overlapping design consists of a set of blades with overlapping edges. In contrast, the sinusoidal wave design consists of a set of blades with rounded edges and catchments

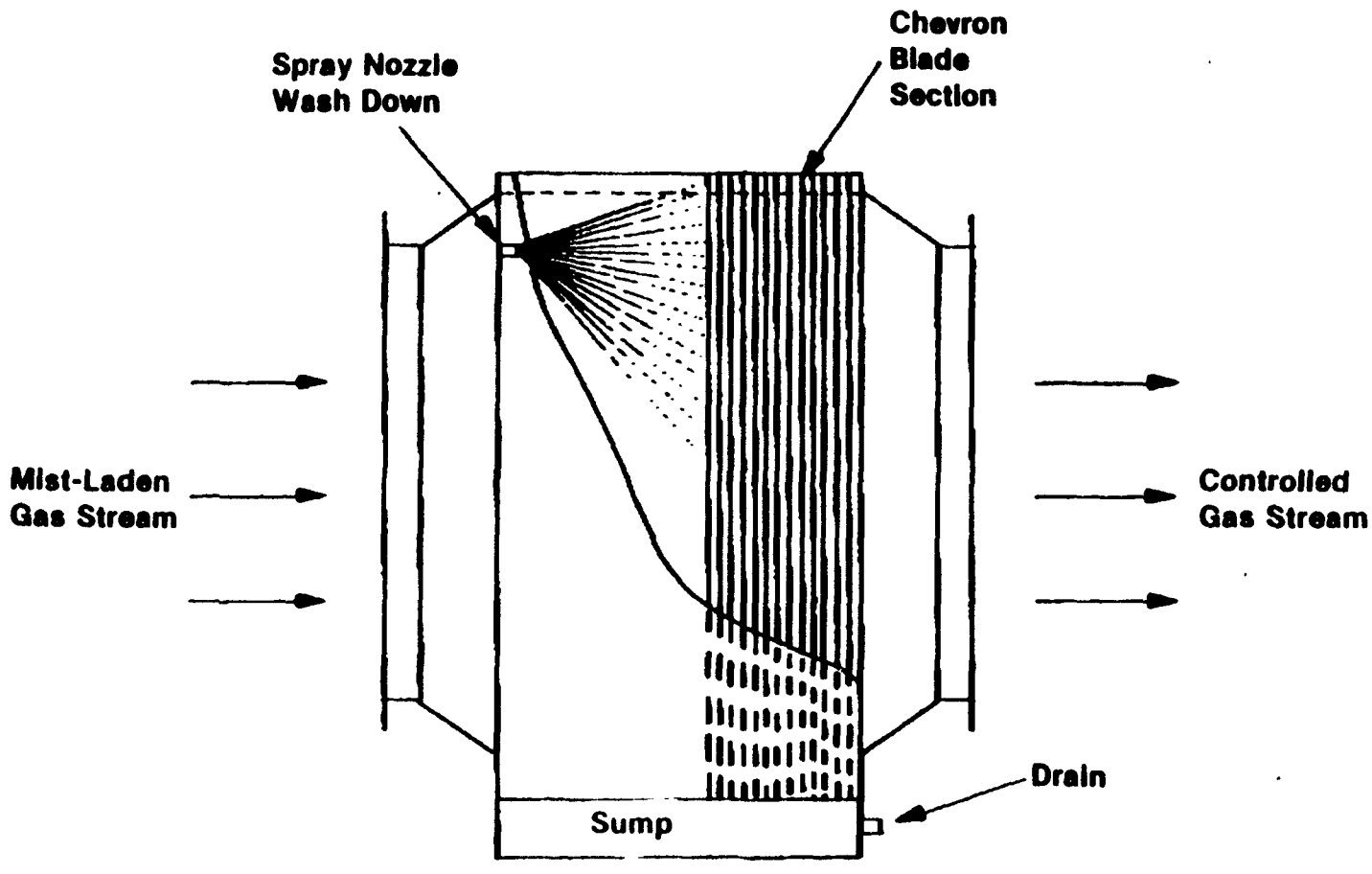


Figure 4-4. Horizontal-flow chevron-blade mist eliminator with a single set of blades.

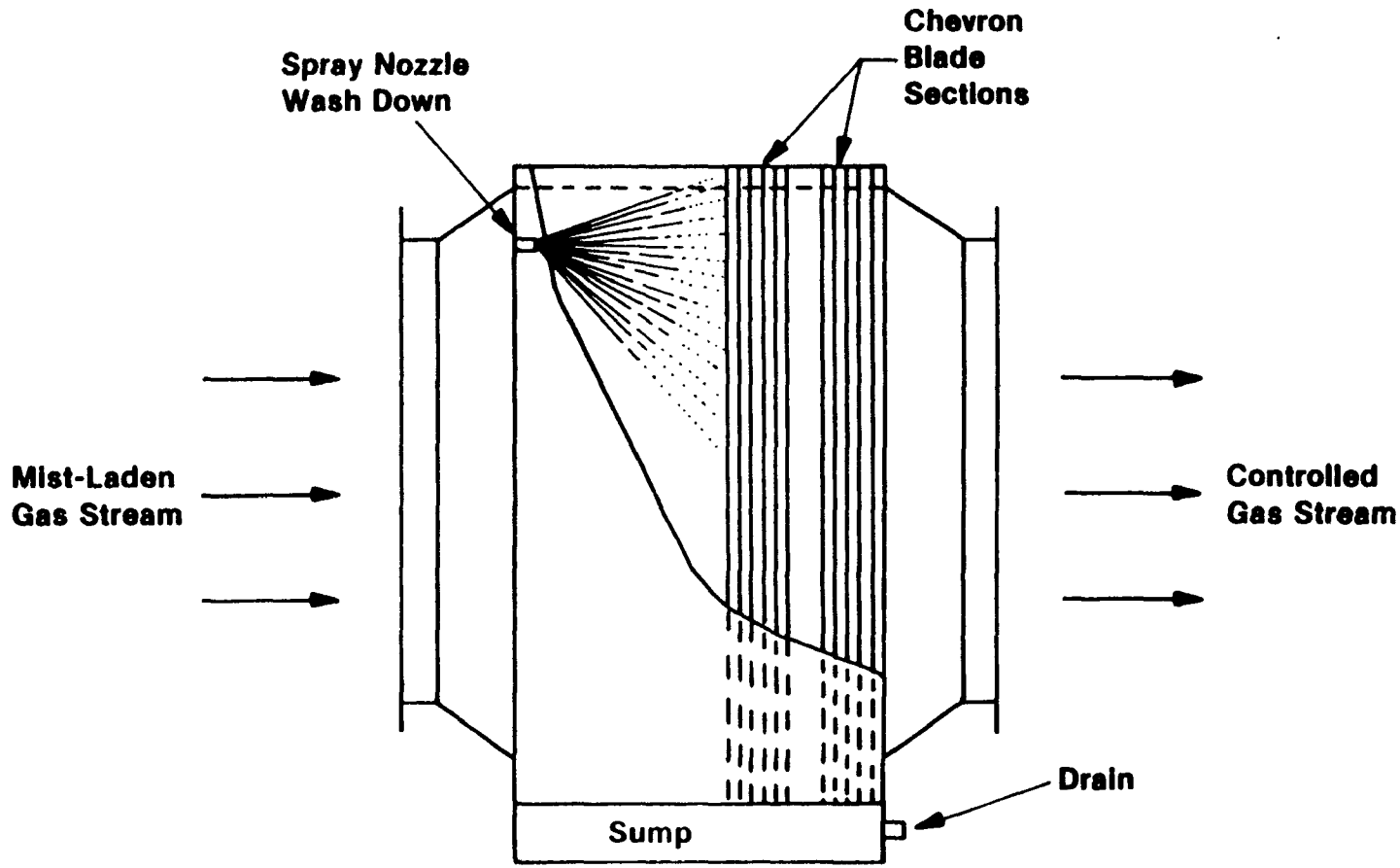
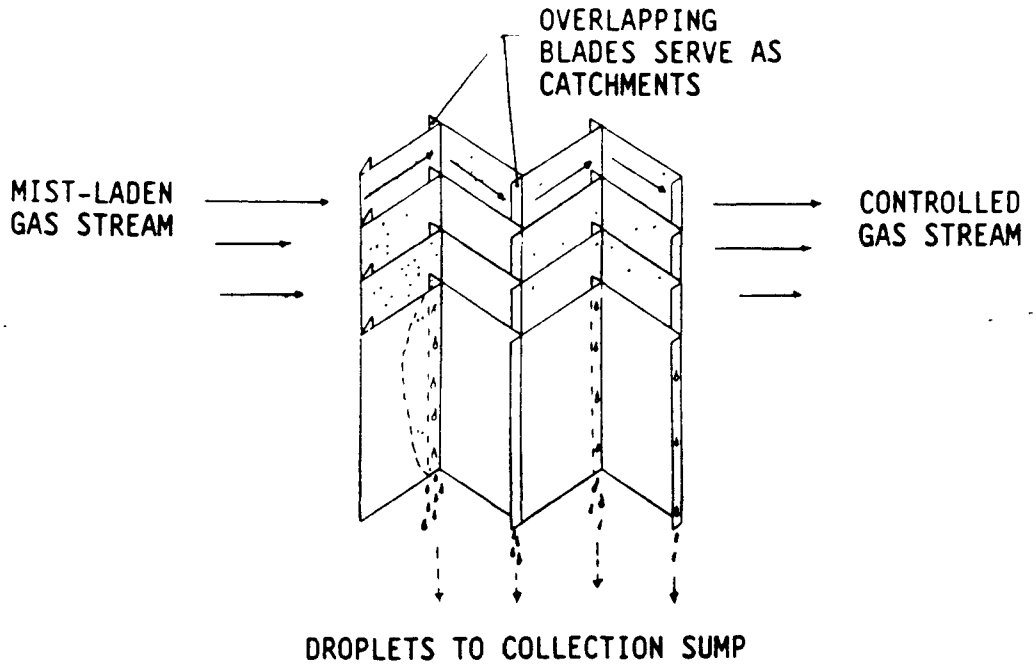
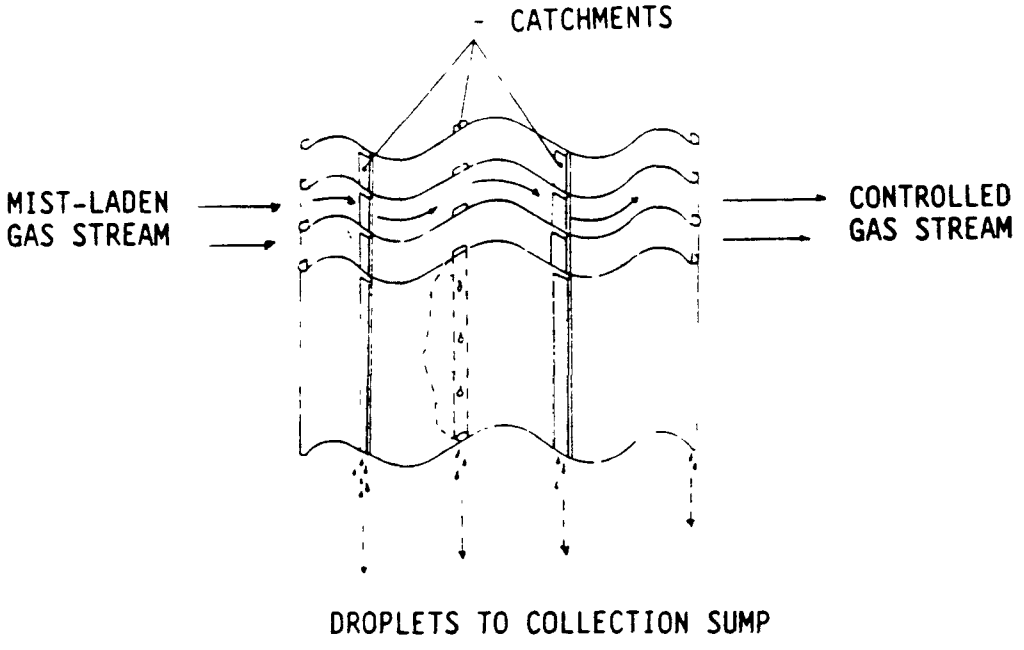


Figure 4-5. Horizontal flow chevron-blade mist eliminator with a double set of blades.



a) Overlapping-type blades.



b) Sinusoidal wave-type blades.

Figure 4-6. Blade designs for chevron-blade mist eliminators.

located between the rounded edges. The overlapping edges, or catchments, act as collection troughs for droplets and facilitate drainage of the droplets into a collection sump.

Factory-assembled units are available for gas flow rates from 14 to 1,700 standard m^3/min (500 to 60,000 standard ft^3/min). Units are designed to maintain gas velocities through the mist eliminator between 120 to 270 m/min (400 to 900 ft/min). Blades typically range from 15 to 30 cm (6 to 12 in.) in depth. The spacing between blades may vary but is normally 3.18 cm (1.25 in.). The static pressure drop across a mist eliminator with one set of blades and with two sets of blades is about 0.20 kPa (0.75 in. w.c.) and 0.5 kPa (2 in. w.c.), respectively. Control device vendors estimate that removal efficiencies range from 80 to 90 percent.[6]

4.2.1.2 Factors Affecting Performance of Chevron-Blade Mist Eliminators. Major factors that affect the performance of chevron-blade mist eliminators include the face velocity of the gas stream across the blades, the spacing between blades, and the tightness of seals between the blades and the walls of the unit. Gas stream velocities must be maintained within design specifications to maximize the operating efficiency of the unit. Gas velocities less than the specified minimum (typically 120 m/min [400 ft/min]) will not provide the inertial force required to maximize impingement of chromic acid droplets on the blades, and gas velocities greater than the specified maximum (typically 270 m/min [900 ft/min]) may cause droplets to become reentrained in the gas stream. The spacing of the blades is also an important factor. If the blades are too close together, the unit could plug; if the blades are too far apart, portions of the gas stream could travel through the unit with little or no change in direction, which could result in breakthrough of chromic acid droplets. Also, the blades must be sealed tightly to the walls of the unit to prevent contaminated gases from by-passing the chevron blades.

Another important factor affecting the performance of chevron-blade mist eliminators is the frequency of washing. The

unit should be washed for 10 minutes at least once per day. During washing, the fan must be turned off to prevent water droplets from being drawn through the stack and discharged to the atmosphere.

4.2.1.3 Mesh-Pad Mist Eliminators. A diagram of a mesh-pad mist eliminator is presented in Figure 4-7. Mesh-pad mist eliminators consist of layers of interlocked filaments densely packed between two supporting grids. The principal control mechanisms are inertial impaction and direct interception. Inertial impaction occurs when particles larger than about 3 μm (0.12 mil), traveling with sufficient velocity, collide with the filaments and adhere to their surface. Other particles, because of their size and relative velocity, are intercepted by the fluid layer surrounding the surface of the filament. Collected liquid droplets flow along the fibers to a point where adjacent filaments cross. These crossover points rapidly become loaded with liquid, and droplets drain to the bottom of the mist eliminator as a result of gravity.

The mesh pads consist of thin, multiple layers of interwoven fibers. These layers are compacted and fastened together with thin filaments. Three mesh pad weave designs are available, as follows: (1) layers with a crimp in the same direction (each layer is actually a nested double layer), (2) layers with a crimp in alternate directions, and (3) spiral-wound layers. The filament size depends on the application and can vary from about 0.015 cm (0.006 in.) in diameter for fine wire pads to 0.38 cm (0.15 in.) in diameter for some plastic fibers. Pad thicknesses vary from 10 to 15 cm (4 to 6 in.), but occasionally pads as thick as 30.5 cm (12 in.) are used.[8] Mesh densities are generally reported in terms of bulk density (mass per unit volume) because it is easier to determine than surface area-to-volume ratio. Typical bulk mesh densities range from 48 to 529 kg/m^3 (3 to 33 lb/ft^3).[9]

Although design gas velocities across mesh pads depend on the type of mesh material (fiber diameter and configuration), typical velocities range from 180 to 275 m/min (600 to

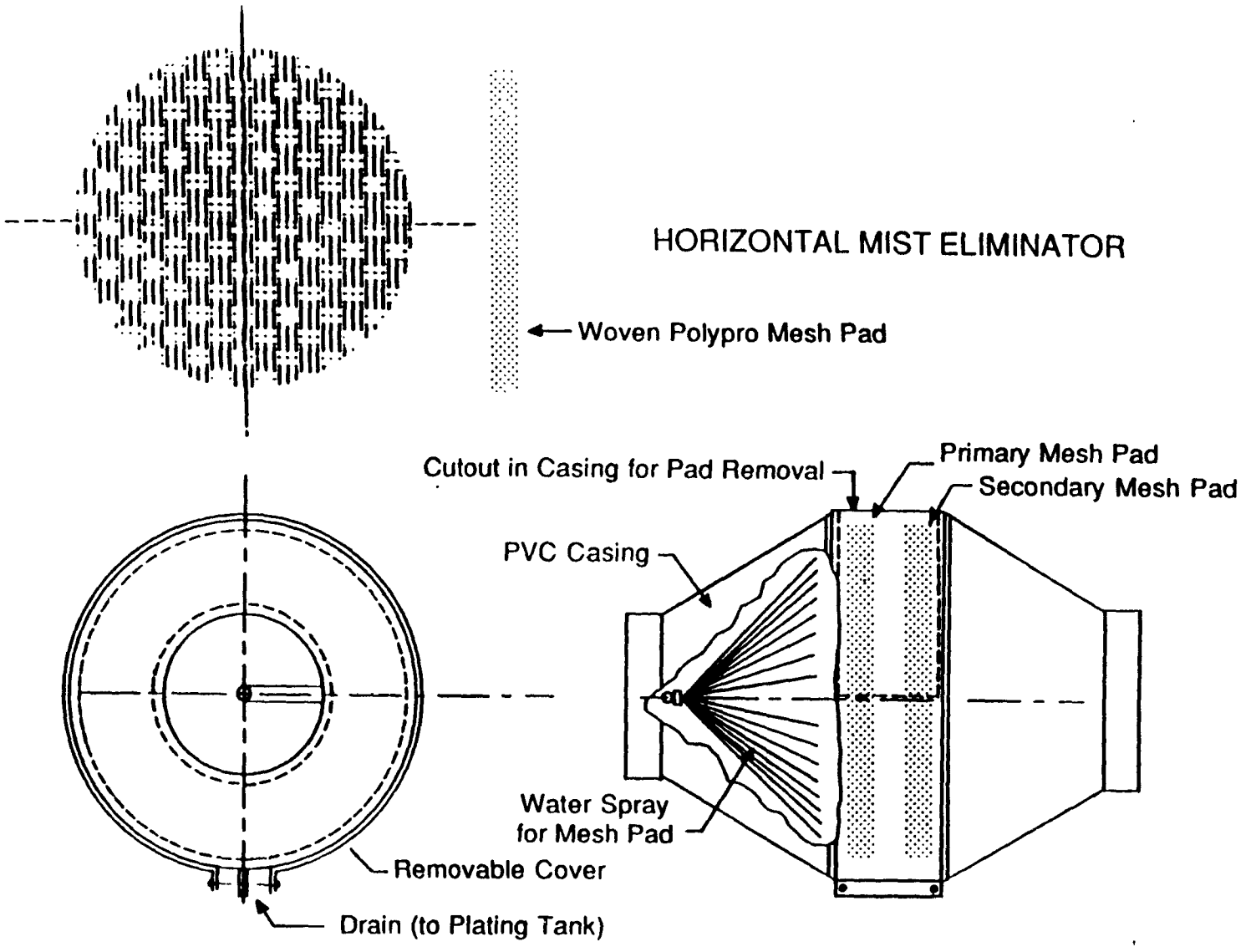


Figure 4-7. Mesh-pad mist eliminator.[7]

900 ft/min) for vertical-flow units and from 275 to 420 m/min (900 to 1,380 ft/min) for horizontal-flow units.[10]

Often two mesh-type separators in series are used to remove particles in the 1 to 5 μm (0.04 to 0.20 mil) diameter range. The first mesh, normally made of fine fibers, coalesces the small drops, and the second mesh, made of standard fibers, removes them. The first mesh is operated beyond the flooding velocity and the second under flooding velocity.[11]

In the past, mesh-pad mist eliminators were not frequently used to control chromic acid mist because of the tendency of the units to plug at high inlet loadings. These units consisted of one mesh pad, approximately 15 cm (6.0 in.) thick with a pressure drop of 0.25 kPa (1.0 in. w.c.). The units were installed for vertical gas flow through the unit and were not equipped with a spray system to clean the pad. This type of configuration was not recommended by vendors for use in chromic acid mist control because of the plugging tendency of the unit.[12] However, in recent years, mesh-pad mist eliminators equipped with internal spray systems to clean the pads have been developed, avoiding potential plugging problems. These newer units contain multiple mesh pads in series that are designed to remove chromic acid mist in stages. The first stage removes the bulk of the mist, which is comprised of fairly large particles (above 5 μm [0.20 mil]), and the second stage removes the smaller particles (between 3 and 5 μm [0.12 and 0.20 mil]). Because the internal spray system protects the pads from plugging, these units contain pads with a smaller fiber diameter than the older models. As a result of the smaller diameter, the mesh pads are more compact and, therefore, have a higher pressure drop (0.62 kPa [2.5 in. w.c.]). Instead of vertical gas flow, these units are installed for horizontal gas flow through the unit, which allows for better drainage. In addition, these units are designed so that the pads can be removed and cleaned. This feature helps prevent plugging and extends the life of the pad material. The vendor of this technology estimates a control device efficiency between 96 and 99 percent.[13] Because of the reduction in the plugging potential

and its associated maintenance problems, the use of mesh-pad mist eliminators in controlling chromic acid mist has increased.

4.2.1.4 Factors Affecting Performance of Mesh-Pad Mist Eliminators. One of the major factors that affects mesh-pad mist eliminator performance is the tendency of the unit to plug. The mesh pad must be flushed frequently with water to prevent chromic acid buildup and eventual plugging. Mesh-pad mist eliminators should be washed down at least once a day.

Velocity of the gas stream and the particle size of the entrained pollutant are additional factors that affect the performance of the mesh pad assembly. Because the pad consists of stationary surfaces, the entrained particles must have adequate velocity to collide with the filaments. As velocity increases, collection of particles through inertial impaction increases. Consequently, low gas velocities result in less than optimum efficiency. However, high gas velocities can cause collected particles to be reentrained in the gas stream, which may result in lower overall control efficiency. Therefore, gas velocities should be maintained high enough to optimize collection through inertial impaction yet not cause reentrainment.

Tests have been conducted to compare the performance of units with vertical airflow and horizontal airflow. These tests show that:

1. Reentrainment velocities are higher in the systems with horizontal gas flow (i.e., vertically installed mesh pads) because this configuration provides better drainage, and

2. When the units are operated at the same gas velocities, there is less reentrainment in the system with horizontal gas flow.[14]

4.2.2 Scrubbers

Single and double packed-bed scrubbers are the predominant types of scrubbers used to control emissions of chromic acid mist from chromium plating and chromic acid anodizing operations. Other scrubber types used less frequently include fan-separator packed-bed and centrifugal-flow scrubbers.

4.2.2.1 Packed-Bed Scrubbers. Packed-bed scrubbers used to control chromic acid mist are either horizontal or vertical countercurrent-flow units equipped with one or two packed beds followed by a chevron-blade mist eliminator. Diagrams of a single packed-bed and a double packed-bed unit are presented in Figures 4-8 and 4-9, respectively. Operating parameters for typical packed-bed scrubbers are presented in Table 4-2. Factory-assembled horizontal-flow scrubbers are available for airflow rates ranging from 14 to 1,700 standard m^3/min (500 to 60,000 standard ft^3/min), and vertical-flow scrubbers are available for airflow rates ranging from 14 to 680 m^3/min (500 to 24,000 ft^3/min). Control device vendors estimate that removal efficiencies for these units range from 95 to 99 percent.[15,16]

In single packed-bed units, removal of chromic acid mist from the gas stream is accomplished by first reducing the velocity of the gas stream to less than 150 m/min (500 ft/min) at the scrubber inlet to maximize impingement efficiency. Water sprayed countercurrent to the flow of the gas stream from spray nozzles located in front of the packed-bed enlarges the mist droplets contained in the gas stream, causing some droplets to settle to the bottom of the scrubber by gravity. The gas stream then passes through a packed bed. The packed bed is usually about 30.5 cm (12 in.) thick and contains packing media that is continuously washed with water from the spray nozzles. Chromic acid droplets in the gas stream impinge on the packing material and are washed to the bottom of the scrubber. In double packed-bed units, these first two stages are repeated. In either case, the scrubber also contains a mist elimination section located downstream of the packed bed(s) to collect any water carry-over. Generally, a conventional chevron-blade mist eliminator is used.[15,17,18]

The depth of the packed bed ranges from 10 to 12 times the major dimension of the packing media. The packing media used to control chromic acid mist typically are made of polypropylene and have a high surface area-to-volume ratio and the capacity to distribute, collect, and redisperse the scrubbing liquid quickly.

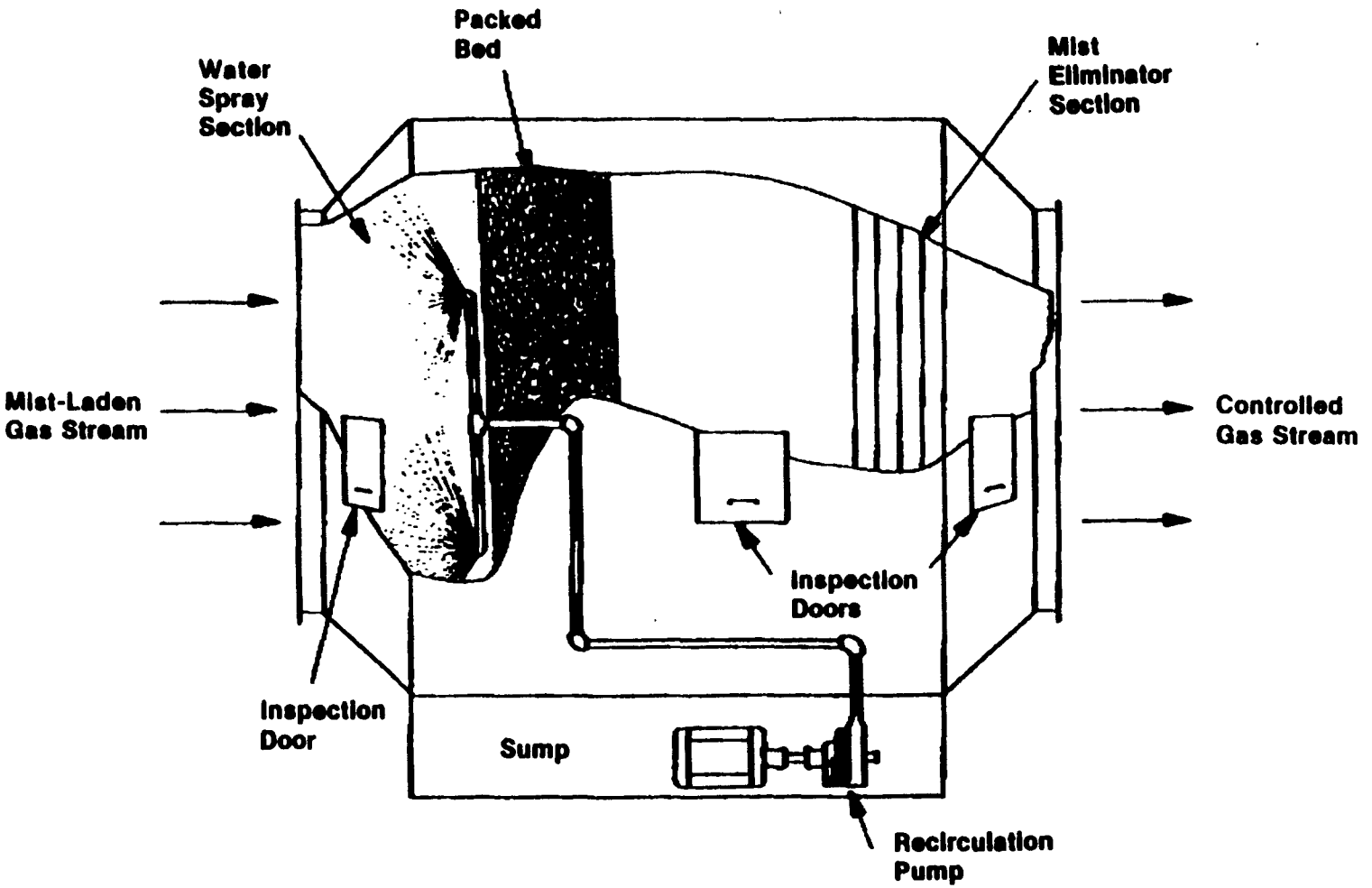


Figure 4-8. Horizontal-flow, single packed-bed scrubber.

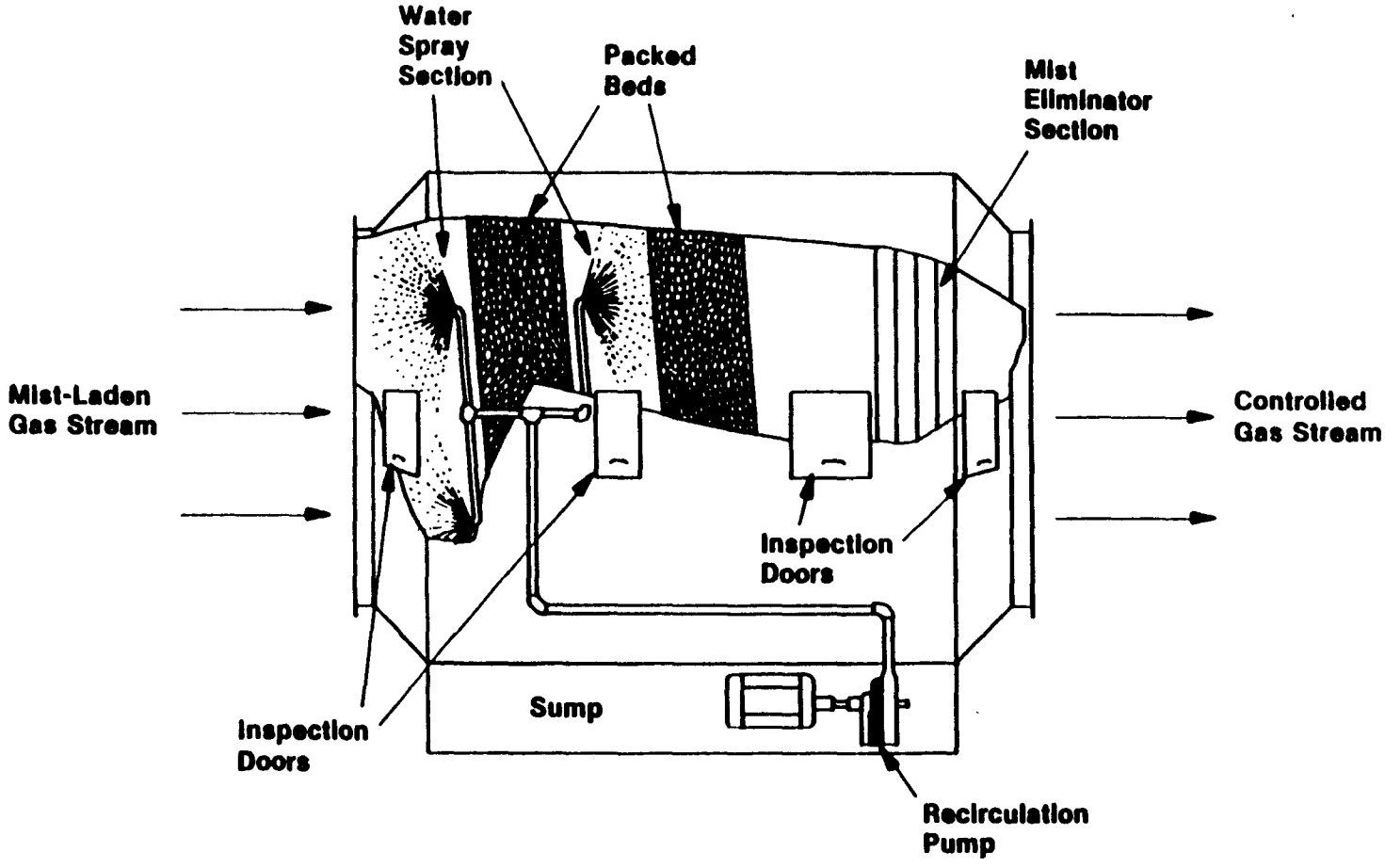


Figure 4-9. Horizontal-flow, double packed-bed scrubber.

TABLE 4-2. TYPICAL OPERATING PARAMETERS FOR PACKED-BED SCRUBBERS

Parameter	Horizontal-flow unit		Vertical-flow unit	
	Single packed bed	Double packed bed	Single packed bed	Double packed bed
Pressure drop, kPa (in. w.c.)	0.5 (2.0)	0.75 (3.0)	0.5 (2.0)	0.75 (3.0)
Gas flow rate, m^3/min (acfm)	14-1,700 (500-60,000)	14-1,700 (500-60,000)	14-680 (500-24,000)	14-680 (500-24,000)
Gas velocity at inlet, m/min (ft/min)	610-1,070 (2,000-3,500)	610-1,070 (2,000-3,500)	610-1,070 (2,000-3,500)	610-1,070 (2,000-3,500)
Gas velocity across beds, m/min (ft/min)	152 (500)	152 (500)	152 (500)	152 (500)
Liquid-to-gas ratio, L/min/1,000 m^3/min (gal/min/1,000 acfm)	400 (3)	800 (6)	400 (3)	800 (6)
Water flow rate, L/min (gal/min)	6-681 (2-180)	11-1,400 (3-360)	6-273 (2-72)	11-545 (3-144)
Makeup water flow rate, L/min/1,000 m^3/min (gal/min/1,000 acfm)	6.7-20 (0.05-0.15)	13-40 (0.1-0.3)	6.7-20 (0.05-0.3)	13-40 (0.1-0.3)

The media typically are ballast rings or saddle-shaped packing that range from 2.5 to 5.1 cm (1 to 2 in.) in diameter and have a void space of 90 to 95 percent and a surface area-to-volume ratio ranging from 98 to 148 m^2/m^3 (30 to 45 ft^2/ft^3).[19]

Most units are equipped with recirculation equipment to conserve water. The scrubbing liquid is continuously recirculated through the scrubber either from a reservoir or sump in the bottom of the scrubber or from a remote recirculation tank. Typically, the chromic acid concentration in the scrubber water is less than 7.5 g/L (1.0 oz/gal). Remote recirculation tanks typically are used in northern climates because the tanks can be located indoors to prevent the scrubbing liquid from freezing during winter. Losses due to evaporation from the scrubber are about 5 percent of the total volume of water. Some plants use once-through water and drain the scrubbing liquid to a wastewater treatment system. However, most plants drain the scrubber water to the plating tanks daily to compensate for evaporative losses from the tanks.

4.2.2.2 Fan-Separator Packed-Bed Scrubbers. A diagram of a fan-separator packed-bed scrubber is presented in Figure 4-10, and typical operating parameters are presented in Table 4-3. The fan-separator packed-bed scrubber consists of two stages: a dynamic scrubbing stage followed by an impingement stage. In the first stage, ventilation air is ducted into the eye of a backward-blade centrifugal fan, where it is sprayed with a small volume of water or other scrubbing liquid under high pressure. Contaminant aerosols are entrained and spun out centrifugally onto the fan scroll. The centrifugal action created by the fan wheel eliminates approximately 50 percent of the incoming chromic acid mist. In the second stage, the exhaust gas flows into an expansion chamber containing one or two packed beds of tubing made of polypropylene. The expansion chamber is designed to reduce the gas flow rate to no more than 150 m/min (500 ft/min) for maximum impingement efficiency. The gases are sprayed with water before the first packed bed. Because the gas flow changes direction numerous times as it passes through the packed bed,

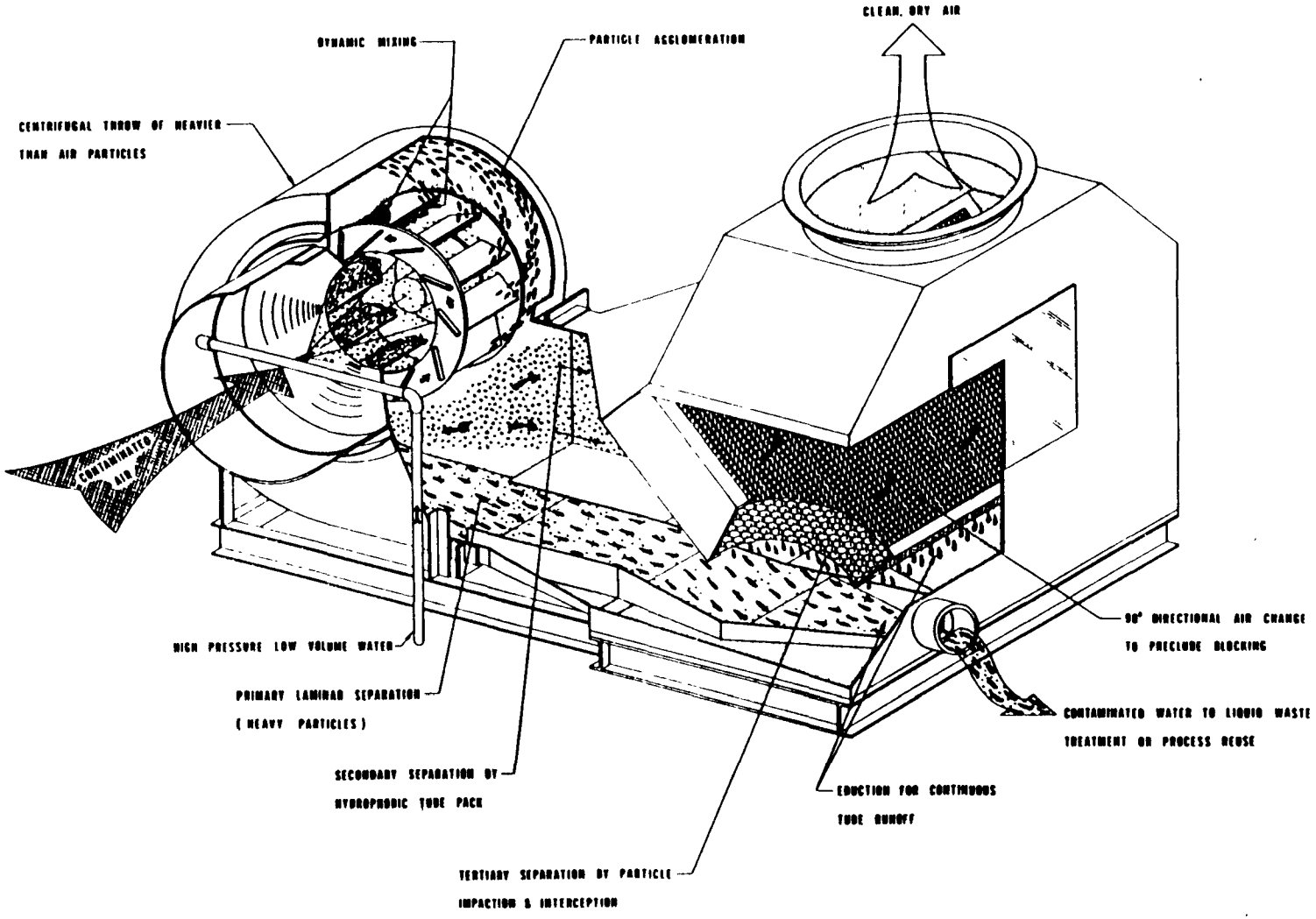


Figure 4-10. Fan-separator packed-bed scrubber.[20]

chromic acid droplets impinge on the packing media. The second packed bed is dry and acts as a mist eliminator. Contaminated water is pumped from the unit to a recirculation tank or a wastewater treatment system. Control efficiencies are estimated to range from 95 to 99 percent.[21]

TABLE 4-3. TYPICAL OPERATING PARAMETERS FOR FAN-SEPARATOR PACKED-BED SCRUBBERS

Pressure drop, kPa (in. w.c.)	0.5 (2.0)
Gas flow rate, m^3/min (acfm)	1.4-2,800 (50-100,000)
Gas velocity at inlet of fan, m/min (ft/min)	610-1,070 (2,000-3,500)
Water flow rate, L/min (gal/min)	0.5-190 (0.1-50)
Gas velocity across bed(s), m/min (ft/min)	152 (500)

4.2.2.3 Factors Affecting Packed-Bed Scrubber Performance. The primary operating parameters affecting the performance of packed-bed scrubbers are the liquid-to-gas (L/G) ratio and the superficial gas velocity entering the packed bed. If the L/G ratio is too high, the packed bed will become flooded and the gas flow will be restricted. A L/G ratio that is too low will result in insufficient wetting of the packed bed, leaving portions of the bed dry. This inhibits interception of particles by the fluid boundaries on the packing material. Also, the inlet gas stream will not be wetted enough to allow enlargement of the chromic acid droplets. Therefore, a L/G ratio that is too low will result in lower collection efficiencies.

Removal of chromic acid mist is accomplished by reducing the velocity of the gas stream to less than 150 m/min (500 ft/min) to maximize impingement. This is accomplished by an expansion chamber at the inlet of the scrubber. However, the velocity must be maintained at a rate such that the droplets possess sufficient energy to collide with the packing media. Operation of packed-bed units at greater than the design superficial gas velocity will decrease gravitational settling of chromic acid droplets

upstream of the packed bed. Increasing the superficial gas velocity above optimal levels will also cause reentrainment of chromic acid droplets from the packed bed and result in an overall decrease in collection efficiency.

Other factors that affect the performance of a packed-bed scrubber are the surface contact area of the packing media and the distribution of the packing media in the packed bed. A decrease in the surface contact area of the packing media will result in an increase in the amount of chromic acid mist escaping the packed bed.[22] If the packing media are not uniformly distributed in the bed, excessive channeling will occur and decrease the efficiency of the scrubber.[22] Channeling also occurs if the packed-bed housing becomes bowed and the packing material settles. Numerous types of packing media are available, and, therefore, the selection of media is based on the chemical and physical properties of the particular gas stream being controlled. Packing media are selected to maximize removal efficiency for the given particle size distribution while minimizing pressure drop.

The performance of a packed-bed scrubber can be affected by plugging of the spray nozzles, which reduces the volume and changes the spray pattern of the water going into the scrubber. Another factor affecting performance is the excessive buildup of chromic acid on the packing material that may lead to reentrainment of the chromic acid droplets from the packed bed or plugging of the bed.

4.2.2.4 Centrifugal-Flow Scrubbers. There are many types of centrifugal-flow scrubbers. The configuration used to control chromic acid mist, shown in Figure 4-11, is discussed here. Contaminated air is drawn through the intake duct and sprayed with clean or recirculated water. Water sprays impinge on the high-speed blower wheel and are reduced to fog. The fog mixes with the contaminated air and entrains the contaminants. The blower wheel, which is located axially within the separating chamber, also serves as the impeller of a centrifuge. The centrifugal action separates the water-entrained contaminants

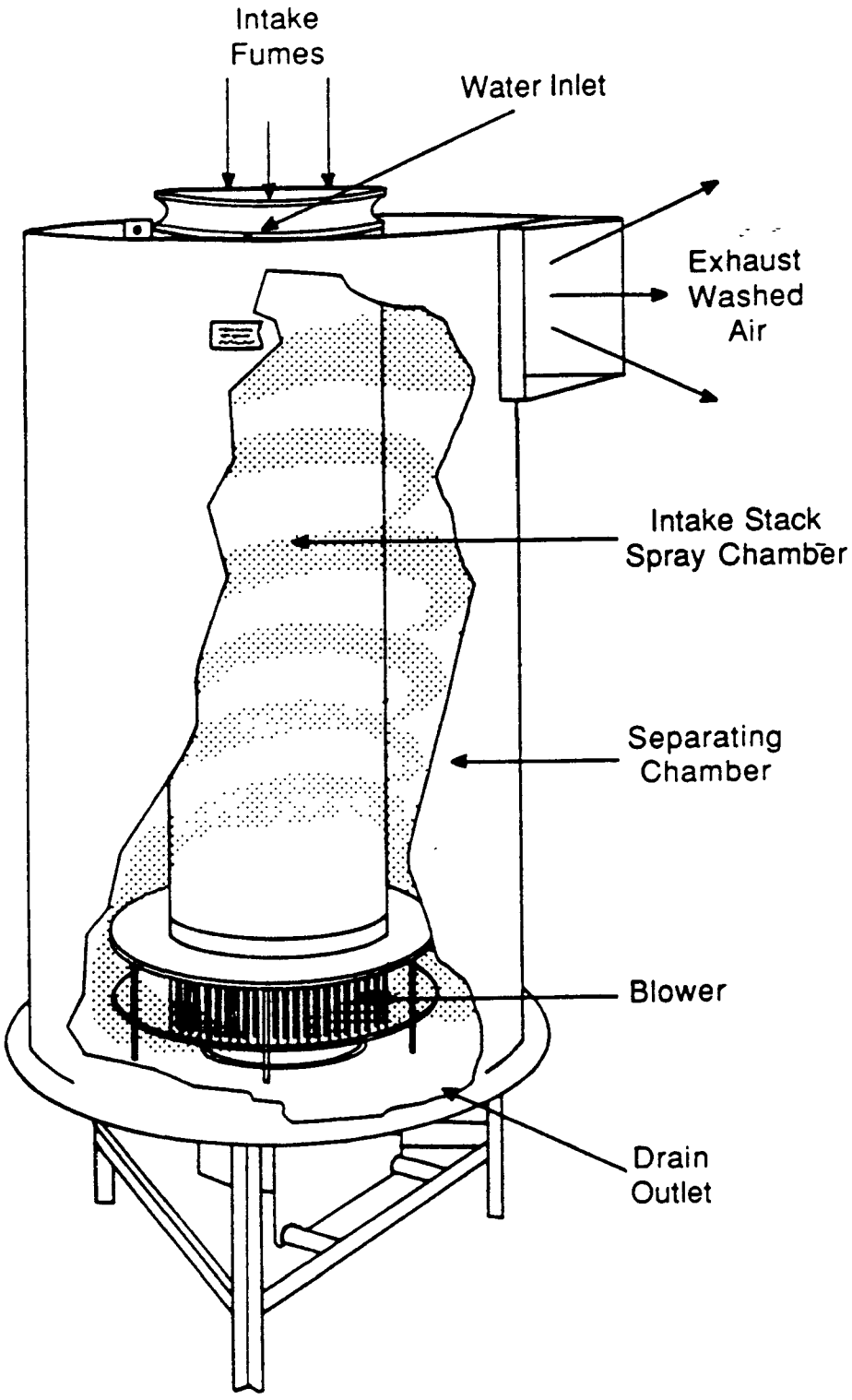


Figure 4-11. Centrifugal-flow scrubber.[23]

from the exhaust gas, and the contaminants and water are drained to the bottom of the unit. The cleaned air is discharged from the top of the unit.[23] The pressure drop across the scrubber ranges from 0.12 to 0.31 kPa (0.5 to 1.25 in. w.c.). Estimated removal efficiencies range from 95 to 99 percent.[24]

4.2.2.5 Factors Affecting Centrifugal-Flow Scrubber Performance. The primary factors affecting the performance of centrifugal-flow scrubbers are water distribution and quality, droplet size, and gas velocity. Uniform water distribution is necessary for optimal scrubber performance. If the solids content of the scrubber water is too high, wear and abrasion of the spray nozzle tips can occur, resulting in poor spray distribution and reduced performance of the scrubber.

If the water droplets inside the scrubber are too large, performance also will be adversely affected because as droplet size increases, net surface area per unit volume decreases.[25] Water droplet size can increase if the header water pressure at the spray nozzles is too low, resulting in poor atomization. Poor atomization can also result if the solids content of the scrubber water is allowed to increase beyond design levels.

Centrifugal-flow scrubbers must operate within specific gas velocity limits. Low gas velocities result in inadequate contaminant removal due to low contact/turbulence. High gas velocities cause flooding and carry-over.[25]

4.2.3 Chemical Fume Suppressants

Chemical fume suppressants are surface-active compounds that are added directly to chromium plating and chromic acid anodizing baths to reduce or inhibit misting.

Fume suppressants are classified as temporary or as permanent. Temporary fume suppressants are depleted primarily by decomposition of the active chemical components, and permanent fume suppressants are depleted by drag-out of the solution. Fume suppressants, which are manufactured in liquid, powder, or tablet form, include wetting agents, foam blankets, and combinations of both wetting agents and foam blankets.

Wetting agents are surface-active compounds that reduce or inhibit misting by lowering the surface tension of the plating or anodizing bath. When the surface tension of the solution is lowered, gases escape at the surface of the plating solution with less of a "bursting" effect, forming less mist. Fume suppressants that produce a foam blanket do not preclude the formation of chromic acid mist, but rather trap the mist formed under the blanket of foam.

Fume suppressants are used widely by decorative chromium electroplaters. In contrast, hard chromium platers seldom use fume suppressants. Fluorinated wetting agents have a tendency to aggravate pitting, which affects the quality of the hard chromium plate. Also, when foam blankets are used, there is a potential for explosion of the entrapped hydrogen gas. These tendencies are more pronounced in hard chromium plating than in decorative chromium plating because of the higher current densities and longer plating times associated with hard chromium electroplating operations.

4.2.3.1 Wetting Agents. The most common type of wetting agents used are fluorinated wetting agents because they are very stable throughout a wide range of operating temperatures, current densities, chromic acid concentrations, and oxidation-reduction reactions. Examples of wetting agent formulations include potassium perfluorooctane sulfonate ($C_8F_{17}SO_3K$) and tetraethylammonium perfluorooctane sulfonate ($C_8F_{17}SO_3^-N^+(C_2H_5)_4$).[26]

A number of fume suppressant formulators indicate that wetting agents that are fluorocarbon-based may aggravate pitting and defects in base metals when plating thickness exceeds 13 to 25 μm (0.5 to 1 mil).[27-29] Some fume suppressant vendor literature recommends caution regarding use of these compounds as the chromium thickness increases beyond 25 to 100 μm (1 to 4 mils) (depending on the product).[30] However, some manufacturers now state that certain base metals have a tendency to pit and that this tendency is not aggravated by the use of fume suppressant additives.[31,32] Some fume suppressants are not

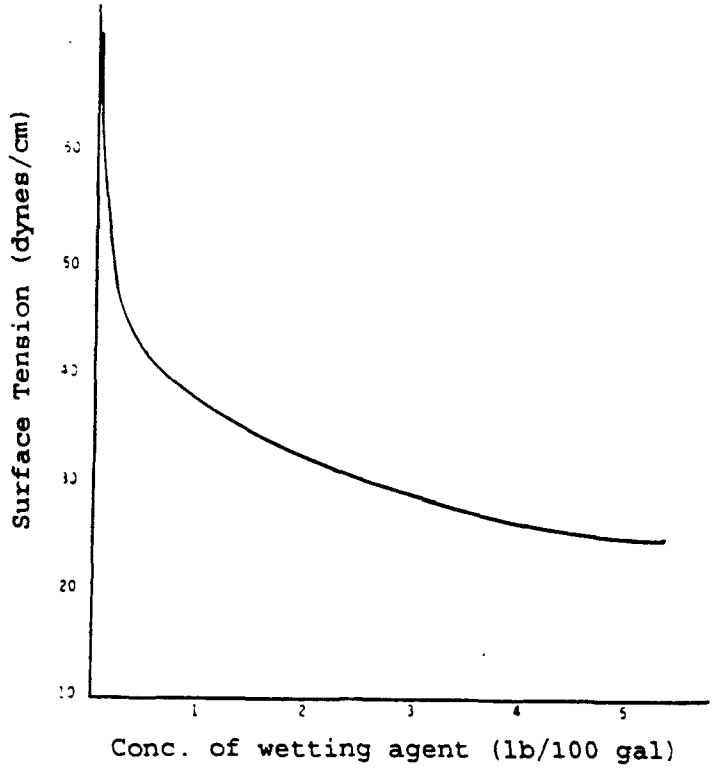
fluorinated and are reported to be successfully used for hard chromium plating deposits of any thickness.[28,33]

Figure 4-12(a) shows that additions of a wetting agent to a plating bath can significantly reduce the surface tension of the bath. Plating baths typically have a surface tension of about 70 dynes/cm (4.8×10^{-3} lb_f/ft). The addition of 120 g of wetting agent per 100 L (1.0 lb of wetting agent per 100 gal) of plating solution reduced the surface tension of the bath from about 70 dynes/cm (4.8×10^{-3} lb_f/ft) to about 40 dynes/cm (2.7×10^{-3} lb_f/ft).[34] Further additions of the wetting agent will lower the surface tension of the plating solution slightly; however, a point is reached where additions of the wetting agent will not produce a lower surface tension. As shown in Figure 4-12(b), chromic acid emissions are significantly lower for surface tensions below 30 to 40 dynes/cm (2.0×10^{-5} to 2.7×10^{-5} lb_f/ft) than for surface tensions above these levels.

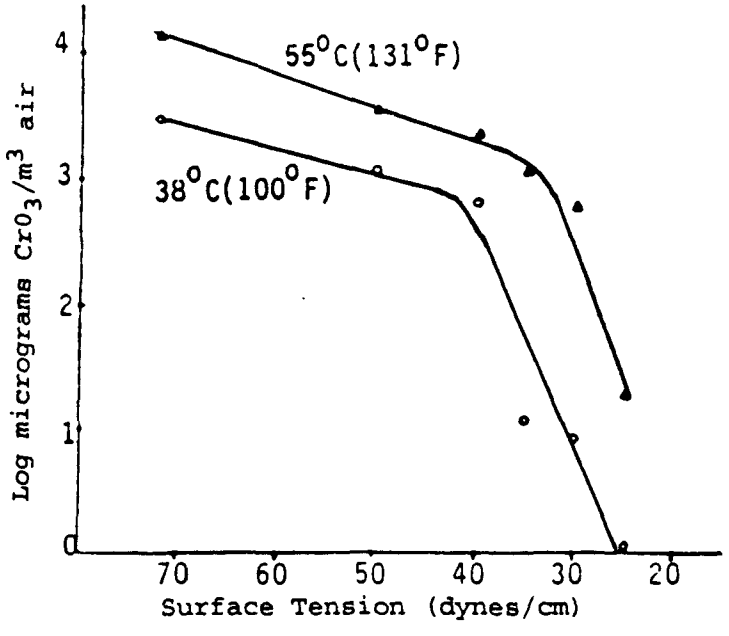
The initial makeup volume of wetting agents is determined by the volume of plating or anodizing solution and the temperature of the bath. Wetting agents are depleted from plating and anodizing baths by drag-out. Monitoring the surface tension of the plating or anodizing bath is the most effective method for determining when to add wetting agent to the bath. The surface tension of the bath can be determined by using a stalagmometer or by comparing the rise in a capillary tube with a calibration curve prepared for that purpose. Another method to determine if an addition is needed is to hold a white piece of paper over the bath for several minutes and observe whether spots caused by misting appear on the paper.

4.2.3.2 Foam Blankets. Foam blankets are usually 1.3 to 2.5 cm (0.5 to 1.0 in.) thick and cover the entire surface of the plating bath. The foam blanket is formed by agitation produced by the hydrogen and oxygen gas bubbles generated during plating.

Foam blankets entrap the hydrogen gas and chromic acid mist in the foam layer. If a heavy layer of foam (thickness greater than 2.5 cm [1.0 in.]) is present, the hydrogen gases will build up in the foam layer, and if a spark is generated (e.g., from the



(a) Wetting agent concentration vs. surface tension of chromic acid.



(b) Surface tension vs. chromic acid emissions.

Figure 4-12. Effect of wetting agent on chromic acid emissions.[34]

contacting equipment) a hydrogen explosion can occur. As a result of this minor explosion, the foam layer along with a portion of the plating solution is blown out of the tank and the chromium plate on the part could be damaged. However, if the foam layer is not maintained at a minimum reasonable thickness, the ability of the foam layer to inhibit misting is reduced.

Initial makeup volumes of foam blanket solutions are determined by the surface area of the solution, amount of current applied, and temperature and chromic acid concentration of the plating bath. Generally, the lower the temperature, the less product is needed. Foam blankets are depleted primarily by decomposition; however, drag-out of the foam may also be a factor. Also, foam blankets may be pulled into ventilation hoods if the solution level is too close to the hoods. Some types may also be depleted by excessive air agitation of the bath. Appreciable concentrations of alkali metal ions, especially potassium, tend to reduce the solubility of some foam blankets. Visual monitoring of the thickness of the foam blanket is the most common method for determining when to add foam blanket solution to the bath. The frequency of the maintenance additions depends on the amount of work processed through the plating tank and the drag-out rate of the solution.

4.2.3.3 Combination Wetting Agent/Foam Blanket. Combination fume suppressants (wetting agent plus a foam blanket) reduce the surface tension of the plating bath while forming a foam blanket over the surface. Because of the synergistic effects of the two components, less product is required than if either the wetting agent or the foam blanket were used alone.

4.2.3.4 Factors Affecting Performance. The main factor affecting the performance of chemical fume suppressants is the amount of fume suppressant present in the plating or anodizing bath. If insufficient wetting agent is present in the bath, the surface tension of the solution will not be reduced below 40 dynes/cm (2.7×10^{-3} lb_f/ft), and, therefore, the effectiveness of the wetting agent in inhibiting misting will be substantially reduced. If a foam blanket is used, proper care

must be taken to maintain the foam blanket at the specified thickness because a thin foam layer will not entrap the chromic acid mist efficiently, and a heavy foam blanket may cause a hydrogen gas buildup and explosion potential.

4.2.4 Plastic Balls

4.2.4.1 Description. Floating polypropylene balls are often used in plating baths to reduce heat loss, evaporation, and (to a limited extent) misting. The balls are approximately 3.2 cm (1.25 in.) in diameter and are typically recommended to be two layers deep across the surface of the plating solution.

4.2.4.2 Factors Affecting Performance. Polypropylene balls are generally used on hard chromium plating baths to reduce evaporation of plating solution and inhibit misting. They are generally not used in automated plating or anodizing operations because plating racks drag the balls out of the baths. The balls tend to be pushed away from the anodes and cathodes where the surface of the bath is agitated by gassing, thus reducing their effectiveness for inhibiting misting.

4.2.5 Moisture Extractors

Moisture extractors are often used preceding or following the principal air pollution control device. Moisture removal is accomplished centrifugally as the air passes through a set of stationary blades. A moisture extractor used prior to a control device reduces the inlet loading on the primary control unit. Moisture extractors are commonly used prior to a mesh-pad mist eliminator to help reduce plugging. When the device is used following the primary control device, its function is to minimize reentrainment or carry-over from the primary control device if the primary device malfunctions or is operated improperly.

4.3 PERFORMANCE CAPABILITIES OF CONTROL TECHNIQUES FOR CHROMIUM EMISSIONS

Based on evaluations of information obtained from the literature, contacts with air pollution control device vendors, and site visits to electroplating facilities, applicable alternative air pollution control techniques were identified. An emissions test program was designed to evaluate the performances

of the techniques determined to be most representative of those applied in the industry.

The results of 10 EPA-conducted emissions tests are summarized in Tables 4-4a and 4-4b. Facilities selected for emission testing were representative of typical hard and decorative chromium plating shops based on the size of the plating tanks, the types of parts plated, and the plating bath operating parameters. The operating parameters examined at each facility were the current, voltage, plating time, temperatures, and chromic acid concentration of the plating bath. The air pollution control devices tested include six mist eliminators and three packed-bed scrubbers. Emissions tests were conducted at the inlet and outlet of each control device to characterize uncontrolled emissions and the performance of the control device. A summary and discussion of the emissions test results for hard chromium electroplating are presented in Section 4.3.1. In addition, EPA also conducted a test on a decorative chromium plating operation to evaluate the performance of fume suppressants. The fume suppressant test data are summarized and discussed in Section 4.3.2. A summary discussion of the emissions test results and conclusions regarding performance are presented in Section 4.3.3. Complete information about each test is presented in Appendix C ("Summary of Test Data"), and the testing and analysis methodologies are described in Appendix D ("Emission Measurements") of this document.

During the early part of the test program, both hexavalent and total chromium were measured at each site (Plants A, B, D, I, and K). The results of these tests indicate that, considering the precision of the sampling and analytical methods used, the hexavalent and total chromium levels were essentially the same (varying within ±10 percent in most instances). Therefore, essentially all the chromium was in the hexavalent form, which would be expected, given the fact that chromic acid is a hexavalent compound of chromium. For these reasons, and for reasons discussed in Appendix D, total chromium analyses were discontinued for the remainder of the plants tested. The

TABLE 4-4a. SUMMARY OF EMISSION TEST RESULTS FOR HEXAVALENT CHROMIUM (Metric Units)[a]

Plant	Control device	Outlet process rate, Ah	Hexavalent chromium mass emission, kg/hr x10 $^{-3}$		Range of control device efficiencies, percent	Hexavalent chromium emission concentration, mg/dscm x10 $^{-3}$		Hexavalent chromium emissions per process rate, mg/Ah	
			Inlet	Outlet		Inlet	Outlet	Inlet	Outlet
Chevron-blade mist eliminators									
A	b	13,100	26	3.3	83.1-91.0	2,030	310	4.5	0.59
B	c	14,400	15	1.3	86.9-95.1	1,760	150	3.2	0.27
D	d	19,900	76	1.2	98.0-98.7	7,960	120	9.2	0.14
Mesh-pad mist eliminators									
E[e]	f	12,100	31	0.4	98.4-99.0	3,070	40	6.2	0.08
F	g	12,200	83	0.23	99.2-99.9	11,400	33	16.0	0.04
G	g	8,800	24	0.27	98.7-99.0	4,410	43	6.6	0.07
Packed-bed scrubbers									
I	h	8,150	90	0.52	99.1-99.6	5,510	30	23.0	0.14
K	i	8,750	46	1.5	94.9-98.1	1,670	52	16.0	0.56
L[j]	h	5,300	23	1.2	94.3-95.1	715	39	9.0	0.45
L[k]	h	7,200	22	0.71	96.3-97.2	668	23	6.0	0.20
L[l]	h	7,800	24	0.65	97.2-97.3	723	21	8.0	0.22
Polypropylene balls									
G[m]	n	7,800	22	5.4	68.0-81.9	3,980	960	7.2	1.8
Fume suppressant									
N	o	8,500	3.6	0.02	99.3-99.6	921	4.7	1.4	0.007
N	p	10,500	3.6	0.01	99.7-99.9	921	2.2	1.4	0.003

[a]All tests were conducted by EPA.
[b]Chevron-blade mist eliminator with a single set of sinusoidal wave-type blades.
[c]Chevron-blade mist eliminator with a single set of overlapping-type blades.
[d]Chevron-blade mist eliminator with a double set of overlapping-type blades.
[e]Moisture extractor preceded mist eliminator. Tests were conducted at the inlet to the moisture extractor and the outlet of the mist eliminator. Combined efficiencies are presented here.
[f]Mist eliminator containing a double set of overlapping-type chevron blades followed by two mesh pads in series.
[g]Double mesh-pad mist eliminator.
[h]Single packed-bed, horizontal-flow wet scrubber.
[i]Double packed-bed, horizontal-flow wet scrubber.
[j]No overhead washdown of the scrubber packing.
[k]Periodic overhead washdown of the scrubber packing.
[l]Continuous overhead washdown of the scrubber packing.
[m]Tests were conducted at the mist eliminator inlet with and without polypropylene balls.
[n]Polypropylene balls 3.8 cm in diameter with two to three layers of coverage.
[o]Foam blanket.
[p]Wetting agent in combination with a foam blanket.

TABLE 4-4b. SUMMARY OF EMISSION TEST RESULTS FOR HEXAVALENT CHROMIUM (English Units)[a]

Plant	Control device	Outlet process rate, Ah	Hexavalent chromium mass emission, lb/hr x 10^{-3}		Range of control device efficiencies, percent	Hexavalent chromium emission concentration, gr/dscf x 10^{-3}		Hexavalent chromium emissions per process rate, gr/Ah	
			Inlet	Outlet		Inlet	Outlet	Inlet	Outlet
Chevron-blade mist eliminators									
A	b	13,100	57	7.3	83.1-91.0	0.89	0.13	0.07	0.009
B	c	14,400	33	2.9	86.9-95.1	0.77	0.07	0.05	0.004
D	d	19,900	170	2.7	98.0-98.7	3.5	0.05	0.14	0.002
Mesh-pad mist eliminators									
E[e]	f	12,100	69	0.93	98.4-99.0	1.3	0.02	0.10	0.001
F	g	12,200	180	0.51	99.2-99.9	5.0	0.01	0.25	0.001
G	g	8,800	53	0.59	98.7-99.0	1.9	0.02	0.10	0.001
Packed-bed scrubbers									
I	h	8,150	200	1.2	99.1-99.6	2.4	0.01	0.35	0.002
K	i	8,750	100	3.4	94.9-98.1	0.73	0.02	0.24	0.009
L[j]	h	5,300	51	2.6	94.3-95.1	0.31	0.02	0.14	0.007
L[k]	h	7,200	48	1.6	96.3-97.2	0.29	0.01	0.09	0.003
L[l]	h	7,800	52	1.4	97.2-97.3	0.32	0.01	0.12	0.003
Polypropylene balls									
G[m]	n	7,800	48	12	68 0-81.9	1.7	0.42	0.11	0 028
Fume suppressant									
N	o	8,500	7.9	0.04	99.3-99.6	0.40	0.002	0.02	0.00010
N	p	10,500	7.9	0.02	99.7-99.9	0.40	0.001	0.02	0.00005

[a]All tests were conducted by EPA.
[b]Chevron-blade mist eliminator with a single set of sinusoidal wave-type blades.
[c]Chevron-blade mist eliminator with a single set of overlapping-type blades.
[d]Chevron-blade mist eliminator with a double set of overlapping-type blades.
[e]Moisture extractor preceded mist eliminator. Tests were conducted at the inlet to the moisture extractor and the outlet of the mist eliminator. Combined efficiencies are presented here.
[f]Mist eliminator containing a double set of overlapping-type chevron blades followed by two mesh pads in series.
[g]Double mesh-pad mist eliminator.
[h]Single packed-bed, horizontal-flow wet scrubber.
[i]Double packed-bed, horizontal-flow wet scrubber.
[j]No overhead washdown of the scrubber packing.
[k]Periodic overhead washdown of the scrubber packing.
[l]Continuous overhead washdown of the scrubber packing
[m]Tests were conducted at the mist eliminator inlet with and without polypropylene balls.
[n]Polypropylene balls 3.8 cm (1.5 in.) in diameter with two to three layers of coverage.
[o]Foam blanket.
[p]Wetting agent in combination with a foam blanket.

following discussions of emissions test results address emissions in terms of hexavalent chromium.

4.3.1 Tests at Hard Chromium Electroplating Operations

4.3.1.1 Chevron-Blade Mist Eliminator Tests.

4.3.1.1.1 Plant A. Plant A is a medium-size job shop that performs hard chromium electroplating of textile, hydraulic, woodworking, and laundry machine parts. The hard chromium plating facility consists of six tanks. Tests were conducted across a mist eliminator on Tank 6, which is 6.4 m (21 ft) long, 0.9 m (3 ft) wide, and 1.8 m (6 ft) deep and has a capacity of 9,800 L (2,590 gal). The tank is equipped with a transformer/rectifier rated at 8 to 10 V and 5,000 to 8,000 A. The tank is laterally exhausted. The plating bath is a conventional hard chromium plating solution containing about 255 g/L (34 oz/gal) of chromic acid and 2.55 g/L (0.34 oz/gal) of sulfuric acid catalyst. The bath normally operates at 50° to 60°C (120° to 140°F).[35]

Emissions that are captured by the exhaust system are vented to a chevron-blade mist eliminator with a single set of sinusoidal wave-type blades. The blades are approximately 1.2 m (4.0 ft) in height, cover an area of about 1.2 m (4.0 ft) in width, and extend 0.2 m (0.8 ft) back into the unit. The mist eliminator was installed in 1980. The design parameters of the mist eliminator include a gas flow rate of 280 standard m^3/min (10,000 standard ft^3/min), cross-sectional velocity of 270 m/min (900 ft/min), and a pressure drop of 0.19 kPa (0.75 in. w.c.). During emissions testing, the actual gas flow rate to the mist eliminator was 230 m^3/min (7,970 ft^3/min).[36] The mist eliminator contains 31 chevron blades spaced 3.2 cm (1.3 in.) apart. The blades are arranged to change the direction of the gas flow four times at 30° angles. The mist eliminator is periodically washed with water, which then drains into the plating tank. During testing, the mist eliminator was washed down after each test run.

Four test runs were conducted by EPA at the inlet and outlet of the mist eliminator on Tank 6. The results are summarized in Table 4-5. Uncontrolled emissions measured at the inlet averaged

2.0 mg/dscm (0.89 x 10^{-3} gr/dscf), or 26 x 10^{-3} kg/hr (57 x 10^{-3} lb/hr). Emissions measured at the outlet averaged 0.31 mg/dscm (0.13 x 10^{-3} gr/dscf), or 3.3 x 10^{-3} kg/hr (7.3 x 10^{-3} lb/hr). The removal efficiency of the mist eliminator ranged from 83.1 to 91.0 percent. The average total current applied to the system during outlet testing was 13,100 Ah. Therefore, the hexavalent chromium process emission rate from the mist eliminator was 0.59 mg/Ah (0.009 gr/Ah).

TABLE 4-5. PERFORMANCE DATA FOR PLANT A[37]

	Inlet			Outlet			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1	1.52	20.3	3.44	0.168	1.83	0.296	91.0
2	2.45	31.2	6.00	0.377	4.15	0.804	86.7
3	1.55	20.0	2.52	0.173	1.87	0.236	90.7
4	2.59	32.3	6.09	0.507	5.45	1.04	83.1
AVG	2.03	26.0	4.51	0.306	3.32	0.594	87.9

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.1.1.2 Plant B. Plant B manufactures and refurbishes industrial rolls for the packaging and textile industries. The plant operates six hard chromium plating tanks. Emissions tests were conducted across a chevron-blade mist eliminator with a single set of overlapping-type blades that treats ventilation air from two of the hard chromium plating tanks.

Tank 1 is 1.5 m (5.0 ft) long, 0.7 m (2.3 ft) wide, and 1.8 m (6.0 ft) deep and holds about 1,780 L (470 gal) of plating solution. Tank 2 is 1.8 m (6.0 ft) long, 0.8 m (2.5 ft) wide, and 1.8 m (6.0 ft) deep and holds about 2,350 L (620 gal) of plating solution. The chromic acid concentration of the plating baths is 210 g/L (28 oz/gal) of solution. The normal operating temperature of the plating baths ranges from 43°C (110°F) to 54°C

(130°F). Both tanks are equipped with a circulating water cooling system.[38]

Tank 1 contains two work stations, each of which is equipped with a 3,000-A rectifier. Tank 2 is equipped with one 5,000-A rectifier. The operating voltage and current for each roll plated typically ranges from 10 to 15 V and 1,200 to 1,600 A, respectively. About 13 μm (0.5 mil) of chromium plate is applied to each roll.

Both tanks are equipped with double-sided lateral exhaust hoods. Exhaust gases from both tanks are ducted together and vented to a horizontal-flow chevron-blade mist eliminator that was installed in 1987. The mist eliminator contains a single set of overlapping-type blades. The blades are approximately 1.1 m (3.5 ft) in height, cover an area of about 1.0 m (3.3 ft) in width, and extend 0.2 m (0.8 ft) back into the unit. The blades are spaced about 3.2 cm (1.3 in.) apart. The mist eliminator was designed to treat 230 standard m^3/min (8,000 standard ft^3/min) of gas at a pressure drop of 0.19 kPa (0.75 in. w.c.). During emissions testing, the actual gas flow rate at the inlet was 150 m^3/min (5,390 ft^3/min).

A moisture extractor is installed in the stack to control chromium emissions that may be drawn through the mist eliminator. The mist eliminator and moisture extractor are equipped with a spray washdown system. The wash water is drained initially into a 340-L (90-gal) holding tank and then, as needed, into the plating tanks as makeup for plating solution evaporation losses. The mist eliminator and moisture extractor are washed one or two times a day depending on the amount of plating solution makeup needed. During the emissions testing period, the mist eliminator was washed each morning (prior to testing) with about 230 L (60 gal) of water.

Three test runs were conducted by EPA at the inlet and outlet of the mist eliminator. The test results are summarized in Table 4-6. Uncontrolled emissions measured at the inlet averaged 1.8 mg/dscm (0.77×10^{-3} gr/dscf), or 15×10^{-3} kg/hr (33×10^{-3} lb/hr). Emissions measured at the outlet averaged

0.15 mg/dscm (0.07 x 10^{-3} gr/dscf), or 1.3 x 10^{-3} kg/hr (2.9 x 10^{-3} lb/hr). The corresponding removal efficiency ranged from 86.9 to 95.1 percent. The average total current applied during outlet testing was 14,400 Ah. Therefore, the hexavalent chromium process emission rate from the mist eliminator was 0.27 mg/Ah (0.004 gr/Ah).

TABLE 4-6. PERFORMANCE DATA FOR PLANT B[39]

	Inlet			Outlet			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1	1.81	15.5	3.10	0.089	0.76	0.150	95.1
2	1.74	14.8	3.15	0.224	1.94	0.410	86.9
3	1.74	15.2	3.23	0.135	1.21	0.257	92.0
AVG	**1.76**	**15.2**	**3.16**	**0.149**	**1.30**	**0.272**	**91.3**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.1.1.3 Plant D. Plant D is a small-size job shop that performs hard chromium electroplating of industrial rolls. The plant operates two plating tanks. Tests were conducted across the mist eliminator that controls emissions from one of the tanks. The tank is 4.3 m (14.0 ft) long, 1.2 m (4.0 ft) wide, and 3.0 m (10.0 ft) deep and holds about 15,100 L (3,980 gal) of plating solution. The plating bath consisted of a conventional hard chromium plating solution containing about 210 g/L (28 oz/gal) of chromic acid and 1.3 g/L (0.18 oz/gal) of sulfuric acid. The normal operating temperature of the plating bath ranges from 43° to 60°C (110° to 140°F). The tank is cooled with circulating water. The tank is equipped with a transformer/rectifier rated at 12 V and 12,000 A.[40]

The plating tank is equipped with a push-pull capture system and a chevron-blade mist eliminator, both of which were installed in July 1985. The mist eliminator contains two sets of overlapping-type chevron blades. The blades are approximately 1.0 m (3.1 ft) in height, cover an area of about 0.9 m (3.0 ft)

in width, and each set of blades extends 0.2 m (0.8 ft) back into the unit. The design face velocity through the mist eliminator is 190 m/min (630 ft/min) at a pressure drop of 0.5 kPa (2.0 in. w.c.). The pressure drop was not monitored during testing; however, there were no indications of any malfunctions in the mist eliminator or capture system. The system was designed to treat 170 standard m^3/min (6,000 standard ft^3/min). During testing, the gas flow rate measured at the inlet of the mist eliminator averaged 180 actual m^3/min (6,260 actual ft^3/min). A moisture extractor is installed in the stack downstream of the mist eliminator.[41] The mist eliminator and moisture extractor are washed with an average of 280 L (75 gal) of water at the end of each work day and at the beginning of each work day if the tank is operated overnight. During testing, the mist eliminator and moisture extractor were washed with about 320 L (85 gal) of water after the first test run and with about 250 L (70 gal) of water after the third test run.

Three test runs were conducted at the inlet and outlet of the mist eliminator. Testing at the inlet and outlet was performed simultaneously. Test results are presented in Table 4-7. Emissions measured at the inlet averaged 8.0 mg/dscm (3.5×10^{-3} gr/dscf), or 76×10^{-3} kg/hr (170×10^{-3} lb/hr). Outlet emissions averaged 0.12 mg/dscm (0.05×10^{-3} gr/dscf), or 1.2×10^{-3} kg/hr (2.7×10^{-3} lb/hr). The control efficiency across the mist eliminator ranged from 98.0 to 98.7 percent. The average total current applied during outlet testing was about 19,900 Ah. Therefore, the hexavalent chromium process emission rate from the mist eliminator was 0.14 mg/Ah (0.002 gr/Ah).

TABLE 4-7. PERFORMANCE DATA FOR PLANT D[42]

Run No.	Inlet mg/dscm	Inlet kg/hr (10^{-3})	Inlet mg/Ah	Outlet mg/dscm	Outlet kg/hr (10^{-3})	Outlet mg/Ah	Efficiency, percent[a]
1	10.20	95.4	11.1	0.130	1.26	0.147	98.7
2	6.85	68.1	7.24	0.140	1.36	0.140	98.0
3	6.83	65.2	9.18	0.102	0.99	0.134	98.5
AVG	7.96	76.2	9.17	0.124	1.20	0.140	98.4

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.1.2 Discussion of Chevron-Blade Mist Eliminator Performance Data. Table 4-8 presents the performance data for Plants A, B, and D. The mist eliminator in Plant A contained a single set of wave-type blades. Plant B's mist eliminator contained a single set of overlapping-type blades, and Plant D's unit had a double set of overlapping-type blades. A graphic presentation of the outlet concentrations for each plant is presented in Figure 4-13. Based on a comparison of average outlet concentrations for Plants A and B, it appears that the overlapping blade design may be more effective than the sinusoidal wave-type blade design. (Outlet concentrations ranged from 0.168 to 0.507 mg/dscm (7.4×10^{-5} to 2.2×10^{-4} gr/dscf) for Plant A and 0.089 to 0.224 mg/dscm (3.9×10^{-5} to 9.8×10^{-5} gr/dscf) for Plant B, so there is a small amount of data overlap.) As shown in Table 4-8, inlet loadings were very similar for Plants A and B. Therefore, the slightly lower average outlet process emission rate and the 3 percent higher average efficiency for Plant B also suggest that the overlapping blade design may be superior to the wave-type design.

There is no significant difference between the average outlet concentrations for Plants B and D, and as illustrated in Figure 4-13, there is some overlap of the data. This overlap indicates that the second set of overlapping blades may represent redundant control. The lower average outlet process emission rate for Plant D is a reflection of the higher inlet loading.

TABLE 4-8. PERFORMANCE DATA FOR CHEVRON-BLADE MIST ELIMINATORS--PLANTS A, B, AND D (AVERAGES)

Plant	Concentration, mg/dscm		Outlet process emission rates, mg/Ah	Efficiency, percent
	Inlet	Outlet		
A	2.03	0.306	0.59	87.9
B	1.76	0.149	0.27	91.3
D	7.96	0.124	0.14	98.4

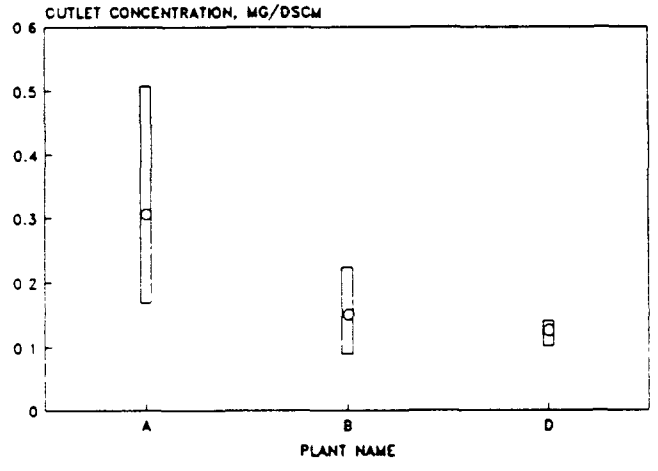


Figure 4-13. Outlet concentration data for chevron-blade mist eliminators.

This higher inlet loading also accounts for the average efficiency of the unit at Plant D being 7 percent higher than that at Plant B. Percent efficiency is always dependent upon inlet concentrations and can be used as a means to compare performance only when there is not a significant variation in the inlet loadings. Therefore, it cannot be concluded that the double set of blades results in better performance for chevron-blade mist eliminators.

4.3.1.3 Mesh-Pad Mist Eliminator Tests.

4.3.1.3.1 Plant E. Plant E is a job shop specializing in precision finishing and refinishing of industrial rolls. There are seven hard chromium plating tanks at the facility. Tests were conducted across the mist eliminator that controls emissions from the tank designated as No. 6. The tank is 3.7 m (12.0 ft) long, 0.91 m (3.0 ft) wide, and 2.9 m (9.6 ft) deep and holds approximately 9,270 L (2,450 gal) of plating solution. The plating solution contains chromic acid in a bath concentration of 250 g/L (33 oz/gal). Sulfuric acid is used as a catalyst at a bath concentration of 2.5 g/L (0.33 oz/gal). The temperature of the plating solution is maintained between 57° and 60°C (135° and 140°F). The typical current and voltage applied to Tank 6 is 8,000 A and 12 V.[43]

The capture and control system on Tank 6 consists of a double-sided lateral hood ducted to a 56-cm (22-in.)-diameter moisture extractor followed by a mist eliminator unit containing two sets of overlapping-type blades and two mesh pads. The mist eliminator blades are approximately 1.3 m (4.4 ft) in height and cover an area of about 1.2 m (4.0 ft) in width, and each set of blades extends 0.2 m (0.8 ft) back into the unit. The mist eliminator unit was installed in June 1988.

The mist eliminator system has a design airflow rate of 280 standard m^3/min (10,000 standard ft^3/min) and a design pressure drop of 0.62 kPa (2.5 in. w.c.) at a velocity of 140 m/min (450 ft/min).[44] The blade section consists of two sets of overlapping-type blades. Two sets of spray nozzles (three nozzles per set) are located in front of each set of blades to provide periodic washdown of the blades. The mesh pad section consists of two pads in series. Each pad is about 1.4 m (4.5 ft) high, 1.5 m (4.8 ft) wide, and 0.15 m (0.5 ft) deep and consists of eight layers of mesh. The layers consist of interlocked polypropylene filaments 0.094 cm (0.037 in.) in diameter. The first two layers of each pad have a void space of 97 percent, and the remaining six layers have a void space of 94 percent. During testing, the airflow rate at the outlet of the mist eliminator

unit averaged 195 m^3/min (6,880 ft^3/min), and the pressure drop was measured at 0.84 kPa (3.4 in. of w.c.).

Three mass emissions tests were conducted at each of the following locations: (1) upstream of the moisture extractor, (2) between the moisture extractor and the mist eliminator (blade and pad) unit, and (3) at the outlet of the mist eliminator unit. The test results are summarized in Table 4-9. Emissions measured at the inlet to the moisture extractor averaged 3.1 mg/dscm (1.3×10^{-3} gr/dscf), or 31×10^{-3} kg/hr (69×10^{-3} lb/hr). Emissions measured at the mist eliminator outlet averaged 0.04 mg/dscm (0.02×10^{-3} gr/dscf), or 0.40×10^{-3} kg/hr (0.93×10^{-3} lb/hr).

TABLE 4-9. PERFORMANCE DATA FOR PLANT E[45]

	Inlet			Outlet			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1	2.84	30.0	6.24	0.030	0.30	0.062	99.0
2	3.32	33.0	6.35	0.043	0.40	0.077	98.8
3	3.06	31.0	5.96	0.047	0.50	0.096	98.4
AVG	**3.07**	**31.3**	**6.18**	**0.040**	**0.40**	**0.078**	**98.7**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

The combined removal efficiencies of the moisture extractor and the mist eliminator ranged from 98.4 to 99.0 percent and averaged 98.7 percent. This combined efficiency is regarded as being representative of the performance of the mist eliminator unit alone because moisture extractors are designed for the removal of large droplets that would also be collected in the first stage of the mist eliminator unit.

The average total current applied to the system during outlet testing was 12,100 Ah. Therefore, the hexavalent chromium emission rate from the mist eliminator unit was 0.08 mg/Ah (0.001 gr/Ah).

4.3.1.3.2 Plant F. Plant F is a small job shop specializing in precision finishing of hydraulic cylinders. The plant currently operates one hard chromium plating tank. The plating tank is 2.4 m (8.0 ft) long, 0.76 m (2.5 ft) wide, and 2.7 m (9.0 ft) deep and holds approximately 4,810 L (1,270 gal) of plating solution. The plating solution contains chromic acid in a concentration of about 210 g/L (28 oz/gal) of water. Sulfuric acid is used as a catalyst at a bath concentration of 2.1 g/L (0.28 oz/gal). The temperature of the plating solution is maintained at about 54°C (130°F). The tank is divided into two cells; each plating cell is equipped with a rectifier. The typical current and voltage applied to each cell ranges from 2,500 to 3,000 A and from 4.5 to 6.0 V, respectively.[46]

The capture and control system on the plating tank consists of a single-sided lateral hood ducted to a mist eliminator with two mesh pads in series. The design airflow rate of the ventilation system is 140 standard m^3/min (5,100 standard ft^3/min). The actual measured flow rate during testing was 125 m^3/min (4,430 ft^3/min). The mesh-pad mist eliminator was installed in May 1988. The unit has a design pressure drop of 0.62 kPa (2.5 in. w.c.) at a velocity of 150 to 210 m/min (500 to 700 ft/min).[47] The pressure drop recorded during testing was 0.62 kPa (2.5 in. w.c.).

The mist eliminator consists of two mesh pads spaced approximately 10 cm (4 in.) apart. Each mesh pad is 79 cm (31 in.) in diameter. The primary mesh pad at the inlet of the unit is 6.4 to 7.6 cm (2.5 to 3.0 in.) thick, and the secondary mesh pad is 3.2 to 3.8 cm (1.25 to 1.5 in.) thick. Each pad consists of layers of interlocked polypropylene filaments 0.051 cm (0.020 in.) in diameter. The thread count is 4.3 by 3.3 per cm^2 (28 by 21 per $in.^2$) and the weave type is honeycomb. The unit is equipped with two spray nozzles that are activated periodically to wash down the pads. One nozzle is located at the inlet and sprays onto the primary mesh pad in the direction of the airflow. The second nozzle, located at the outlet of the unit behind the secondary pad, sprays onto the secondary mesh pad

countercurrent to the airflow. At the end of each day, the ventilation system is shut off and the spray nozzles are activated to wash down the mesh pads. During each washdown, the pads are flooded with 38 L (10 gal) of water at a pressure of 1.7 to 2.0 atm (20 to 30 psi). Once each month, the mesh pads are removed and cleaned by immersion in the plating bath followed by water rinsing. The mesh pads were cleaned by immersion prior to the first test run. The mist eliminator washdown system was activated prior to the second test run. The mesh pads were removed and washed down with water prior to test run No. 4.

Five tests were conducted at the inlet and outlet of the mist eliminator unit. Inlet and outlet testing was performed simultaneously. The test results are summarized in Table 4-10. Emissions measured at the inlet averaged 11.4 mg/dscm (4.98×10^{-3} gr/dscf), or 83×10^{-3} kg/hr (180×10^{-3} lb/hr). Emissions measured at the outlet averaged 0.03 mg/dscm (0.01×10^{-3} gr/dscf), or 0.23×10^{-3} kg/hr (0.51×10^{-3} lb/hr). Removal efficiencies ranged from 99.2 to 99.9 percent and averaged 99.7 percent. The average total current applied during outlet testing was 12,200 Ah. Therefore, the hexavalent chromium process emission rate from the mist eliminator unit was 0.04 mg/Ah (0.001 gr/Ah).

TABLE 4-10. PERFORMANCE DATA FOR PLANT F[48]

	Inlet			Outlet			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1	7.25	51.3	7.78	0.059	0.41	0.062	99.2
2	10.45	78.6	15.7	0.032	0.23	0.046	99.7
3	12.01	85.6	16.5	0.034	0.24	0.046	99.7
4	13.93	103.0	21.5	0.028	0.20	0.042	99.8
5	13.36	96.1	19.8	0.011	0.07	0.014	99.9
AVG	**11.40**	**82.9**	**16.3**	**0.033**	**0.23**	**0.042**	**99.7**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.1.3.3 Plant G. Plant G is a job shop that plates industrial rolls, hydraulic components, dies, and molds. The plant operates one hard chromium plating tank. The tank is 1.8 m (6.0 ft) long, 0.76 m (2.5 ft) wide, and 4.3 m (14.0 ft) deep and holds approximately 5,720 L (1,510 gal) of plating solution. The plating solution contains chromic acid in a concentration of about 210 g/L (28 oz/gal) of water. Sulfuric acid is used as a catalyst at a bath concentration of 2.1 g/L (0.28 oz/gal). The plating tank is equipped with an air agitation system to maintain uniform bath temperature and chromic acid concentration. The temperature of the plating solution is maintained between 54° and 60°C (130° and 140°F). The maximum current and voltage of the rectifier is 8,000 A and 9 V.[49]

The capture and control system on the plating tank consists of a single-sided lateral hood ducted to a mesh-pad mist eliminator that was installed in 1988. The design airflow rate of the ventilation system is 110 standard m^3/min (3,800 standard ft^3/min). During testing, the actual gas flow rate off the plating tank ranged from 92 to 98 m^3/min (3,240 to 3,460 ft^3/min).

The mist eliminator consists of two mesh pads spaced approximately 10 cm (4 in.) apart. Each mesh pad is 79 cm (31 in.) in diameter. The primary mesh pad at the inlet of the unit is 6.4 to 7.6 cm (2.5 to 3.0 in.) thick, and the secondary mesh pad is 3.2 to 3.8 cm (1.25 to 1.5 in.) thick. Each pad consists of interlocked polypropylene filaments 0.051 cm (0.020 in.) in diameter. The thread count is 4.3 by 3.3 per cm^2 (28 by 21 per $in.^2$) and the weave type is honeycomb. The mist eliminator has a design pressure drop of 0.62 kPa (2.5 in. w.c.) at a gas velocity of 150 to 210 m/min (500 to 700 ft/min).[50] The mist eliminator unit is equipped with two spray nozzles to clean the pads. One nozzle is located at the inlet and sprays rinse water (from the first rinse tank following the plating tank) onto the first mesh pad in the direction of the airflow. The second nozzle, located behind the second mesh pad, sprays clean tap water onto the pad countercurrent to the airflow. At the end of

each day, the ventilation system is shut off and the spray nozzles are activated for about 30 seconds to wash down the mesh pads. Once each month, the mesh pads are removed and cleaned by immersion in the plating bath followed by water rinsing.

Five test runs were conducted at the inlet and outlet of the mist eliminator. During this source test program, the plating tank was operated with and without polypropylene balls on the surface of the plating solution. The first three test runs were conducted without polypropylene balls to determine the effectiveness of the mesh-pad mist eliminator under maximum loading and to establish a baseline (i.e., without balls) condition. The two subsequent test runs were conducted while the balls covered the surface of the plating bath to evaluate the effectiveness of an overlay of balls in inhibiting chromic acid misting. The ball cover was complete, consisting of two to three layers in most places. In typical industrial applications, the ball cover is not usually as complete as that tested.

Emissions test results are presented in Table 4-11. Emissions measured at the inlet to the mist eliminator, when no polypropylene balls were being used, averaged 4.4 mg/dscm (1.9×10^{-3} gr/dscf), or 24×10^{-3} kg/hr (53×10^{-3} lb/hr); outlet emissions averaged 0.04 mg/dscm (0.02×10^{-3} gr/dscf), or 0.27×10^{-3} kg/hr (0.59×10^{-3} lb/hr). The control efficiency of the mist eliminator unit ranged from 98.7 to 99.0 percent and averaged 98.9 percent. The average total current applied during outlet testing was 8,800 Ah. Therefore, the hexavalent chromium process emission rate from the mist eliminator unit was 0.07 mg/Ah (0.001 gr/Ah).

TABLE 4-11. PERFORMANCE DATA FOR PLANT G[51]

Run No.	Inlet			Outlet			Efficiency, percent[a]
	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	
Without balls							
1	3.94	20.6	6.87	0.044	0.26	0.087	98.7
2	4.02	22.6	7.53	0.035	0.22	0.073	99.0
3	5.28	29.1	5.39	0.051	0.32	0.059	98.9
AVG	**4.41**	**24.1**	**6.60**	**0.043**	**0.27**	**0.073**	**98.9**
With balls							
4	1.17	6.6	2.20	0.032	0.20	0.067	97.0
5	0.74	4.1	1.37	0.028	0.18	0.060	95.6
AVG	**0.96**	**5.4**	**1.79**	**0.030**	**0.19**	**0.064**	**96.5**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

When polypropylene balls were used (test run Nos. 4 and 5), inlet emissions averaged 0.96 mg/dscm (0.42 x 10^{-3} gr/dscf), or 5.4 x 10^{-3} kg/hr (12 x 10^{-3} lb/hr). Emissions measured at the outlet under these conditions averaged 0.03 mg/dscm (0.01 x 10^{-3} gr/dscf), or 0.19 x 10^{-3} kg/hr (0.42 x 10^{-3} lb/hr). The average total current applied during outlet testing was 7,800 Ah, resulting in a process emission rate from the mist eliminator of 0.06 mg/Ah (0.001 gr/Ah). The difference between the average outlet concentration when polypropylene balls were used and the average outlet concentration when no balls were used is insignificant. Even when the inlet concentration was artificially lowered (i.e., with the use of polypropylene balls on the plating tank), the performance of the mesh-pad mist eliminator remained essentially the same. [For a further discussion of the efficiency of polypropylene balls, see Section 4.3.1.7.]

4.3.1.4 Discussion of Mesh-Pad Mist Eliminator Performance Data. Table 4-12 presents the performance data for Plants E, F,

and G. The four-stage mist eliminator at Plant E contained two sets of overlapping-type blades and two mesh pads installed in series. Units at Plants F and G each contained two mesh pads in series. A graphic illustration of the outlet concentrations for each plant is presented in Figure 4-14. Each of the units achieved consistent average outlet concentrations. The higher inlet concentrations at Plant F resulted in a lower average outlet process emission rate and a higher average percent efficiency, compared to the results for Plants E and G. However, because of the variation in inlet loadings among the three plants, a meaningful comparison of performance levels based on outlet process emission rate or percent efficiency cannot be made.

TABLE 4-12. PERFORMANCE DATA FOR MESH-PAD MIST ELIMINATORS--PLANTS E, F, AND G (AVERAGES)

Plant	Concentration, mg/dscm		Outlet process emission rate, mg/Ah	Efficiency, percent
	Inlet	Outlet		
E	3.07	0.040	0.078	98.7
F	11.40	0.033	0.042	99.7
G	4.41	0.043	0.073	98.9

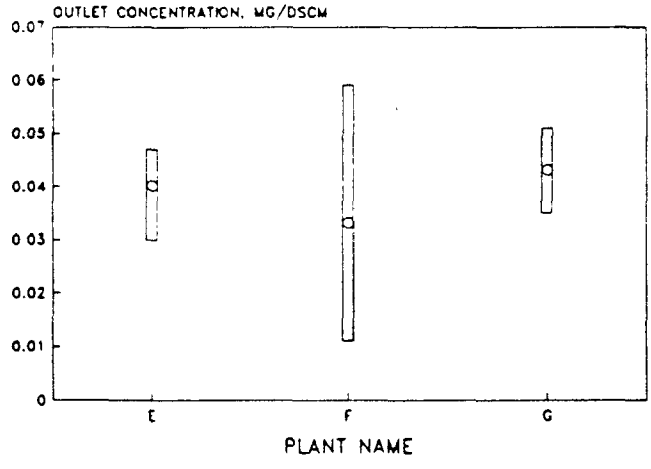


Figure 4-14. Outlet concentration data for mesh-pad mist eliminators.

Based on a comparison of outlet concentrations, the chevron-blade component of the mist eliminator system at Plant E does not directly contribute to the performance level of the control device. The sole purpose of the chevron-blade section is to reduce the inlet loading on the mesh pads and thus minimize plugging of the pads. This, in effect, helps to prevent degradation in the efficiency of the mist eliminator system.

4.3.1.5 Wet Scrubber Tests.

4.3.1.5.1 Plant I. Plant I is a job shop that performs hard chromium electroplating of industrial machine parts, industrial rolls, and steel tubing. The facility consists of three plating tanks. During the source test program, only two tanks, designated as the 23-ft and 10-ft tanks, were operated.

One tank is 7.0 m (23.0 ft) long, 0.9 m (3.0 ft) wide, and 1.2 m (4.0 ft) deep and holds about 6,850 L (1,810 gal) of plating solution. The tank is equipped with one 6,000-A and three 1,000-A rectifiers. When industrial rolls or tubing are plated, the 6,000-A rectifier is used; when smaller and different kinds of parts are plated, up to four work stations can be set up in the tank. Three of the work stations are charged with the 1,000-A rectifiers, and one work station is charged with the 6,000-A rectifier.[52]

The other tank is 3.0 m (10.0 ft) long, 0.9 m (3.0 ft) wide, and 1.2 m (4.0 ft) deep and holds about 2,990 L (790 gal) of plating solution. The 10-foot tank contains up to five work stations, each of which is charged with a separate 1,000-A rectifier. During this source test program, the 23-foot and 10-foot tanks were divided into two and five work stations, respectively.[52]

The plating solution used in the tanks is a conventional hard chromium plating solution containing about 240 g/L (32 oz/gal) of chromic acid and about 2.40 g/L (0.32 oz/gal) of sulfuric acid catalyst.[52] The baths are typically operated at 60°C (140°F).

All three tanks are equipped with double-sided draft hoods that are installed along the length of each tank. All three

tanks are ducted together and vented to a scrubber located outside the plant building. The scrubber, installed in 1984, is a horizontal-flow, single packed-bed unit equipped with a self-contained recirculation system. The scrubber water drains into a sump in the bottom of the scrubber and is recirculated by a 0.75-horsepower pump. A sensor is used to monitor the water level in the sump. About four times a day, clean water is automatically added over the packed bed when the sensor indicates that water is needed to replace evaporation losses. The scrubber water is drained to the plating tanks approximately once a day to make up for plating solution evaporation losses. The scrubber is then recharged with clean water. Water is sprayed through six nozzles countercurrent to the flow of the gas stream. The packed bed is 142 cm (56 in.) in height and width and 30 cm (12 in.) in depth and contains polypropylene, spherical-type mass packing that is continuously washed with water. A two-stage mist elimination section is located behind the packed bed.[53]

The gas flow rate to the scrubber during testing averaged 290 m^3/min (10,300 ft^3/min), and the water flow rate was about 130 L/min (35 gal/min). The L/G ratio was 450 L/min/1,000 m^3/min (3.4 gal/min/1,000 ft^3/min), and the pressure drop across the scrubber was 0.5 kPa (2 in. w.c.).[54]

Hard chromium plating facilities that use scrubbers typically recirculate the scrubber water continuously to reduce both water consumption and wastewater treatment costs and to recover chromic acid for use as plating solution makeup. The purpose of this emissions test was to determine the performance capability of the single packed-bed scrubber and assess the effect on scrubber performance of increasing chromic acid concentrations in the scrubber water. Three emissions test runs, each 2 hours in duration, were conducted simultaneously at the inlet and outlet of the scrubber for each of four target level scrubber water concentrations. The target level scrubber water chromic acid concentrations were selected to represent the range of concentrations that were believed to occur under typical operating conditions. These levels were 0, 30, 60, and 120 g/L

(0, 4, 8, and 16 oz/gal). The chromic acid concentration in the scrubber water was artificially increased after each test series by spiking the scrubber water with plating solution taken from the 23-ft tank. Grab samples of the scrubber water were taken from the scrubber recirculation sump at the beginning, middle, and end of each test run. The composite samples were analyzed onsite using a spectrophotometer to determine the chromic acid concentration. The actual concentrations observed during testing averaged 1.6, 25.1, 45.9, and 99.9 g/L (0.22, 3.36, 6.13, and 13.3 oz/gal).[54]

During the emissions test, the third tank was not operating, so the ventilation hood on the tank was dampered off to increase the ventilation rate for the 23-ft and 10-ft tanks that were in operation during the test.

The emission test results for hexavalent chromium are presented in Table 4-13. Hexavalent chromium emissions measured at the inlet averaged 5.51 mg/dscm (2.4×10^{-3} gr/dscf), or 0.090 kg/hr (0.20 lb/hr). Hexavalent chromium emissions measured at the outlet averaged 0.030 mg/dscm (1.3×10^{-5} gr/dscf), or 0.521×10^{-3} kg/hr (1.2×10^{-3} lb/hr). The efficiency of the scrubber ranged from 99.1 to 99.6 percent. Based on an average process emission rate of 7,500 Ah during outlet testing, the hexavalent chromium process emission rate from the scrubber was 0.143 mg/Ah (0.002 gr/Ah).

TABLE 4-13. PERFORMANCE DATA FOR PLANT I[55]

Sample No.	Inlet			Outlet			Efficiency, percent[a]
	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	
1	4.50	74.3	12.2	0.022	0.381	0.062	99.5
2	7.07	117	17.7	0.028	0.491	0.074	99.6
3[b]	7.04	117	18.0	0.146	2.56	0.391	--
AVG	**6.20**	**103**	**16.0**	**0.025**	**0.436**	**0.068**	**99.6**
4[c]	15.90	255	59.9	0.023	0.400	0.093	--
5	5.48	87.4	18.6	0.028	0.484	0.101	99.4
6	6.42	103	24.4	0.025	0.431	0.102	99.6
AVG	**5.95**	**95.2**	**21.5**	**0.025**	**0.438**	**0.099**	**99.5**
7	4.90	79.7	24.6	0.030	0.517	0.159	99.4
8	4.59	75.6	23.5	0.039	0.680	0.214	99.1
9	4.38	71.7	26.2	0.034	0.578	0.211	99.2
AVG	**4.62**	**75.7**	**24.8**	**0.034**	**0.592**	**0.195**	**99.2**
10	6.07	100	31.5	0.032	0.549	0.174	99.5
11	5.50	89.4	28.7	0.032	0.548	0.175	99.4
12	4.62	74.4	22.3	0.040	0.676	0.202	99.1
AVG	**5.40**	**87.9**	**27.5**	**0.035**	**0.591**	**0.184**	**99.3**
SERIES AVG	**5.51**	**90.0**	**22.5**	**0.030**	**0.521**	**0.143**	**99.4**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

[b]Results for the outlet test of this run were not included in the average; heavy rain entered the stack during testing and may have biased the results.

[c]Results for the inlet test of this run were not included in the average; the nozzle may have contacted the duct wall during testing.

The effect of increasing chromic acid concentrations in the scrubber water is shown in Figure 4-15. Figure 4-15 is a graph of the range of hexavalent chromium concentrations in the outlet gas stream measured at each of the chromic acid concentrations in the scrubber water. As shown in this figure, it appears that scrubber water chromic acid concentrations above 25.1 g/L (3.36 oz/gal) have a negative effect on the performance level of the scrubber. The average outlet hexavalent chromium concentration increased from 0.025 mg/dscm (1.1×10^{-5} gr/dscf) to 0.035 mg/dscm (1.5×10^{-5} gr/dscf) between the first two test series and the last two test series. The effect of the higher scrubber concentrations on the performance of the scrubber is also supported by the fact that there was no overlap in the data

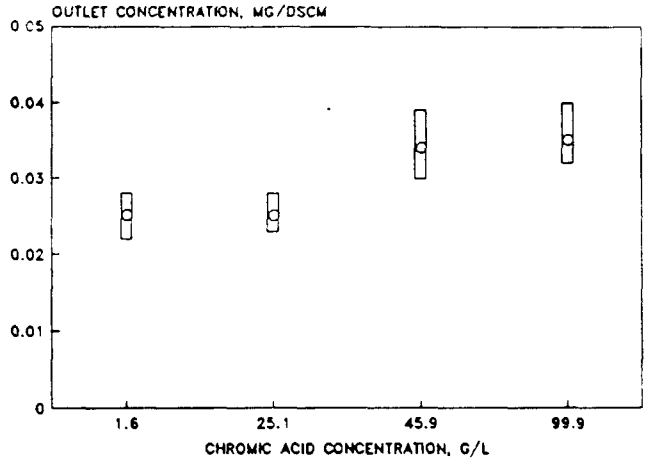


Figure 4-15. Performance data for the packed-bed scrubber at Plant I.

ranges between the first two test series and the last two test series. In addition, the amount of workload processed during the first two test series when the scrubber water concentration was below 30 g/L (4 oz/gal) averaged 10,360 Ah, and during the remaining two test series when the scrubber water concentration was above 46 g/L (6 oz/gal) the workload averaged 6,260 Ah. If the performance of the scrubber was not affected by the scrubber water concentration, it would be anticipated that the outlet hexavalent chromium concentration would be the same or slightly less than that measured during the first two test series. Therefore, the results of these tests suggest that chromic acid concentrations in the scrubber water should be below 46 g/L (6 oz/gal) to optimize the performance level of the scrubber.

4.3.1.5.2 Plant K. Plant K is a manufacturer of parts for textile machinery. Reeds and combs for textile looms and other miscellaneous parts undergo hard chromium plating in four plating tanks.[56]

During this EPA source test, only three of the four tanks were in operation (Tanks 1, 2, and 4). The dimensions and operating parameters for these tanks are presented in Table 4-14. The plating solution used in the tanks is a conventional hard

chromium plating solution containing about 250 g/L (33 oz/gal) of chromic acid and about 2.5 g/L (0.33 oz/gal) of sulfuric acid. Average plating bath temperatures were 52°C (125°F) for Tanks 1 and 2 and 43°C (110°F) for Tank 4. Current applied to all of the tanks during testing ranged from 400 to 2,230 A.[56]

TABLE 4-14. DIMENSIONS AND OPERATING PARAMETERS OF HARD CHROMIUM PLATING TANKS 1, 2, AND 4 TESTED AT PLANT K

Tank No.	Dimensions (l,w,d), m (ft)	Capacity, L (gal)	Voltage, volts[a]	Current, amperes[a]
1	3.8,0.9,0.9 (12.5,3.0,3.0)	2,650 (700)	15	10,000
2	3.0,0.5,0.9 (10.0,1.8,3.0)	1,290 (340)	15	6,000
4	2.1,0.8,0.9 (6.8,2.5,3.0)	1,210 (320)	30	5,000

[a]Values represent maximum operating values.

Tanks 1 and 4 are equipped with push-pull emission capture systems, and Tank 2 is equipped with a single-sided draft hood. Emissions from all three tanks are ducted to a fume scrubber system that is located on the roof of the plating shop. The scrubber is a horizontal-flow, double packed-bed unit that was installed in 1981. The packed beds are 30.5 cm (12 in.) deep and are filled with polypropylene spherical-type mass packing. The design gas flow rate of the scrubber is 540 standard m^3/min (19,000 standard ft^3/min). During testing, the actual gas flow rate averaged 510 m^3/min (18,100 ft^3/min). Scrubber water flow during the tests was set at 450 L/min (120 gal/min). This flow resulted in a L/G ratio of 860 L/min/1,000 m^3/min (6.4 gal/min/1,000 ft^3/min). The pressure drop during testing ranged from 0.7 to 0.8 kPa (2.9 to 3.2 in. w.c.). Each packed bed is 30.5 cm (12 in.) deep.

Six spray nozzles are located in front of each packed bed and are used to spray the beds continuously countercurrent to the flow of the gas stream. Chromic acid mist that impinges on the packing material is washed to the bottom of the scrubber. The scrubber water flows by gravity from the scrubber to a 910-L

(240-gal) recirculation tank located inside the plating shop. Clean water is used to make up for evaporation losses from the system. The ductwork is washed down once a month with water that subsequently drains into the plating tanks. The scrubber also contains a chevron-blade mist elimination section located downstream of the second packed bed.[57]

Three emissions tests were conducted at the inlet and outlet of the scrubber. The test results are summarized in Table 4-15. Emissions measured at the inlet averaged 1.7 mg/dscm (0.7×10^{-3} gr/dscf), or 46×10^{-3} kg/hr (100×10^{-3} lb/hr). Emissions measured at the outlet averaged 0.052 mg/dscm (0.02×10^{-3} gr/dscf), or 1.5×10^{-3} kg/hr (3.4×10^{-3} lb/hr). The removal efficiency of the scrubber ranged from 94.9 to 98.1 percent. The average total current applied to the process during outlet testing was 8,750 Ah. Therefore, the hexavalent chromium process emission rate from the scrubber was 0.56 mg/Ah (0.009 gr/Ah).

TABLE 4-15. PERFORMANCE DATA FOR PLANT K[58]

	Inlet			Outlet			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1	2.68	74.4	19.6	0.051	1.45	0.382	98.1
2	1.20	33.6	16.1	0.052	1.51	0.726	95.5
3	1.13	31.3	10.8	0.055	1.61	0.561	94.9
AVG	**1.67**	**46.4**	**15.5**	**0.052**	**1.52**	**0.556**	**96.2**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.1.5.3 Plant L. Plant L is a job shop that specializes in hard chromium electroplating of crankshafts. Tests were conducted on a single packed-bed scrubber that controls emissions from a plating tank 9.1 m (30 ft) long, 1.1 m (3.5 ft) wide, and 1.2 m (4.0 ft) deep. The tank holds approximately 10,410 L (2,750 gal) of plating solution. The plating tank is equipped with a single rectifier rated at 15 V and 8,000 A. The tank

contains a conventional hard chromium plating solution consisting of 240 g/L (32 oz/gal) of chromic acid and 2.4 g/L (0.32 oz/gal) of sulfuric acid. The plating solution is maintained at 54°C (130°F).[59]

The capture and control system on the plating tank consists of a double-sided draft hood that is vented to a horizontal-flow single packed-bed scrubber that was installed in 1988. The design gas flow rate to the scrubber is 450 m^3/min (16,000 ft^3/min).[60] The scrubbing water flow rate is approximately 180 L/min (48 gal/min). During testing, the actual inlet gas flow rate to the scrubber averaged 575 m^3/min (20,300 ft^3/min), and the monitored pressure drop was close to the design pressure drop of 0.5 kPa (2.0 in. w.c.).

Within the scrubber system, the velocity of the gas stream is reduced to approximately 134 m/min (440 ft/min), and the gas stream is humidified by a spray of water. Water is sprayed countercurrent to the flow of the gas stream through 10 spray nozzles. The saturated gas stream then passes through a packed bed of polypropylene, spherical-type mass packing. The packed bed is wetted continuously with scrubbing water supplied by the series of spray nozzles in front of the bed. The packed bed is approximately 2.0 m (6.4 ft) high, 1.9 m (6.2 ft) wide, and 0.30 m (1.0 ft) deep. Entrained mist and water droplets impinge on the packing and drain into the sump. Behind the packed bed is a two-stage mist elimination section that removes entrained water droplets. The first stage allows large droplets to settle by gravity to the bottom of the scrubber. The second stage contains a series of vertically mounted chevron blades that change the direction of the gas flow four times at 30° angles, forcing chromic acid droplets to impinge on the blades. The mist eliminator is not washed down.[60]

The scrubber water drains into a sump in the bottom of the scrubber and is recirculated by a pump. A level indicator (sight gauge) is used to monitor the water level in the sump, which holds approximately 450 L (120 gal) of water. Once a week, the water in the sump is drained into a 5,680-L (1,500-gal) holding

tank and the sump is recharged with fresh water. Although the plating tank is operated 24 hours a day, the recirculation system on the scrubber is turned off from 11:30 p.m. to 7:30 a.m., when there are no plant employees onsite.[60]

Test results obtained on another horizontal-flow, single packed-bed scrubber (Plant I) demonstrated that better than 99 percent control efficiency and an average outlet hexavalent chromium concentration of 0.030 mg/dscm (1.3×10^{-5} gr/dscf) was achievable. The double packed-bed scrubber tested at Plant K achieved a lower control efficiency of 96 percent, with an average hexavalent chromium concentration of 0.052 mg/dscm (2.3×10^{-5} gr/dscf). The scrubber tested at Plant I was somewhat unique in that it was equipped with an overhead spray system that periodically flooded and cleaned the scrubber packing media with fresh water. Based on the test results obtained from Plants I and K, it appeared that periodic flooding of the packing media may prevent deterioration in scrubber performance caused by chromium buildup. Therefore, the purpose of the source test at Plant L was to determine if the periodic flooding action provided by the scrubber overhead weir system significantly improved the scrubber performance and to establish the average performance level of the scrubber system.

Prior to emissions testing, the scrubber was retrofitted with an overhead weir so that the scrubber could be operated with and without periodic fresh water washdown of the scrubber packing. Three mass emissions test runs were conducted at the inlet and outlet of the scrubber at each of the following conditions: (1) the scrubber recirculation system was in operation and any required makeup water was supplied by a hose through one of the scrubber's inspection doors, and (2) the scrubber recirculation system was in operation and all required makeup water was supplied through a pipe that extended out about 10 to 13 cm (4 to 5 in.) over the top of the packed bed. Two subsequent test runs were conducted at the inlet and outlet of the scrubber with the scrubber recirculation system in operation

and a continuous flow of fresh water supplied through the overhead weir at a rate of 7.6 L/min (2.0 gal/min).

Prior to test run Nos. 1 and 3, the sump in the bottom of the scrubber was drained to the holding tank and the sump was recharged with fresh water supplied by a hose through one of the scrubber's inspection doors. During test run Nos. 1 through 3, makeup water required by the scrubber to replace evaporation losses was added through the inspection doors with a water hose. Prior to test run No. 4, the scrubber was thoroughly cleaned by draining the sump and washing down the inside walls, packing media, and mist elimination section with a pressurized water hose. During test run Nos. 4 through 6, makeup water required by the scrubber to replace evaporation losses was supplied through the pipe located over the top of the packed bed. Prior to test run No. 7, the scrubber was recleaned. During test run Nos. 7 and 8, makeup water was added continuously over the top of the packed bed through the overhead weir at a flow rate of 7.6 L/min (2.0 gal/min).[61]

The emissions test results for hexavalent chromium are presented in Table 4-16. A plot of the range of outlet hexavalent chromium concentrations at each washdown condition is presented in Figure 4-16. The first three emissions test runs were conducted without overhead washdown of the scrubber packing. For these runs, emissions measured at the inlet averaged 0.72 mg/dscm (0.31×10^{-3} gr/dscf), or 23×10^{-3} kg/hr (51×10^{-3} lb/hr). Emissions measured at the outlet averaged 0.04 mg/dscm (0.02×10^{-3} gr/dscf), or 1.2×10^{-3} kg/hr (2.6×10^{-3} lb/hr). Emissions test run Nos. 4, 5, and 6 were conducted with periodic overhead washdown. The emissions measured at the inlet for these runs averaged 0.67 mg/dscm (0.29×10^{-3} gr/dscf), or 22×10^{-3} kg/hr (47×10^{-3} lb/hr). Outlet emissions averaged 0.02 mg/dscm (0.01×10^{-3} gr/dscf), or 0.71×10^{-3} kg/hr (1.6×10^{-3} lb/hr). Test run Nos. 7 and 8 were conducted with continuous overhead washdown of the scrubber packing. Emissions at the inlet averaged 0.72 mg/dscm (0.32×10^{-3} gr/dscf), or 24×10^{-3} kg/hr (52×10^{-3} lb/hr).

Emissions measured at the outlet averaged 0.02 mg/dscm (0.01×10^{-3} gr/dscf), or 0.65×10^{-3} kg/hr (1.4×10^{-3} lb/hr).

TABLE 4-16. PERFORMANCE DATA FOR PLANT L[62]

Run No.	Inlet			Outlet			Efficiency, percent[a]
	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	
			No overhead washdown				
1[b]	0.299	9.7	3.53	0.038	1.13	0.419	--
2	0.646	20.8	6.93	0.039	1.19	0.397	94.3
3	0.783	25.2	11.0	0.041	1.24	0.539	95.1
AVG	**0.715**	**23.0**	**8.97**	**0.039**	**1.19**	**0.452**	**94.7**
			Periodic overhead washdown				
4	0.850	27.8	7.72	0.026	0.786	0.221	97.2
5	0.576	18.7	5.19	0.022	0.646	0.179	96.5
6	0.579	18.6	5.03	0.023	0.684	0.185	96.3
AVG	**0.668**	**21.7**	**5.98**	**0.023**	**0.705**	**0.195**	**96.6**
			Continuous overhead washdown				
7	0.752	24.7	7.89	0.023	0.686	0.219	97.2
8	0.693	22.5	8.04	0.020	0.613	0.219	97.3
AVG	**0.723**	**23.6**	**7.97**	**0.021**	**0.650**	**0.219**	**97.3**

[a]Efficiencies are calculated from mass emission rates, and the average is based on an averaging efficiencies for each run.
[b]Results for the inlet test of this run were not included in the average due to possible sample contamination.

As shown in Figure 4-16, periodic washdown improved the performance level of the scrubber, whereas continuous washdown did not provide any additional benefit beyond that achieved by periodic washdown. At comparable inlet loadings, the average scrubber removal efficiencies were 94.7 percent when no overhead washdown was used, 96.6 percent with periodic washdown, and 97.3 percent with continuous washdown. The average hexavalent chromium process emission rates from the scrubber were 0.45 mg/Ah (0.007 gr/Ah) with no overhead washdown, 0.20 mg/Ah (0.003 gr/Ah) with periodic washdown, and 0.22 mg/Ah (0.003 gr/Ah) with continuous washdown. Therefore, these test results suggest that periodic flooding of the packing material is beneficial in maintaining the scrubber performance, but continuous flooding is unnecessary.

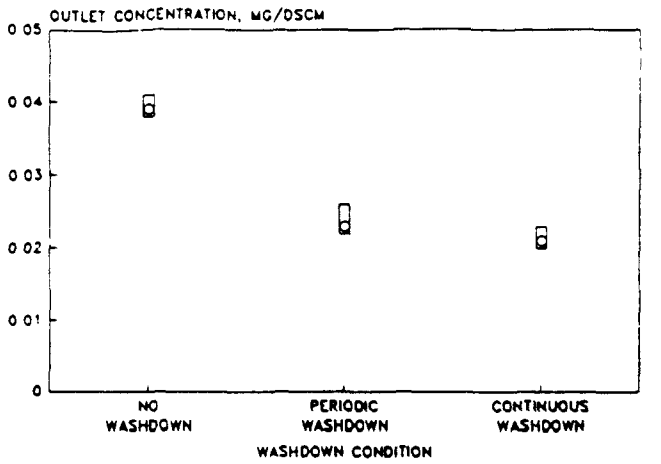


Figure 4-16. Performance data for the packed-bed scrubber at Plant L.

4.3.1.6 Discussion of Wet Scrubber Tests. Table 4-17 and Figure 4-17 present the performance data for each of the wet scrubber systems tested. When the test program began, it was anticipated that the double packed-bed scrubber would be the most efficient of the control devices tested because: (1) it operates at a higher pressure drop than the other devices, and (2) the redundancy of the second packed bed should provide more impaction opportunities for the chromic acid mist. However, test results from Plants I and K clearly demonstrate that the best performance level was achieved by the single packed-bed scrubber at Plant I. The average outlet concentration at Plant I was 0.030 mg/dscm (1.3×10^{-5} gr/dscf), whereas the average outlet concentration achieved by the double packed-bed scrubber at Plant K was 0.052 mg/dscm (2.3×10^{-5} gr/dscf).

The process operating conditions were evaluated to determine if there were any operational reasons for the observed results. The processes tested were representative of typical hard chromium plating operations. Also, the scrubbers appeared to be operated normally during testing. All had pressure drops, L/G ratios, and gas velocities at or near acceptable design levels. The size of the packing used in the scrubbers was also comparable.

TABLE 4-17. PERFORMANCE DATA FOR PACKED-BED SCRUBBERS PLANTS I, K, AND L (AVERAGES)

Plant	Concentration, mg/dscm Inlet	Concentration, mg/dscm Outlet	Outlet process emission rate, mg/Ah	Efficiency, percent
I[a]	6.20	0.025	0.068	99.6
I[b]	5.95	0.025	0.099	99.5
I[c]	4.62	0.034	0.195	99.2
I[d]	5.40	0.035	0.184	99.3
SERIES	**5.51**	**0.030**	**0.143**	**99.4**
K	1.67	0.052	0.556	96.2
L[e]	0.715	0.039	0.452	94.7
L[f]	0.668	0.023	0.195	96.6
L[g]	0.723	0.021	0.219	97.3

[a]Test runs with an average scrubber water chromic acid concentration of 1.6 g/L.
[b]Test runs with an average scrubber water chromic acid concentration of 25.1 g/L.
[c]Test runs with an average scrubber water chromic acid concentration of 45.9 g/L.
[d]Test runs with an average scrubber water chromic acid concentration of 99.9 g/L.
[e]Test runs with no overhead washdown.
[f]Test runs with periodic overhead washdown.
[g]Test runs with continuous overhead washdown.

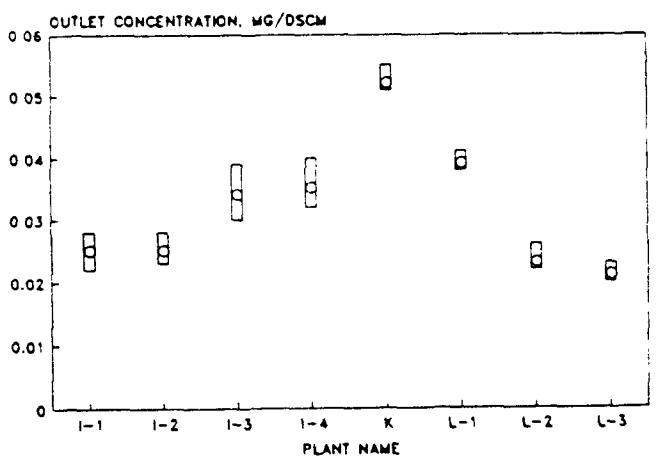


Figure 4-17. Outlet concentration data for packed-bed scrubbers.

At the time of the emissions tests, the single packed-bed scrubber at Plant I was 2 years old, and the double packed-bed scrubber at Plant K was 4 years old. Any scrubber system that has been in operation for any length of time requires a certain amount of routine maintenance for the scrubber to operate at optimum performance levels. Each of the scrubbers tested was inspected and any needed repairs were made prior to the source tests.

The single packed-bed scrubber at Plant I was equipped with an overhead water distribution weir. This feature was not included in the double packed-bed scrubber at Plant K. The overhead weir in the single packed-bed scrubber was located above the packed-bed and was activated when makeup water was required to refill the sump due to evaporation losses or following drainage of the sump to the plating tank. The double packed-bed scrubber at Plant K was equipped with a water line that added makeup water directly to the sump rather than over the packed bed. The flooding action provided by the addition of water through an overhead weir provides frequent cleaning of the packing media and may prevent degradation in the performance of the packed-bed scrubber. Therefore, it was thought that the performance difference between the two scrubbers might be accounted for by the presence of the overhead weir in the single packed-bed scrubber tested.

At Plant L, the primary purpose of the source test was to determine if the periodic flooding action provided by the scrubber overhead weir system significantly improved the scrubber performance. Three sets of test runs were conducted: one set with no overhead washdown, one set with periodic overhead washdown, and one set with continuous overhead washdown. As shown in Table 4-17 and Figure 4-17, the results of this test indicated there was an improvement in the performance level of the scrubber when periodic washdown was used. With no overhead washdown of the scrubber packing, the average removal efficiency was 94.7 percent and the outlet hexavalent chromium concentration averaged 0.039 mg/dscm (1.7×10^{-5} gr/dscf). With periodic

washdown, the efficiency increased to 96.6 percent and the average outlet hexavalent chromium concentration was reduced to 0.023 mg/dscm (1.0×10^{-5} gr/dscf). The use of continuous overhead washdown did not significantly increase the control efficiency or reduce the outlet concentration of the scrubber over that achieved with periodic washdown. These data suggest that periodic overhead washdown of the scrubber packing is needed to maintain the scrubber at optimum performance levels.

Results of the recirculation study at Plant I showed that increasing the scrubber water chromic acid concentration from the baseline of 1.6 g/L (0.22 oz/gal) to 99.9 g/L (13.3 oz/gal) did not decrease the control efficiency of the scrubber below 99 percent. However, the outlet hexavalent chromium concentration increased between the two test series conducted at scrubber water concentrations of 25.1 g/L (3.4 oz/gal) and 45.9 g/L (6.1 oz/gal). At the baseline concentration of 1.6 g/L (0.22 oz/gal), hexavalent chromium emissions from the scrubber were 0.44×10^{-3} kg/hr (0.96×10^{-3} lb/hr). Increasing the concentration to 25.1 g/L (3.4 oz/gal) resulted in no significant measured increase in outlet hexavalent chromium emissions over the baseline condition. However, for scrubber water concentrations of 45.9 and 99.9 g/L (6.1 and 13.3 oz/gal), hexavalent chromium emissions increased by about 34 percent (0.15×10^{-3} kg/hr [0.34×10^{-3} lb/hr]) above baseline. This is an indication that the scrubber water chromic acid concentration needs to be below 46 g/L (6 oz/gal) for optimum scrubber performance.

4.3.1.7 <u>Discussion of Performance Data for Polypropylene Balls</u>. During the testing of the mesh-pad mist eliminator at Plant G (see Section 4.3.1.3.3), the plating tank was operated with and without polypropylene balls on the surface of the plating solution. The cover was two to three layers thick in most places. In typical industrial applications, coverage is usually not as complete as that tested.

Two test runs were conducted while the balls were in place, and the results are presented in Table 4-18. Emissions measured

at the inlet of the mist eliminator when the balls were in place (test run Nos. 4 and 5) averaged 0.96 mg/dscm (0.42×10^{-3} gr/dscf), or 5.4×10^{-3} kg/hr (12×10^{-3} lb/hr). These values were compared to measurements made at the inlet when no balls were used (test run Nos. 1 and 2) to assess the performance of polypropylene balls in controlling chromium emissions. Run Nos. 1 and 2 were used for comparison because the same pieces were being plated at the same current and plating times as those in test run Nos. 4 and 5. The removal efficiency averaged 74.9 percent.

TABLE 4-18. PERFORMANCE DATA FOR PLANT G--POLYPROPYLENE BALLS[51]

	Without balls			With balls			
Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
1 (4)[b]	3.94	20.6	6.87	1.17	6.6	2.20	68.0
2 (5)[b]	4.02	22.6	7.53	0.74	4.1	1.37	81.9
AVG	**3.98**	**21.6**	**7.20**	**0.96**	**5.4**	**1.79**	**74.9**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

[b]Run Nos. 1 and 2 were conducted with no polypropylene balls. Run Nos. 4 and 5 were conducted with polypropylene balls.

4.3.2 Tests at Decorative Chromium Electroplating Operations

4.3.2.1 Chemical Fume Suppressant Testing--Plant N.

Plant N is a small job shop that performs decorative chromium electroplating of automotive trim. The plating facility consists of two decorative chromium plating lines: the main plating line and a rework plating line.[63] Tests were conducted at the chromium plating tank in the main plating line to characterize the performance of two types of chemical fume suppressants. The chromium plating segment of this line consists of a chromium predip, the plating tank, a chromium saver tank, and three bisulfite rinses. The plating line is serviced by an automatically controlled overhead conveyor that transfers racks of parts to each tank in a programmed sequence.

The chromium plating tank is 3.4 m (11.0 ft) long, 0.85 m (2.8 ft) wide, and 1.5 m (5.0 ft) deep and is divided into six cells that are each 0.55 m (1.8 ft) long. The plating tank holds approximately 3,940 L (1,040 gal) of plating solution, which contains chromic acid in a concentration of 280 g/L (37 oz/gal) of water. The plating solution contains both fluoride and sulfuric acid catalysts. The temperature of the plating bath is maintained between 43° and 47°C (110° and 116°F). The plating tank is equipped with three rectifiers.

After immersion into the plating tank, the surface area of the parts is activated for 15 seconds prior to plating. During activation, the rectifier connected to cell No. 1 is operated at 0 to 5.0 V and 0 to 200 A. After activation, the racks are automatically moved toward the center of the plating tank. During plating, the rectifier connected to cell Nos. 2 through 5 is set at 5.2 V and 3,000 A. The rectifier connected to cell No. 6 is set at 3.0 V and minimal to no current.[64]

The chromium plating tank is equipped with a single-sided draft hood. The exhaust gases captured by the hood are ducted to a vertical-flow, single packed-bed scrubber.

During the source test, the chromium plating tank was operated under three conditions: (1) without a fume suppressant, (2) with a foam blanket, and (3) with a "combination" fume suppressant consisting of a foam blanket and a wetting agent. The foam blanket forms a layer of foam approximately 2.5 cm (1.0 in.) thick over the plating bath when the plating solution is agitated by the gas bubbles formed during the plating process. The combination fume suppressant forms a layer of foam 2.5 cm (1.0 in.) thick over the surface of the plating solution and lowers the surface tension of the plating solution from 70 dynes/cm (4.8×10^{-3} lb_f/ft) to below 40 dynes/cm (2.7×10^{-3} lb_f/ft). Because the surface tension of the plating solution is lower, the gases formed escape the surface with less of a "bursting" effect, and less mist is produced. The foam layer is designed to capture any mist that is formed. The foam blanket and the combination fume suppressants used during the

test program were applied and maintained according to the manufacturer's recommendations.

Three test runs at each condition were conducted at a location in the ductwork between the ventilation hood and the inlet of the scrubber to characterize the performance of the two types of chemical fume suppressants. The results of testing with and without fume suppressants are presented in Table 4-19. Hexavalent chromium emissions measured during the uncontrolled runs (when no fume suppressant was used) averaged 9.2×10^{-1} mg/dscm (0.40×10^{-3} gr/dscf), or 3.6×10^{-3} kg/hr (7.9×10^{-3} lb/hr).

Hexavalent chromium emissions measured during the test runs when the foam blanket was used averaged 4.7×10^{-3} mg/dscm (2.0×10^{-6} gr/dscf), or 1.8×10^{-5} kg/hr (4.0×10^{-5} lb/hr). Hexavalent chromium emissions measured during the test runs when the combination fume suppressant was used averaged 2.2×10^{-3} mg/dscm (9.5×10^{-7} gr/dscf), or 8.3×10^{-6} kg/hr (1.8×10^{-5} lb/hr).

The efficiency of the foam blanket ranged from 99.3 to 99.6 percent for the removal of hexavalent chromium emissions. The efficiency of the combination fume suppressant ranged from 99.7 to 99.9 percent for the removal of hexavalent chromium emissions. Based on average total current of 8,500 Ah and 10,500 Ah during testing, the hexavalent chromium process emission rates when the foam blanket and combination fume suppressant were maintained in the tank were 0.007 mg/Ah (1.0×10^{-4} gr/Ah) and 0.003 mg/Ah (5.0×10^{-5} gr/Ah), respectively.

4.3.2.2 Discussion of Chemical Fume Suppressant Tests. The test results from Plant N show that removal efficiencies of chemical fume suppressants ranged from 99.3 to 99.9 percent for hexavalent chromium with an average hexavalent chromium emission rate of 1.3×10^{-5} kg/hr (2.9×10^{-5} lb/hr), or 0.005 mg/Ah (6.9×10^{-5} gr/Ah).

TABLE 4-19. PERFORMANCE DATA FOR PLANT N--HEXAVALENT CHROMIUM EMISSIONS[65]

Run No.	mg/dscm	kg/hr (10^{-3})	mg/Ah	Efficiency, percent[a]
		Uncontrolled		
1	0.846	3.3	1.22	
2	0.923	3.6	1.50	
3	0.993	3.9	1.39	
AVG	**0.921**	**3.6**	**1.37**	
		Foam blanket		
4	0.003	0.013	0.005	99.6
5	0.007	0.027	0.010	99.3
6	0.004	0.015	0.005	99.6
AVG	**0.005**	**0.018**	**0.007**	**99.5**
	Combination foam blanket and wetting agent			
7	0.002	0.007	0.003	99.8
8	0.001	0.005	0.002	99.9
9	0.003	0.013	0.005	99.7
AVG	**0.002**	**0.008**	**0.003**	**99.8**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run.

4.3.3 Summary and Discussion of Emission Test Results

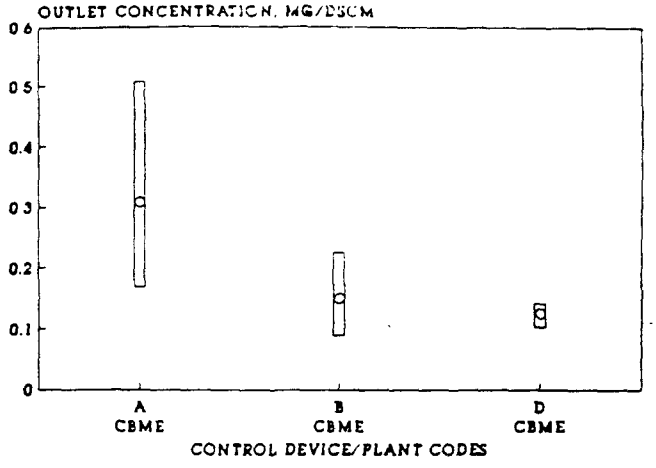
The emission data for all of the control techniques tested are summarized in Tables 4-4a and 4-4b. During the early part of the test program, total chromium and hexavalent chromium were measured at each site. The results of these tests indicated that the hexavalent chromium levels and the total chromium levels were about the same, so emissions could all be assumed to be hexavalent chromium. For this reason, and for reasons discussed in Appendix D (Emission Measurements), total chromium analyses were discontinued for the remainder of the plants tested. The values for hexavalent chromium were assumed to be approximately the same as those obtained for total chromium.

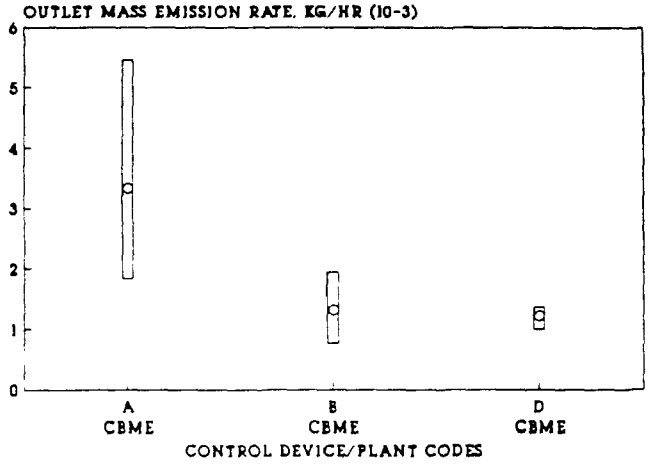
The following is a summary of the conclusions about each individual control unit tested during the source test program. Source test results on chevron-blade mist eliminators indicate that: (1) overlapping-type blades are more effective than wave-type blades, and (2) a double set of blades does not significantly increase the performance level beyond that achieved by a single set of blades. For mesh-pad mist eliminators, the test results indicate that the units achieved consistent outlet results, which suggests that the units had comparable performance levels.

The source test results for packed-bed scrubbers indicate that: (1) a second packed bed does not improve the performance level above that achieved by a single packed bed, (2) periodic flooding of the packing media with fresh water helps to clean the packing media and prevent degradation in the scrubbers performance, and (3) the chromic acid concentration in the scrubber water should be less than 30 g/L (4 oz/gal) to optimize the performance level of the scrubber. The test results also showed that chemical fume suppressants are very effective in inhibiting chromic acid mist from decorative chromium plating tanks.

There are three distinct performance levels achieved by the control devices. The lowest performance level is associated with the use of chevron-blade mist eliminators, which achieved an average outlet hexavalent chromium emission concentration of 0.190 mg/dscm (0.08×10^{-3} gr/dscf) for the three chevron-blade mist eliminators tested. The intermediate performance level is associated with the use of mesh-pad mist eliminators and packed-bed scrubbers, which achieved an average outlet hexavalent chromium concentration of 0.035 mg/dscm (0.02×10^{-3} gr/dscf). The highest performance level is associated with the use of chemical fume suppressants (by decorative chromium plating operations), which achieved an average outlet hexavalent chromium concentration of 0.0047 mg/dscm (0.002×10^{-3} gr/dscf).

Figure 4-18 is a graphical presentation of the performance level achievable by chevron-blade mist eliminators. The





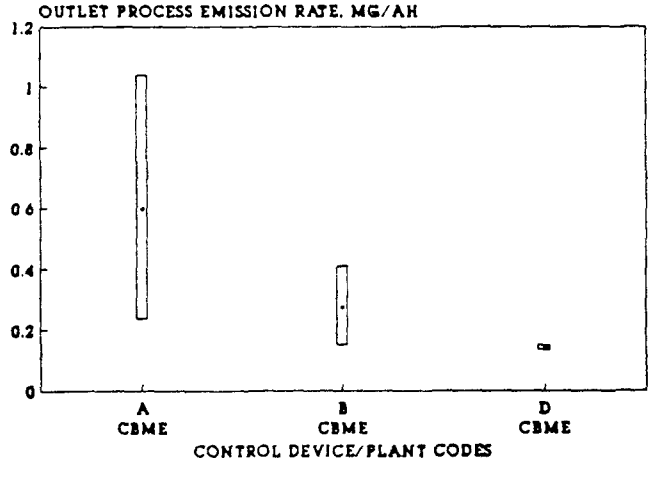
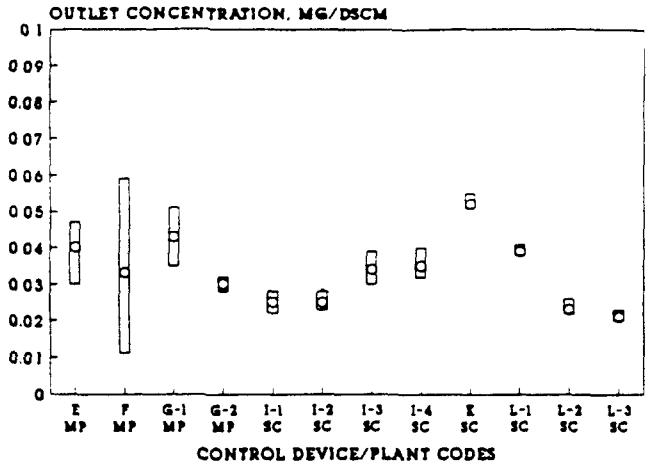
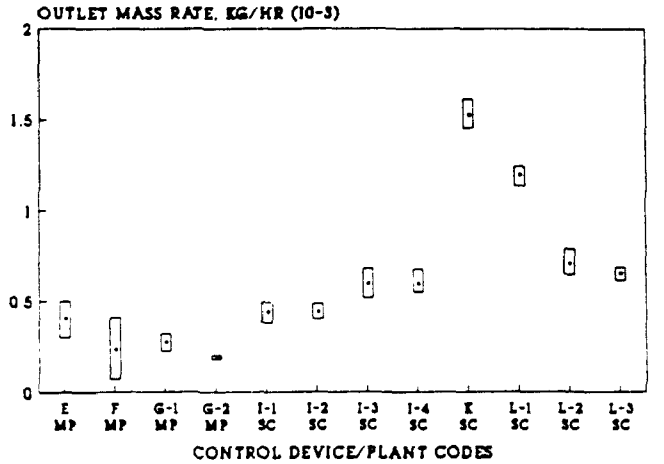


Figure 4-18. Performance data for chevron-blade mist eliminators.

individual test averages for the outlet hexavalent chromium concentration ranged from 0.120 to 0.310 mg/dscm (0.05×10^{-3} to 0.13×10^{-3} gr/dscf). The average mass emission rates varied from 1.2×10^{-3} to 3.3×10^{-3} kg/hr (2.7×10^{-3} to 7.3×10^{-3} lb/hr), while the average process emission rates varied from 0.14 to 0.59 mg/Ah (0.002 to 0.009 gr/Ah).

Figure 4-19 is a graphical presentation of the performance levels achievable by mesh-pad mist eliminators and packed-bed scrubbers. The individual test averages for the outlet hexavalent chromium concentration ranged from 0.021 to 0.052 mg/dscm (0.01×10^{-3} to 0.02×10^{-3} gr/dscf). The average mass emission rates varied from 0.23×10^{-3} to 1.5×10^{-3} kg/hr (0.51×10^{-3} to 3.4×10^{-3} lb/hr), while the average process emission rates varied from 0.04 to 0.56 mg/Ah (0.001 to 0.009 gr/Ah). A review of the test data for mesh-pad mist eliminators and packed-bed scrubbers presented in Tables 4-4a and 4-4b and Figure 4-19 suggests that inlet concentration has an effect on the performance efficiency of the control devices. Regardless of the variation in inlet concentrations, outlet concentrations are fairly constant. A plot of efficiency versus concentration, presented in Figure 4-20, suggests the relationship is a logarithmic function. When the log of the concentrations is plotted versus the corresponding efficiencies (Figure 4-21), and a linear regression analysis is performed, a high correlation coefficient is obtained ($r = 0.87$). To verify that this correlation does exist, two test series that have a wide variation in inlet concentrations were selected, and the log of the concentrations and the corresponding efficiency values were plotted for each test run. This graph is shown in Figure 4-22. The linear regression performed on the data resulted in essentially the same regression line ($r = 0.98$) as that shown in Figure 4-21. This supports the conclusion that inlet concentration has an effect on the performance efficiency of the control device and that the outlet hexavalent chromium concentration is a better measure of the performance capability of the units than percent efficiency.





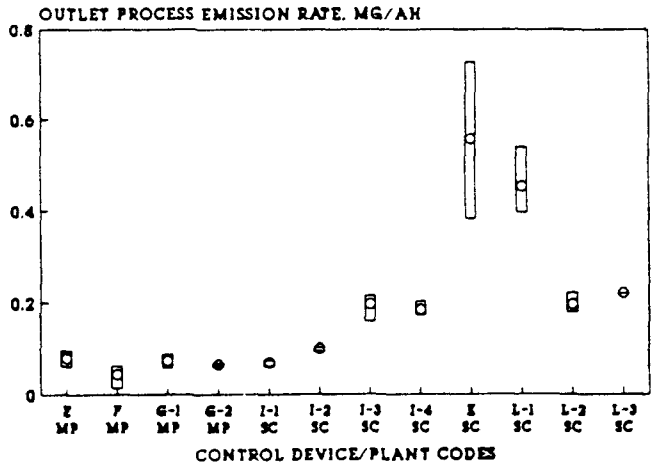


Figure 4-19. Performance data for mesh-pad mist eliminators and packed-bed scrubbers.

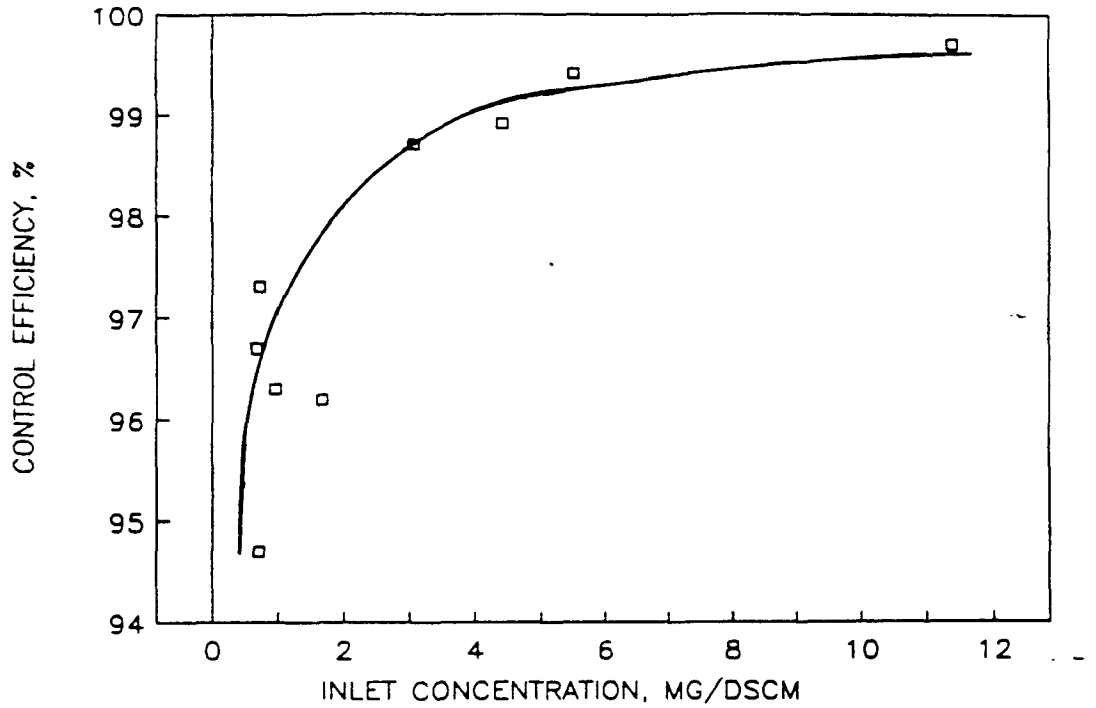


Figure 4-20. Average control device efficiency versus average inlet concentration for scrubbers and mesh-pad mist eliminators.

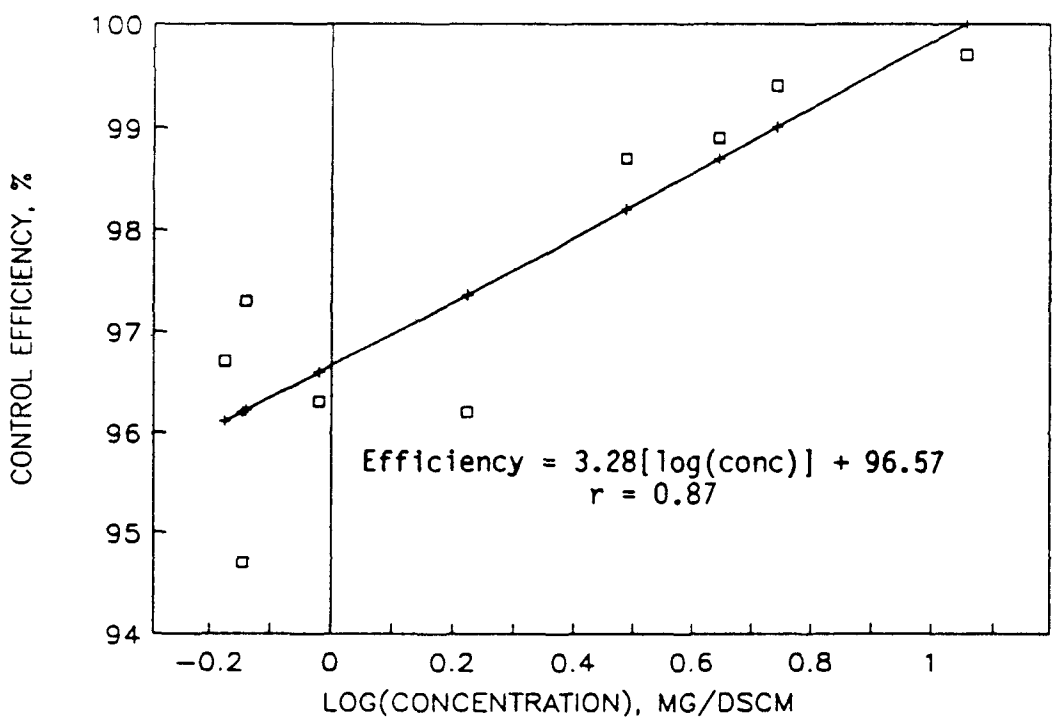


Figure 4-21. Average control device efficiency versus average $\log_{10}$ (concentration) for scrubbers and mesh-pad mist eliminators.

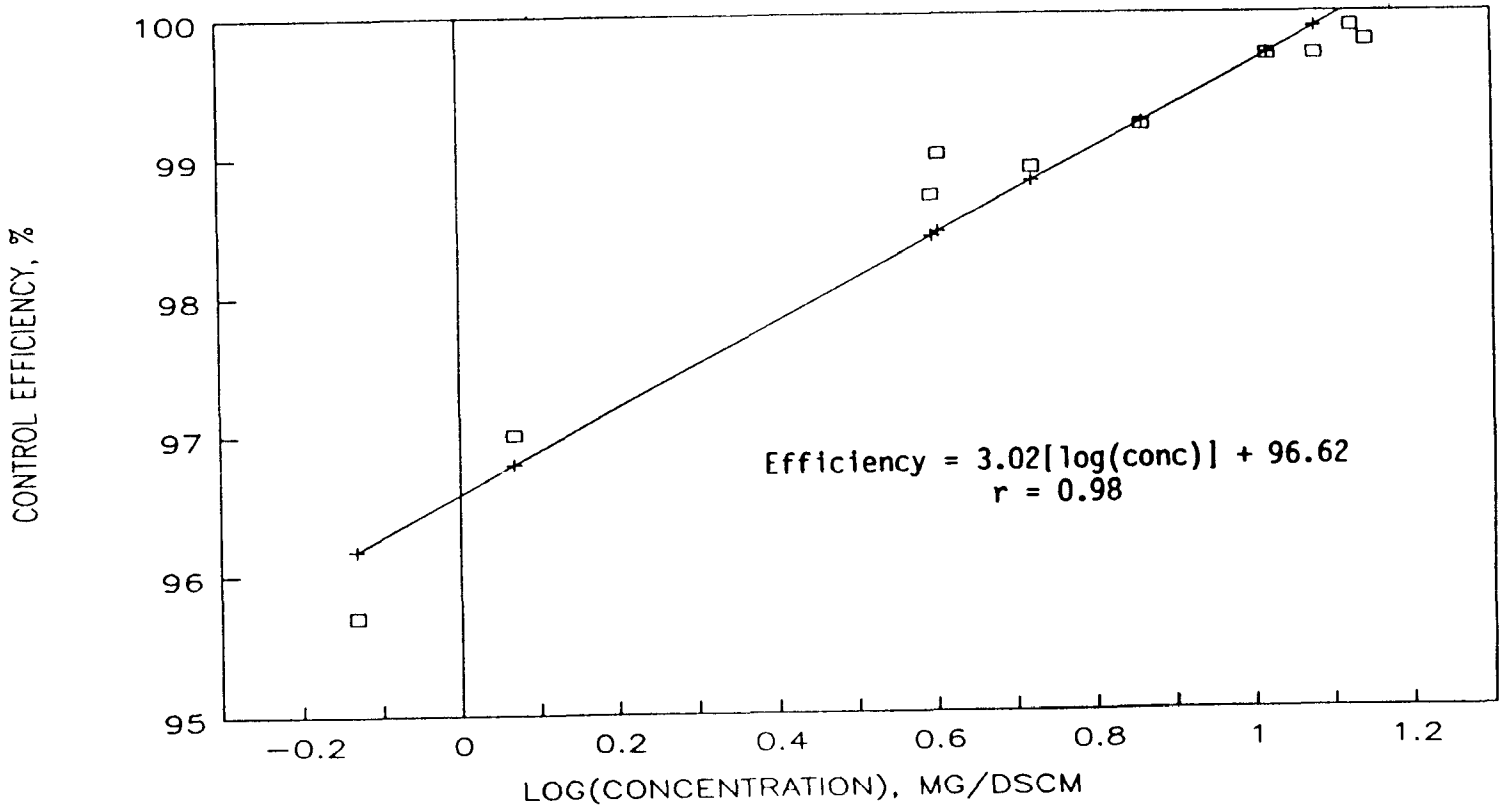


Figure 4-22. Control device efficiency versus $\log_{10}$ (concentration) per test run for two mesh-pad mist eliminator test series (Precision Machine and Hydraulic, Inc., and Hard Chromium Specialists, Inc.).

In comparing the bar graphs in Figures 4-18 and 4-19, several observations can be made about the performance levels of the control devices. The most important observation is that the outlet concentration levels for packed-bed scrubbers and mesh-pad mist eliminators are much lower than those for chevron-blade mist eliminators. However, there is some overlap of the outlet mass emission rates between the two data graphs. This overlap is a result of the variance in ventilation rates among the facilities tested. There is also a significant overlap of the process emission rate values (mg/Ah) presented in the graphs because ampere-hour values are a reflection of inlet loadings, which do not have a significant effect on the outlet concentrations. For this reason, outlet process emission rate values cannot be used to evaluate control device performance.

4.4 REFERENCES FOR CHAPTER 4

1. American National Standard Practices for Ventilation and Operation of Open-Surface Tanks. ANSI Z9.1-1977. New York, American National Standards Institute, Inc. 1977. pp. 13-14.

2. Industrial Ventilation: A Manual of Recommended Practice. American Conference of Governmental Industrial Hygienists. 19th edition. 1986. pp. 5-68 to 5-70.

3. Duall Industries, Owosso, Michigan. Technical Bulletin No. 111-9. Typical Exhaust Hood Applications, Type "BD" Exhaust Hood. March 3, 1980.

4. Duall Industries, Owosso, Michigan. Technical Bulletin No. 111-11. Typical Exhaust Hood Applications, Type "B2L" Exhaust Hood. October 13, 1975.

5. Reference 2, p. 4-21.

6. Memo from Strait, R., MRI, to Vervaert, A., EPA/ISB. March 6, 1986. Trip report for Duall Industries, Inc., Owosso, Michigan. p. 2.

7. Chromium Electroplaters Test Report: Precision Machine and Hydraulics, Inc., Worthington, West Virginia. Peer Consultants, Inc., Dayton, Ohio. Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-14. September 1988. p. 6.

8. Fair, J. Liquid-Gas Systems. In: Perry's Chemical Engineers' Handbook. 6th edition. Perry, R., and D. Green, eds. New York, McGraw-Hill Book Company. 1984. pp. 18-78.

9. York, O. Performance of the Wire Mesh Demister. Chemical Engineering Progress. 59(6):45-50. June 1963.

10. Schifftner, K. C., and H. E. Hesketh. Wet Scrubbers: A Practical Handbook. Chelsea, Michigan, Lewis Publishers, Inc. 1986. p. 56.

11. Calvert, S., S. Yung, and J. Leung. Entrainment Separators for Scrubbers: Final Report. U. S. Environmental Protection Agency, Office of Research and Development, Washington, D.C. August 1975. p. 65.

12. Telecon. Barker, R., MRI, with Zitko, L., ChromeTech, Inc. February 21, 1989. Information about mesh-pad mist eliminators.

13. Telecon. Kowalski, A., MRI, with Gillette, B., KOCH Engineering Company, Inc. December 17, 1986. Information about mist eliminators used to control chromic acid mist.

14. Reference 11, p. 71.

15. Meet Your Pollution Control Requirements With the Leader in PVC Fabrications. Product Information Brochure. Duall Industries, Inc., Owosso, Michigan. April 1979. p. 6.

16. KCH Fume Scrubbers: Average Removal Efficiencies. Product Information Sheet. KCH Services, Inc., Forest City, North Carolina. 1982.

17. Scrubbers. Product Information Brochure. KCH Services, Inc., Forest City, North Carolina. 1982. pp. 2-3.

18. Bethea, R. Air Pollution Control Technology. New York, Van Nostrand Reinhold Company. 1978. p. 259.

19. Tower Packing and Internals Including Mist Eliminators. Glitsch, Inc., Dallas, Texas. Bulletin No. 217, 3rd ed., 1975, pp. 7-8.

20. The Tri-Mer Fan/Separator Product Information Brochure. Tri-Mer Corp., Owosso, Michigan. Undated. p. 1.

21. Memo from Strait, R., MRI, to Vervaert, A., EPA/ISB. March 14, 1986. Trip report for Tri-Mer® Corp., Owosso, Michigan. pp. 2-4.

22. Hesketh, H. E. Air Pollution Control. Ann Arbor, Michigan, Ann Arbor Science Publishers, Inc. 1981. p. 250.

23. Niehaus Fume Separators. Product Information Brochure. Niehaus Brothers, Inc., Indianapolis, Indiana. pp. 2-4.

24. Telecon. Barker, R., MRI, with Brown, G., Niehaus Brothers, Inc. October 1, 1986. Operating parameters for fume separator scrubbers.

25. Reference 10, p. 9.

26. Fluorine Surfactant FT 248 as a Chrome Bath Wetting Agent (Chrome Mist Suppressant). Product Information Brochure. Mobay Chemical Corp., Inorganic Chemicals Division, Pittsburgh, Pennsylvania. pp. 3, 4.

27. Memo from Strait, R., MRI, to Vervaert, A., EPA/ISB. March 6, 1986. Trip report for OMI™ International Corp., Warren, Michigan. Attachment: Product Information Sheets for Zero-Mist™, Zero-Mist™ HT, and Zero-Mist™ HT-2.

28. Telecon. Cassidy, M., MRI, with Varuolo, A., MacDermid, Inc. February 15, 1989. Information on use of fume suppressants at hard chromium plating operations.

29. Telecon. Cassidy, M., MRI, with Zaki, N., Frederick Gumm Chemical Company, Inc. February 21, 1989. Information on use of fume suppressants at hard chromium plating operations.

30. Technical Data Sheets for Fumetrols 205, 205-T, 201, 208 and 210. M&T Chemicals, Inc. Rahway, New Jersey.

31. Telecon. Cassidy, M., MRI, with Harrison, L., M&T Chemicals, Inc. February 22, 1989. Information on use of fume suppressants at hard chromium plating operations.

32. Telecon. Cassidy, M., MRI, with Plyer, G., Frederick Gumm Chemical Company, Inc. February 24, 1989. Information on use of fume suppressants at hard chromium plating operations.

33. Telecon. Cassidy, M., MRI, with Sharples, T., OMI International. February 15, 1989. Information on use of fume suppressants at hard chromium plating operations.

34. Hama, G., W. Fredrick, D. Millage, and H. Brown. Absolute Control of Chromic Acid Mist: Investigation of a New Surface-Active Agent. Reprint from American Industrial Hygiene Association Quarterly. 1954. p. 4.

35. Chromium Electroplaters Test Report: Greensboro Industrial Platers, Greensboro, North Carolina. Entropy Environmentalists, Inc., Research Triangle Park, North Carolina. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-1. March 1986. pp. 2-1 to 2-4.

36. Reference 35, pp. 2-4 to 2-8.

37. Reference 35, p. 3-6.

38. Chromium Electroplaters Test Report: Consolidated Engravers Corporation, Charlotte, North Carolina. Peer Consultants, Inc., Rockville, Maryland. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 87-CEP-9. May 1987. p. 4.

39. Reference 38, p. 16.

40. Chromium Electroplaters Test Report: Able Machine Company. Taylors, South Carolina. PEI Associates, Inc., Cincinnati, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-3. June 1986. p. 5-1.

41. Reference 40, p. 5-3.

42. Reference 40, p. 2-6.

43. Chromium Electroplaters Test Report: Roll Technology Corporation, Greenville, South Carolina. Peer Consultants, Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-13. August 1988. pp. 2-1 through 2-2.

44. Reference 43, p. 2-2.

45. Reference 43, pp. 3-5 through 3-12.

46. Reference 7, p. 3.

47. Reference 7, p. 5.

48. Reference 7, pp. 14 and 16.

49. Chromium Electroplaters Test Report: Hard Chrome Specialists, York, Pennsylvania. Peer Consultants, Inc., Dayton, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina . EMB Report 89-CEP-15. February 1989. p. 4.

50. Reference 49, p. 6.

51. Reference 49, pp. 18 and 20.

52. Chromium Electroplaters Test Report: Piedmont Industrial Plating Company, Statesville, North Carolina. Entropy Environmentalists, Inc., Research Triangle Park, North Carolina. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-04. August 1986. p. 2-1.

53. Reference 52, p. 2-2.

54. Reference 52, pp. 2-4 to 2-6.

55. Reference 52, p. 3-6.

56. Chromium Electroplaters Test Report: Steel Heddle, Inc., Greenville, South Carolina. PEI Associates, Inc., Cincinnati, Ohio. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 86-CEP-2. June 1986. pp. 5-1, 5-3, and 5-6.

57. Reference 56, pp. 5-1 and 5-4.

58. Reference 56, p. 2-6.

59. Chromium Electroplaters Test Report: Fusion, Inc., Houston, Texas. Peer Consultants, Inc., Dayton, Ohio. Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 89-CEP-16. May 1989. p. 4.

60. Reference 59, pp. 5-8.

61. Reference 59, p. 10.

62. Reference 59, pp. 20-21.

63. Chromium Electroplaters Test Report: Automatic Die Casting Specialties, St. Clair Shores, Michigan. Peer Consultants, Inc., Dayton, Ohio. Prepared for the U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. EMB Report 88-CEP-11. April 1988. p. 2-1.

64. Reference 63, pp. 2-1 through 2-2.

65. Reference 63, pp. 3-5 through 3-10.

5. MODEL PLANTS AND CONTROL OPTIONS

This chapter describes the model plants and the control options for reducing chromium emissions from affected sources. The model plants portray different combinations of plating tanks for each type of operation and are representative of both existing operations and those that are expected to be built in the future. The model plants are used to evaluate the environmental, cost, economic, and energy impacts of control options on the affected sources.

5.1 MODEL PLANTS

Eight model plants were developed to characterize chromium electroplating and chromic acid anodizing operations that are capable of plating or anodizing a wide variety of items. The model plant parameters were developed based on information obtained from responses to an industry survey, site visits, and control device vendors. Industry survey responses were obtained from 120 operations that, combined, operate 215 hard chromium plating tanks, 102 decorative chromium plating tanks, and 31 chromic acid anodizing tanks. Site visit reports for 17 hard chromium plating operations, 11 decorative chromium plating operations, and 3 chromic acid anodizing operations were also considered in developing the model plants. The model plants developed include three each (small, medium, and large) for hard and decorative plating operations and two (small and large) for anodizing operations. Production rates, operating times, process equipment, and operating conditions for each model plant are presented in Tables 5-1 through 5-3.

5.1.1 Model Plant Sizes

Model plant sizes and process parameters for each model plant were determined from the data collected through the industry survey and site visits. Process information obtained from the industry survey and site visits were compiled into three data bases that were operation-specific--hard chromium plating, decorative chromium plating, and chromic acid anodizing. Frequency distributions of total tank capacity per plant were developed to assist in selecting representative model plant sizes for hard and decorative chromium plating operations. These frequency distributions are shown in Figures 5-1 and 5-2. Three model plant sizes, representative of small, medium, and large operations, were selected for both the hard and decorative chromium plating categories. The total tank capacity cutoff values selected for hard chromium electroplating operations are less than 15,100 L (4,000 gal) for a small plant; between 15,100 and 37,850 L (4,000 and 10,000 gal) for a medium plant; and greater than 37,850 L (10,000 gal) for a large plant. The total tank capacity cutoff values for decorative chromium electroplating plants are less than 7,570 L (2,000 gal) for a small plant, between 7,570 and 30,280 L (2,000 and 8,000 gal) for a medium plant, and greater than 30,280 L (8,000 gal) for a large plant.

A frequency distribution was not used to select model plant sizes for chromic acid anodizing operations. The available data indicated that chromic acid anodizers could be placed into one of two distinct size ranges, small and large. Information on total tank volumes indicated that these volumes range from 378 to 7,570 L (100 to 2,000 gal) at small operations, while tank volumes at large operations exceed 27,250 L (7,200 gal). Consequently, two model plants (small and large) were developed to represent chromic acid anodizing operations.

Cutoffs for total tank capacity were used to divide the operation-specific data bases into size classifications. Information on total tank capacity within each size classification was used to determine typical values for each size

model plant. In addition, available information on the dimensions and volumes of individual tanks used for plating and anodizing were used to develop six model tanks typical of those used in the industry. These model tanks, along with the total tank capacity values for the model plants, were used to determine the number and size of the model tanks used within each model plant.

5.1.2 Model Plant Production and Process Parameters

5.1.2.1 Hard and Decorative Chromium Plating. Several different measures were considered for defining model plant production rates. Surface area plated per year provides a common basis for comparing production rates because it accounts for variations in both the number and types of parts plated. However, respondents to the industry survey indicated that surface area plated was not generally monitored. Another measure considered was chromic acid consumption. However, because of the diverse chromic acid recovery practices, this was also rejected. An alternative measure of production rate is energy consumption, or amount of current applied over time (i.e., Ah/yr). This is generally derivable for hard and decorative chromium plating operations based on available information. Also, energy consumption is directly related to the amount of chromium deposited and plating thickness. Therefore, Ah/yr was chosen as the basis for establishing production rates for the model hard and decorative chromium plating plants.

The amount of surface area capable of being plated during each plating cycle is limited by the size of the plating tank. Information gathered during the emissions test program was used to establish typical surface area-to-plating tank volume ratios (the amount of surface area plated per volume of plating solution) for each type of operation. Different surface area-to-volume ratios were developed for each type of operation because of the variation in the types of parts plated. These ratios were then used to determine the amount of surface area plated in a given plating cycle for each type of model operation. For example, the average surface area-to-volume ratio for hard

chromium plating tanks tested during the emissions test program was 0.06 ft^2/ft^3. For a model hard chromium plating tank with a capacity of 231 ft^3, the amount of surface area plated during one plating cycle is:

$$231\ ft^3 \times 0.06\ ft^2/ft^3 = 14\ ft^2$$

The typical surface area plated during one plating cycle for the model decorative chromium plating tanks was determined using an average surface area-to-volume ratio of 0.09 ft^2/ft^3.

Surface area plating capacities for each model tank and type of operation, in conjunction with assumed values for the plating thickness and plating time, were combined with the electrochemical equivalent for chromium to calculate current settings for each model tank. The electrochemical equivalent for chromium at a cathode efficiency of 10 percent is 518 Ah. This means that 518 Ah are required to plate a part with a surface area of 1 ft^2 to an overall plating thickness of 1 mil.

The current settings for the model hard chromium plating tanks were calculated assuming a plating thickness of 1 mil and a plating time of 2 hr. For example, for the model tank mentioned above, the current setting is calculated as follows:

$$[518\ Ah/mil \cdot ft^2][1\ mil][14\ ft^2][1/(2\ hr)] = 3{,}625\ A$$

The current settings for the model decorative chromium plating tanks were calculated assuming a plating thickness of 0.012 mil and a plating time of 0.05 hr.

The values assigned for plating times and plating thicknesses are typical values, based on information obtained from plant visits and survey responses. The value used for cathode efficiency (10 percent) is based on plating bath efficiencies provided by vendors of hexavalent chromium plating bath solutions.

The production rate, in terms of Ah/yr, for each model tank was calculated by multiplying the current settings for the model

tank by the amount of time the model tank operated within a year. The model plant production rate, in terms of Ah/yr, was calculated by summing the individual Ah/yr values for each model tank used within a model plant. For example, the model small hard chromium plating plant has one model tank with a capacity of 231 ft^3. The tank is in operation 70 percent of the time that the plant operates (percent time electrodes are energized), and the plant operates 2,000 hr/yr. As calculated above, this model tank would have a current setting of 3,625 A. Therefore, the production rate for the model small hard chromium plating plant can be calculated as follows:

$$Ah/yr = (3,625\ A)(2,000\ hr/yr)(0.70) = 5.0 \times 10^6\ Ah/yr$$

Similar calculations were performed for the other model hard and decorative chromium plating plants. These calculations are presented in Appendix E along with the derivation of the electrochemical equivalent at 10 percent cathode efficiency.

The values for the percent time electrodes are energized and for the operating time of the plants were assigned based on averages of survey responses pertinent to each plant size.

The values assigned for the operating voltage, current density, and other plating bath parameters (chromic acid concentration, catalyst concentration, and temperature) are representative of typical values encountered in the industry. All of the above parameters were defined for the model plants because each parameter has an impact on the generation of chromic acid mist. (For further discussions of the relationship between production and process parameters and emissions, see Chapter 3, Section 3.3.1.4.)

5.1.2.2 Chromic Acid Anodizing. Unlike electroplating, chromic acid anodizing is a voltage-controlled process. Because of the current fluctuations during the anodizing cycle, the average current supplied to the tank is difficult to determine, which, in turn, makes it difficult to use energy input as an indicator of the production rate. As in the case of the hard and

decorative plating survey respondents, chromic acid anodizing respondents indicated that the surface area of the parts was difficult to quantify. Therefore, this parameter could not be used as a measure of production rate (and thus, emissions). For this reason, tank surface area was selected as the best measure of emissions because it limits the amount of workload processed, and the amount of workload processed is related to emission-generating mechanisms.

Operating times, chromic acid concentrations, temperatures of the plating solutions, and tank operating voltages for the model plants were assigned based on averages of survey responses.

5.1.3 Capture System, Control Device, and Stack Parameters

Each model tank is equipped with a ventilation system to ensure adequate capture of chromic acid mist. Ventilation rates for the model tanks were established based on guidelines developed by the American Conference of Governmental Industrial Hygienists (ACGIH) and the American National Standards Institute (ANSI).[1,2] The type of hood specified for each model tank was determined based on the ANSI recommendations that lateral hoods be used on tanks that are less than 107 cm (42 in.), and push-pull hoods be used on tanks greater than 107 cm (42 in.) wide.[3] Minimum ventilation rates for each model tank were determined based on the minimum control velocity recommended by ANSI for capture of chromic acid mist (46 m/min [150 ft/min), the assumption that all model tanks are free-standing (not against a wall) and not baffled, and the width-to-length ratio of each model tank.[4] Table 5-4 presents the minimum ventilation rates for hoods used to capture chromic acid mist.

All model tanks equipped with lateral hoods were ventilated at a rate of 76 $m^3/min/m^2$ (250 $ft^3/min/ft^2$) of tank surface area.[5] As recommended by ANSI, tanks equipped with push-pull hoods were ventilated at 50 percent of the value recommended for lateral hoods with a push air volume less than 1.52 $m^3/min/m^2$ (5.0 $ft^3/min/ft^2$) of tank surface area.[6] Based on the above criteria, specifications for ventilation hoods and takeoffs for

the individual model tanks were assigned and are presented in Table 5-5.

Figures 5-3 through 5-10 present schematics and ductwork specifications for the various combinations of tanks used to configure the model plants. Mesh-pad mist eliminators are designed to handle a maximum airflow rate of 340 m^3/min (12,000 ft^3/min), which is considerably lower than the maximum design airflow rates for packed-bed scrubbers and chevron-blade mist eliminators. Therefore, two configurations of tank/control device ventilation arrangements were required to accommodate these differences. Table 5-6 shows the ventilation specifications for the control device configurations used to treat emissions from the model tanks. In some cases, total ventilation rates were rounded to the values representing the gas flow rates for which factory-assembled units are available. Parameters for the control devices and stacks are based on technical data supplied by control device vendors for each of the applicable control systems and are summarized for each model plant in Tables 5-7 through 5-9. The control device inlet gas flow rates presented in these tables are based on the total ventilation rates for the combinations of model tanks described in Table 5-6.

5.2 BASELINE CONDITIONS

Because few States have air pollution regulations specific to chromium, the baseline conditions in this study are not based on existing State regulations. Rather, the baseline conditions are based on information about the level of control currently achieved at existing operations and an estimate of the number of existing operations nationwide.

Nearly all of the operations use some type of capture system to comply with Occupational Safety and Health Administration (OSHA) regulations that limit concentrations of chromic acid and chromates inside the plant to a ceiling concentration of 0.1 mg/m^3 (4 x 10^{-5} gr/ft^3) of air.[7] Therefore, emission capture systems are considered part of the baseline equipment

configuration for all operations, including those with no control devices.

5.2.1 Baseline Levels of Control

Baseline control levels were determined based on the distribution of control techniques currently being applied in the electroplating industry and the performance test data for these control techniques presented in Chapter 4.

5.2.1.1 Baseline Control Techniques. Information on the types of control techniques currently applied in the electroplating industry were obtained from responses to an industry survey conducted by EPA in 1987. The survey provided information on control techniques used at 44 hard chromium plating operations, 63 decorative chromium plating operations, and 25 chromic acid anodizing operations. Table 5-10 presents the resultant baseline conditions. Listed under each class of operation is the type of control technique applied and the percentage of total operations applying the given control technique. For operations that use two different control devices in series, only the more efficient control device was considered to be in use.

In the case of hard chromium platers, 30 percent are uncontrolled, 30 percent are controlled by chevron-blade mist eliminators, and 40 percent are controlled by packed-bed scrubbers. Although 3 of the 44 hard chromium plating shops contacted use a fume suppressant, the use of fume suppressants is considered to be atypical for purposes of defining baseline conditions for hard chromium plating operations. In the case of decorative platers, 15 percent are uncontrolled, 40 percent are controlled with fume suppressants, 40 percent are controlled with a combination of fume suppressants and packed-bed scrubbers, and 5 percent are controlled by packed-bed scrubbers. Finally, in the case of chromic acid anodizers, 40 percent are uncontrolled, 10 percent are controlled by chevron-blade mist eliminators, 30 percent are controlled by fume suppressants, and 20 percent are controlled by packed-bed scrubbers.

5.2.1.2 Performance Levels at Baseline Conditions. As highlighted in Chapter 4, each unit tested within a class of control devices achieved essentially the same outlet emission concentration. Consequently, the percent reduction achieved by an individual control device varies depending on the concentration at the inlet to the control device; units with high inlet loadings have larger percent reductions than units with low inlet loadings. Because percent reductions achieved vary depending on the loading at the inlet of the control unit, percent reductions assigned at baseline conditions were developed considering two factors: (1) expected performance levels at typical inlet conditions for each type of operation, and (2) recognition that control devices currently in use in the electroplating industry are often poorly operated and maintained.

Operation and maintenance problems actually observed during site visits to numerous facilities included plugged spray nozzles, plugged and warped packed beds and mesh pads, and beds in which the packing material had settled to the point where channeling occurred. At facilities where fume suppressants were used, makeup additions were frequently not added to the plating tank in accordance with vendor recommendations. Foam blankets were allowed to deplete until relatively large holes were evident in the blanket. Because of concerns that these types of problems may be widespread among existing facilities, control levels at baseline conditions were adjusted, as discussed below, to account for deficiencies in operation and maintenance.

Inlet loadings at the hard chromium plating operations tested averaged 4.0 mg/dscm (1.7×10^{-3} gr/dscf). At this inlet loading, the regression equation developed in Chapter 4 predicts an overall performance efficiency of 99 percent for packed-bed scrubbers and mesh-pad mist eliminators. However, while the performance data were gathered at operations where the control devices were well maintained, actual operating practices in the industry are generally less than ideal. Therefore, the average performance level estimated to exist at baseline conditions was adjusted downward a few percentage points to 97 percent to

reflect an overall less-than-ideal performance level. The performance level assigned to chevron-blade mist eliminators (90 percent) was based on the percent efficiency (95 percent) calculated by using the average inlet and outlet concentrations achieved by the three chevron-blade mist eliminators tested and adjusting this efficiency downward to account for the less-than-ideal operation and maintenance practices across the industry.

Inlet loadings at the two decorative chromium plating operations tested averaged 1.2 mg/dscm (5.2×10^{-4} gr/dscf). At this inlet loading, the regression equation presented in Chapter 4 predicts a percent reduction of 97 percent for packed-bed scrubbers and mesh-pad mist eliminators. However, the percent reduction assigned to the baseline condition was lowered to 95 percent, again to account for less-than-ideal operation and maintenance practices. Percent reduction demonstrated by chemical fume suppressants during the test program exceeded 99 percent. However, as stated previously, vendor maintenance requirements are rarely met in practice. Therefore, the percent reduction assumed at baseline conditions was lowered to 97 percent.

No test data were available for chromic acid anodizing operations. The inlet loadings for anodizing operations are more similar to those observed in decorative chromium plating than those in hard chromium plating operations. Thus, the performance levels assigned to the control techniques applied to anodizing operations were identical to those established for decorative chromium plating operations. The only exception is the control level assigned to chevron-blade mist eliminators, which was assumed to be the same for anodizing operations as for hard chromium plating operations.

5.2.2 Number of Operations Nationwide

Table 5-11 presents estimates by size of the numbers of hard and decorative chromium plating and chromic acid anodizing operations nationwide. The total number of each type of operation was obtained from information published in the 1982 Census of Manufacturers--Selected Metalworking Operations and

Finishers' Management Media/Market Bulletin.[8,9] Differentiation by size (small, medium, and large) is based on the size distribution obtained from the EPA industry survey of 44 hard and 63 decorative plating operations. The numbers of small and large operations for chromic acid anodizing are based on the assumptions that all captive shops that manufacture aerospace parts are large and that all job shops and captive shops that manufacture electronic parts are small. As shown in Table 5-11, 70 percent of the total number of hard chromium plating operations are small, 20 percent are medium, and 10 percent are large; while 80 percent of the total number of decorative chromium plating operations are small, 15 percent are medium, and 5 percent are large. In the case of chromic acid anodizers, 75 percent of the total number are small and 25 percent are large.

5.3 CONTROL OPTIONS

5.3.1 General

Table 5-12 presents control options being considered for chromium plating and chromic acid anodizing operations. Each control option represents a different level of emission control. The level of control assigned to each control technique is based on the percent reduction achievable by well-maintained units at average inlet loadings for each type of operation.

For each type of operation, Option I is the "no action" or baseline option. The "no action" option reflects the level of control achieved at existing operations in the absence of further regulation.

5.3.2 Hard Chromium Plating

Control Option I (no action) for hard chromium plating operations reflects the baseline condition described in Section 5.2. The baseline condition assumes that 30 percent of all existing operations are uncontrolled, 30 percent are controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent, and 40 percent are controlled by packed-bed scrubbers that reduce uncontrolled emissions by 97 percent. Control Option II is based on the use

of chevron-blade mist eliminators that reduce uncontrolled emissions by 95 percent. Control Option III is based on the use of packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent. The percent reductions assigned to each control option are based on the control levels determined in Section 5.2.1.2 for well-maintained units.

5.3.3 Decorative Chromium Plating

Control Option I (no action) for decorative chromium plating operations is based on the assumption that approximately 15 percent of all existing operations are uncontrolled, 40 percent are controlled by fume suppressants that reduce uncontrolled emissions by 97 percent, 40 percent are controlled by a combination of fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent, and 5 percent are controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent. Control Option II is based on the use of packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent. Control Option III is based on the use of chemical fume suppressants, applied in accordance with vendor recommendations, that reduce uncontrolled emissions by 99.5 percent. The percent reduction assigned to Control Options II and III are based on the control levels determined in Section 5.2.1.2 for well-maintained units. Control Option IV, the most stringent option for decorative chromium plating operations, is based on the use of the trivalent chromium plating process instead of the hexavalent chromium plating process. The use of this process would reduce hexavalent chromium emissions by 100 percent. However, there are some application problems with the trivalent chromium process that might limit its use at some decorative chromium plating operations. For a discussion of these problems, refer to Chapter 3, Section 3.2.6.1.

5.3.4 Chromic Acid Anodizing

Control Option I (no action) for chromic acid anodizing is based on the assumption that approximately 40 percent of all existing operations are uncontrolled, 10 percent are controlled

by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent, 30 percent are controlled by fume suppressants that reduce uncontrolled emissions by 97 percent, and 20 percent are controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent. Control Option II is based on the use of packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emission by 97 percent. Control Option III, the most stringent option, is based on the use of chemical fume suppressants, applied in accordance with vendor recommendations, that reduce uncontrolled emissions by 99.5 percent. The percent reductions assigned for Control Options II and III are based on the percent reductions calculated in Section 5.2.1.2 for well-maintained decorative chromium plating operations. The percent reductions are based on decorative chromium plating data because no data were available for chromic acid anodizing operations. The expected inlet concentrations for chromic acid anodizing operations should be more similar to the inlet concentrations measured at decorative chromium plating operations than those measured at hard chromium plating operations.

5.3.5 Impact Assessment

For purposes of assessing energy and cost impacts, some assumptions were made regarding chevron-blade mist eliminator and packed-bed scrubber designs. Information provided in the industry survey was not sufficient to predict the prevalence of chevron-blade mist eliminators with a double set of blades vs. those with a single set of blades or the prevalence of double packed-bed scrubbers vs. single packed-bed scrubbers. A chevron-blade mist eliminator with a single set of blades was assumed for baseline purposes (existing level of control), and a chevron-blade mist eliminator with a double set of blades was assumed for the control options. A single packed-bed scrubber was assumed for the energy and cost impacts associated with baseline and the control options.

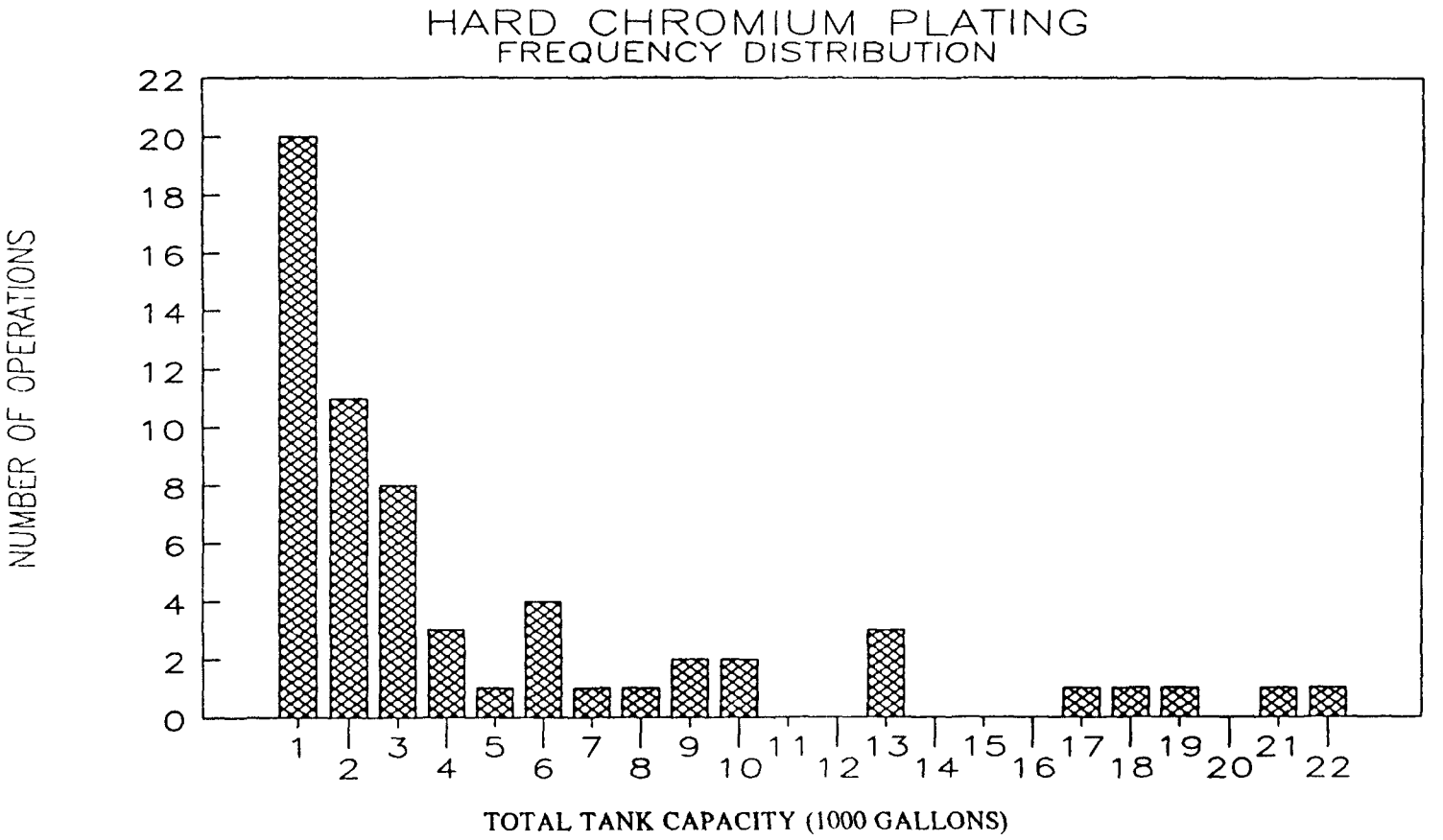


Figure 5-1. Frequency distribution of total tank capacity for hard chromium plating.

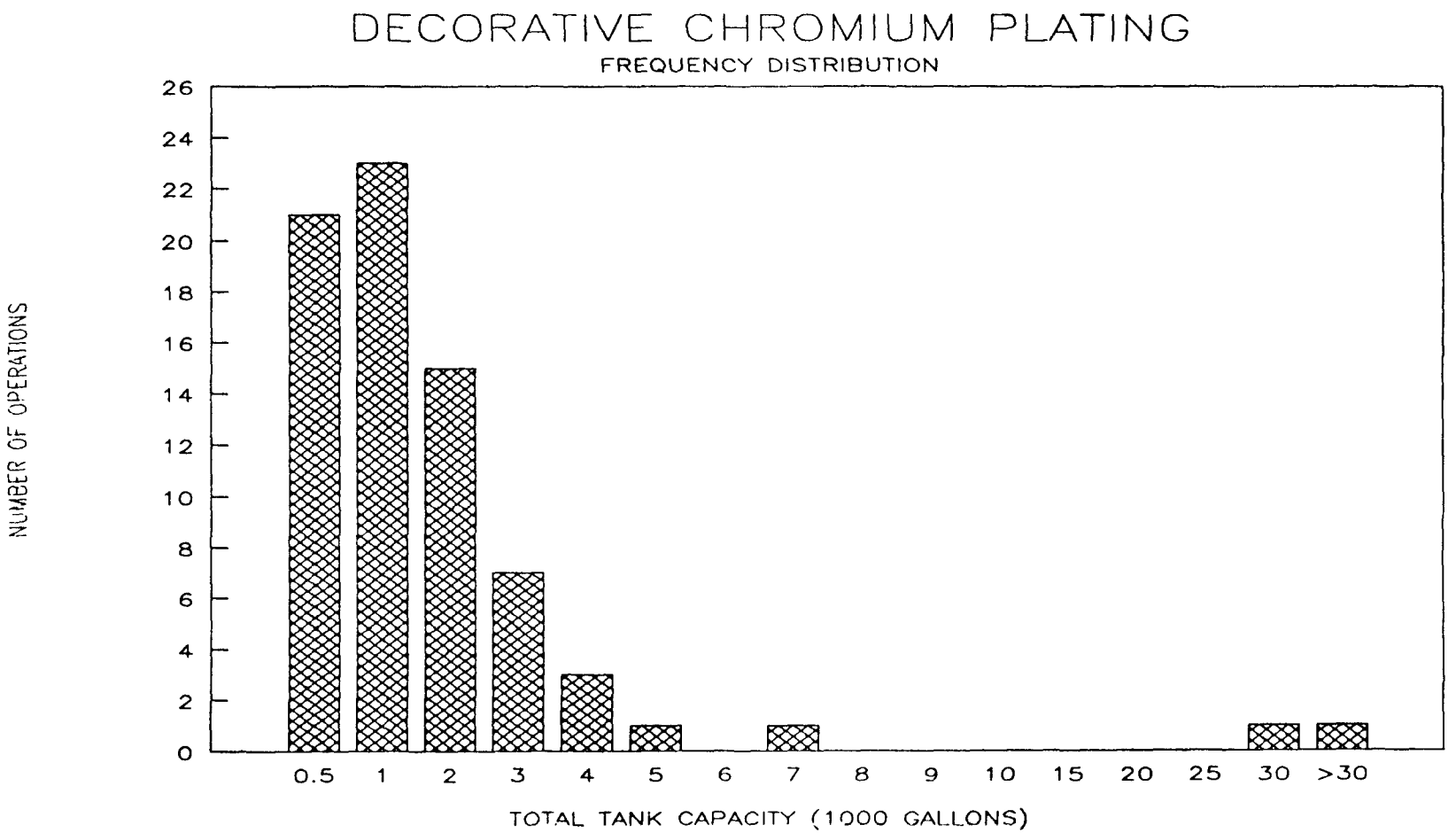
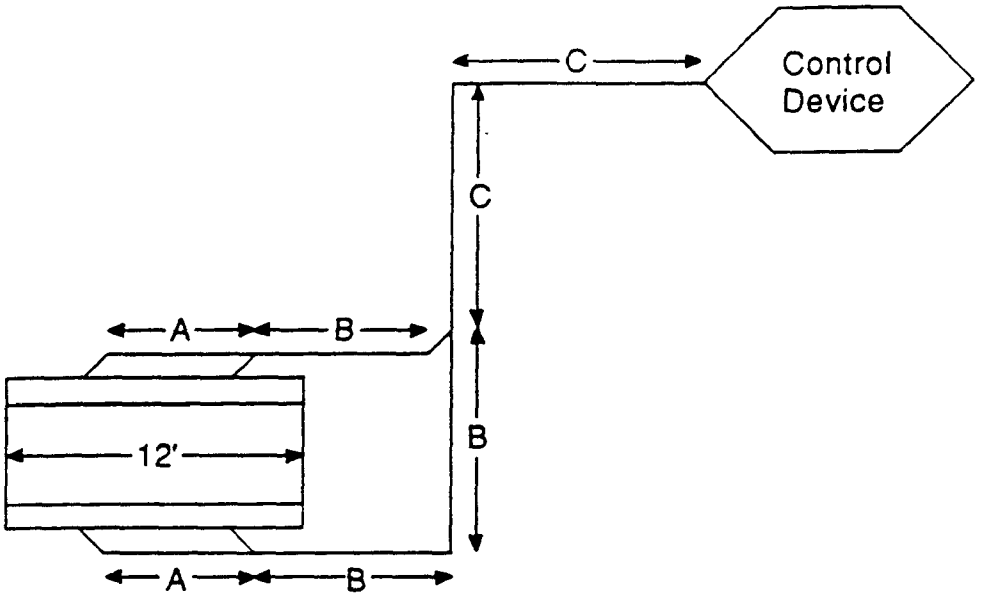
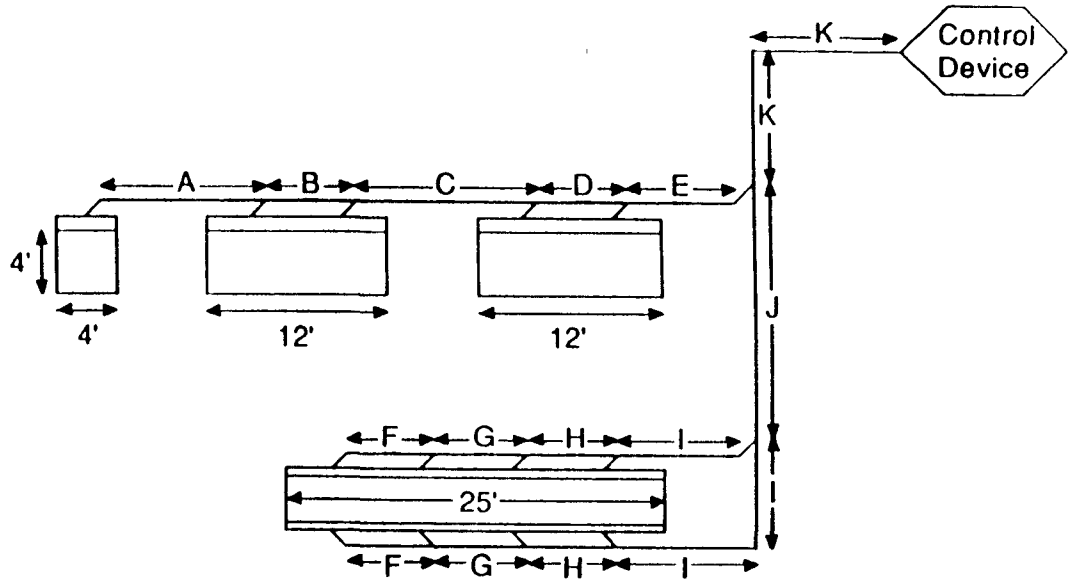


Figure 5-2. Frequency distribution of total tank capacity for decorative chromium plating.



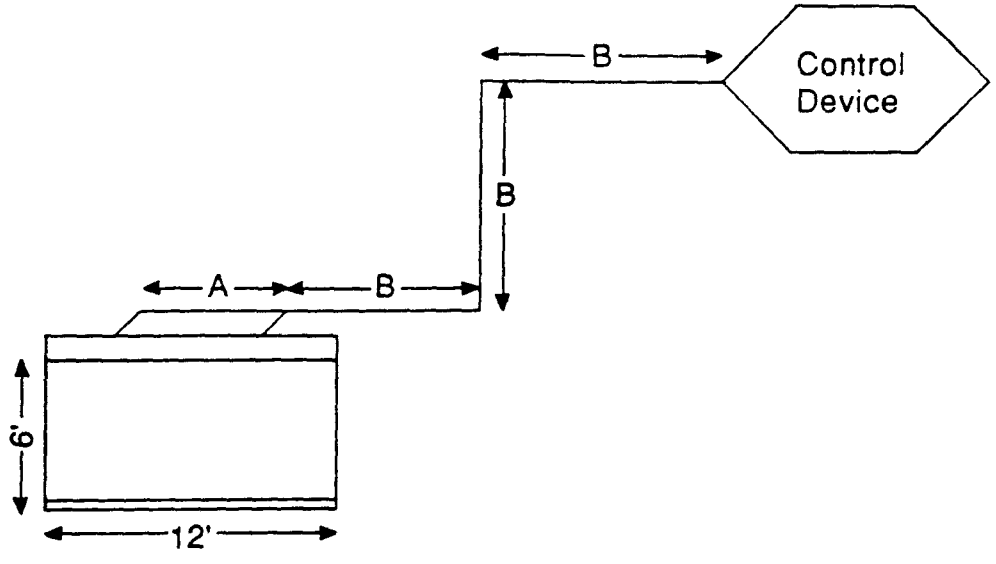
Duct Component Specification	Duct Section Location		
	A	B	C
Gas flow rate, cfm	2,625	5,250	10,500
Duct diameter, in.	12	18	24
Duct length, ft.	12	27	20
No. of 30 degree entries	2	3	0
No. of one step tapers	0	2	1
No. of 90 degree elbows	0	1	1

Figure 5-3. Schematic and ductwork specifications for the small hard, small and medium decorative chromium plating, and small anodizing model tanks.



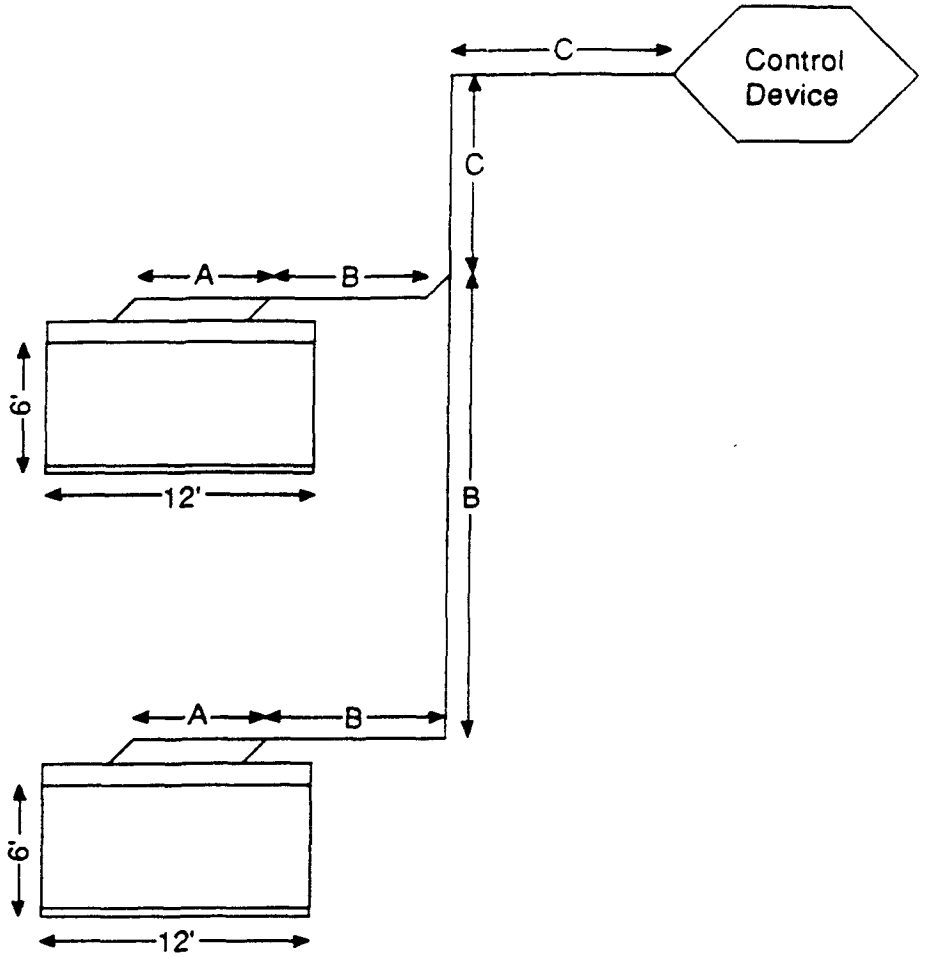
Duct Component Specification	Duct Section Location										
	A	B	C	D	E	F	G	H	I	J	K
Gas flow rate, cfm	2,000	5,000	8,000	11,000	14,000	2,344	4,688	7,032	9,376	18,752	32,752
Duct diameter, in.	10	16	20	24	28	12	16	20	22	32	42
Duct length, ft.	11	6	12	6	9	12	12	12	24	16	20
No. of 30 degree entries	1	1	1	1	2	2	2	2	3	0	0
No. of one step tapers	0	1	1	1	1	2	2	2	3	1	1
No. of 90 degree elbows	0	0	0	0	0	0	0	0	1	0	1

Figure 5-4. Schematic and ductwork specifications of the medium and large hard chromium plating model plants (Configuration 1).



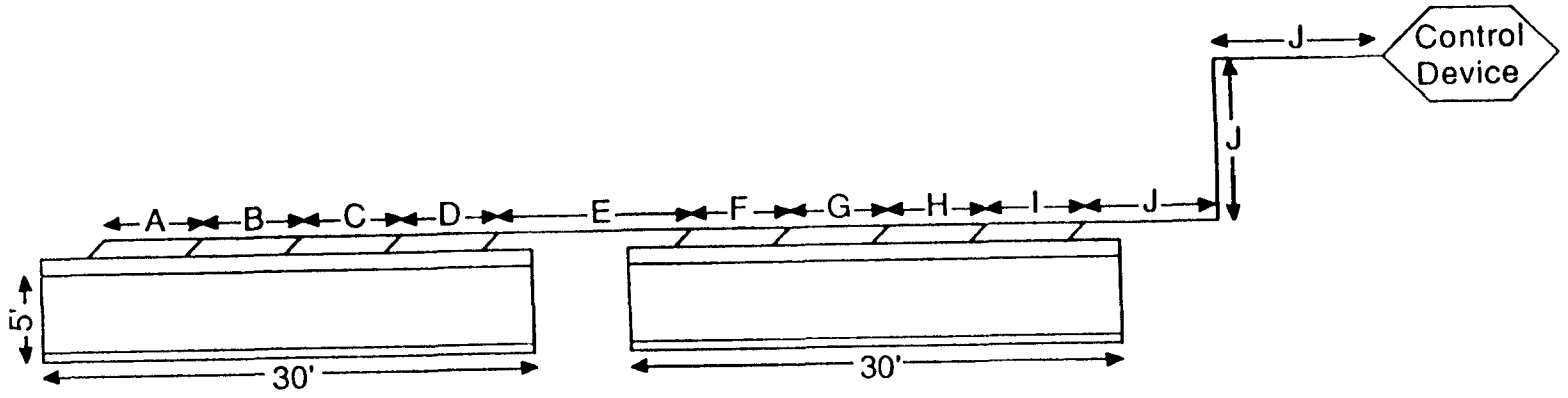
Duct Component Specification	Duct Section Location	
	A	B
Gas flow rate, cfm	4,500	9,000
Duct diameter, in.	16	22
Duct length, ft.	6	29
No. of 30 degree entries	1	1
No. of one step tapers	0	1
No. of 90 degree elbows	0	2

Figure 5-5a. Schematic and ductwork specifications for one of the 12-ft tanks used in the large decorative chromium plating model plants (Configurations 1 and 2).



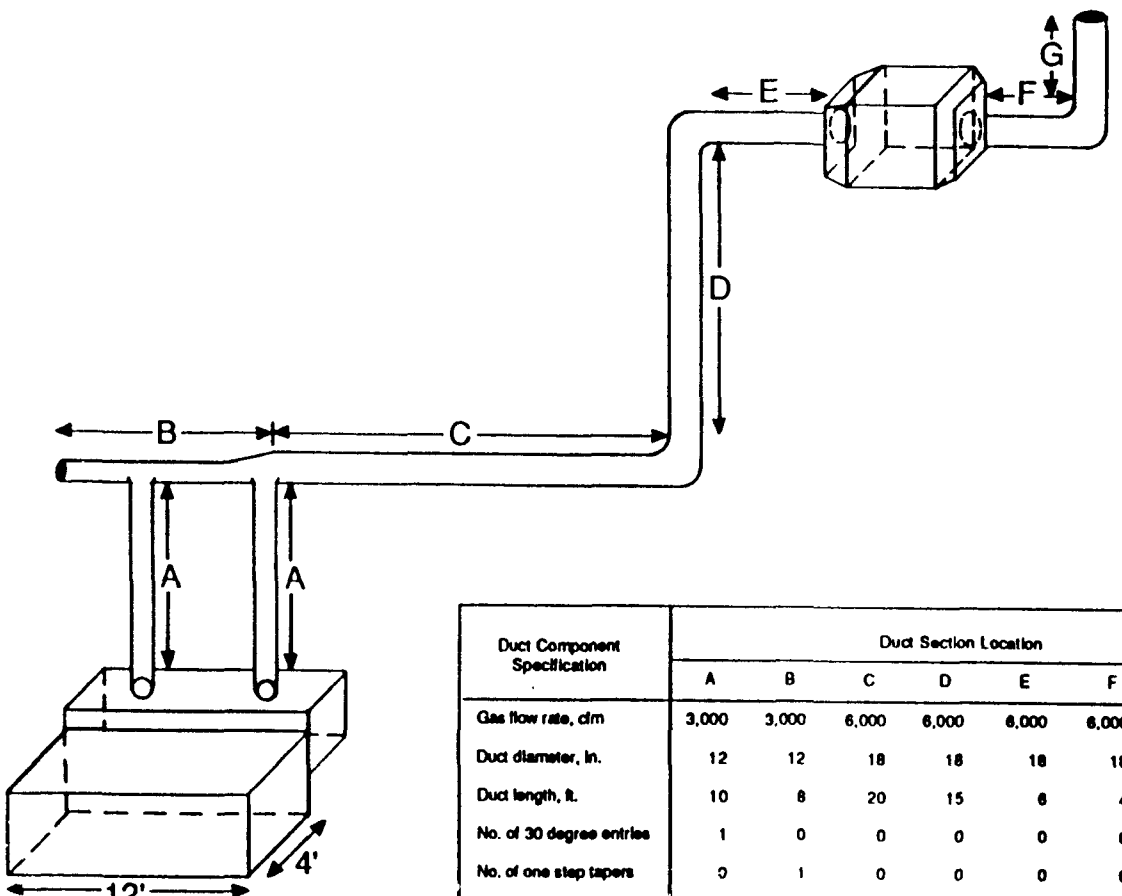
Duct Component Specification	Duct Section Location		
	A	B	C
Gas flow rate, cfm	4,500	9,000	18,000
Duct diameter, in.	16	22	32
Duct length, ft.	12	40	20
No. of 30 degree entries	2	3	0
No. of one step tapers	0	2	1
No. of 90 degree elbows	0	1	1

Figure 5-5b. Schematic and ductwork specifications of two 12-ft tanks for the large decorative chromium plating model plants (Configuration 1).



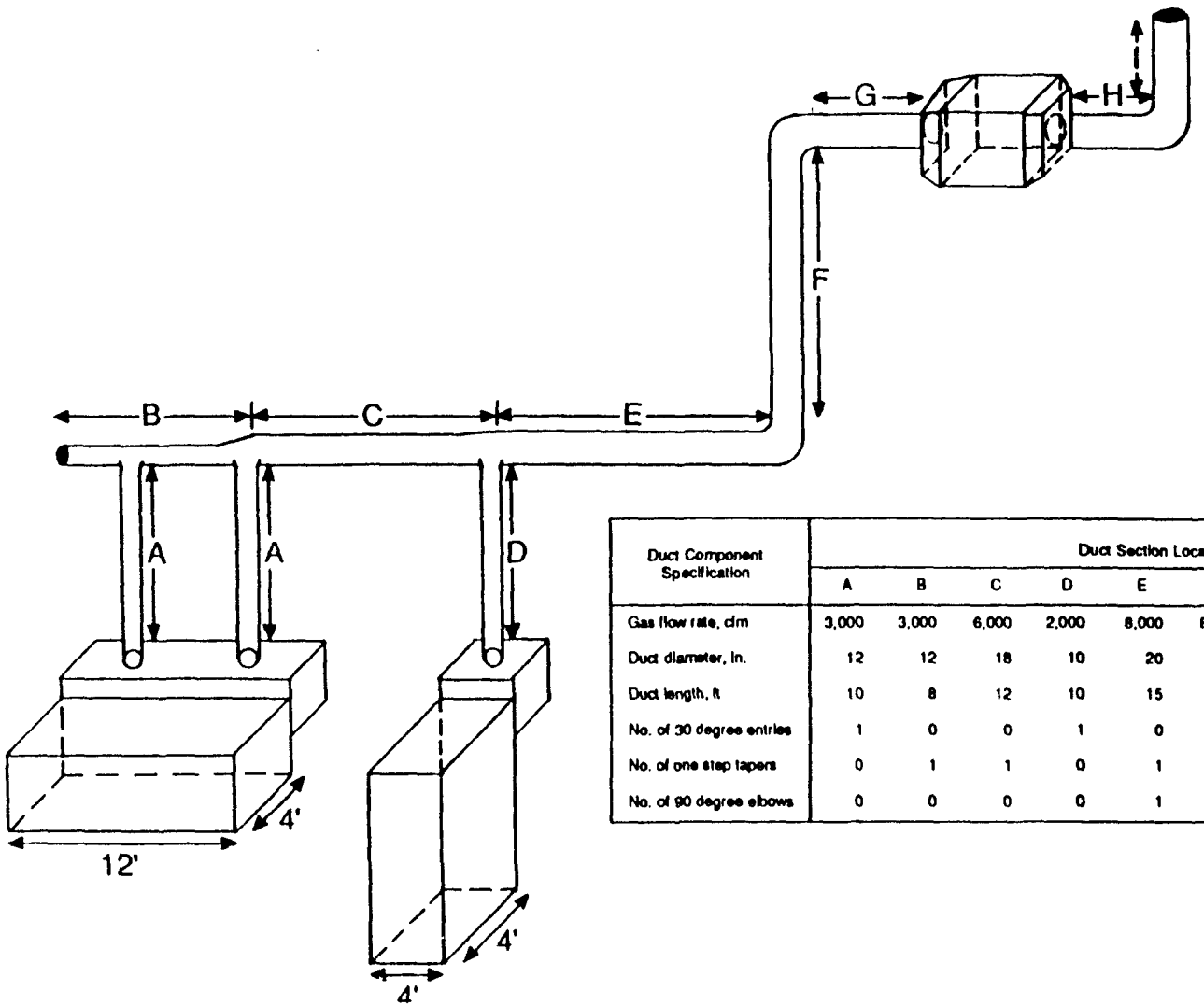
Duct Component Specification	Duct Section Location									
	A	B	C	D	E	F	G	H	I	J
Gas flow rate, cfm	3,750	7,500	11,250	15,000	18,750	22,500	26,250	30,000	33,750	37,500
Duct diameter, in.	14	20	24	28	32	34	38	40	42	44
Duct length, ft.	6	6	6	6	12	6	6	6	6	29
No. of 30 degree entries	1	1	1	1	1	1	1	1	1	1
No. of one step tapers	0	1	1	1	1	1	1	1	1	1
No. of 90 degree elbows	0	0	0	0	0	0	0	0	0	2

Figure 5-6. Schematic and ductwork specifications of the large chromic acid anodizing model plants (Configuration 1).



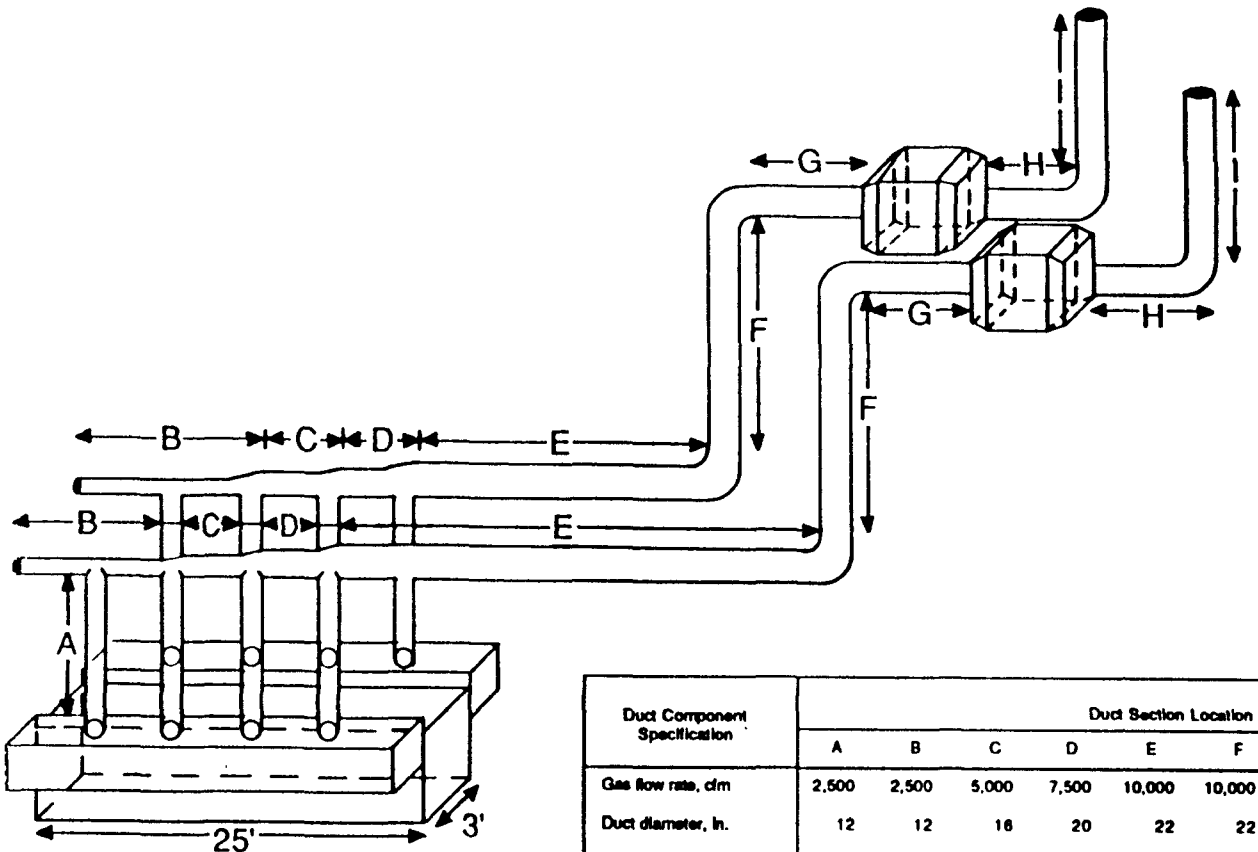
Duct Component Specification	Duct Section Location						
	A	B	C	D	E	F	G
Gas flow rate, cfm	3,000	3,000	6,000	6,000	6,000	6,000	6,000
Duct diameter, in.	12	12	18	18	18	18	18
Duct length, ft.	10	8	20	15	6	4	10
No. of 30 degree entries	1	0	0	0	0	0	0
No. of one step tapers	0	1	0	0	0	0	0
No. of 90 degree elbows	0	0	1	1	0	1	0

Figure 5-7. Schematic and ductwork specifications for one of the 12-ft model tanks used in the medium and large hard chromium plating model plants (Configuration 2).



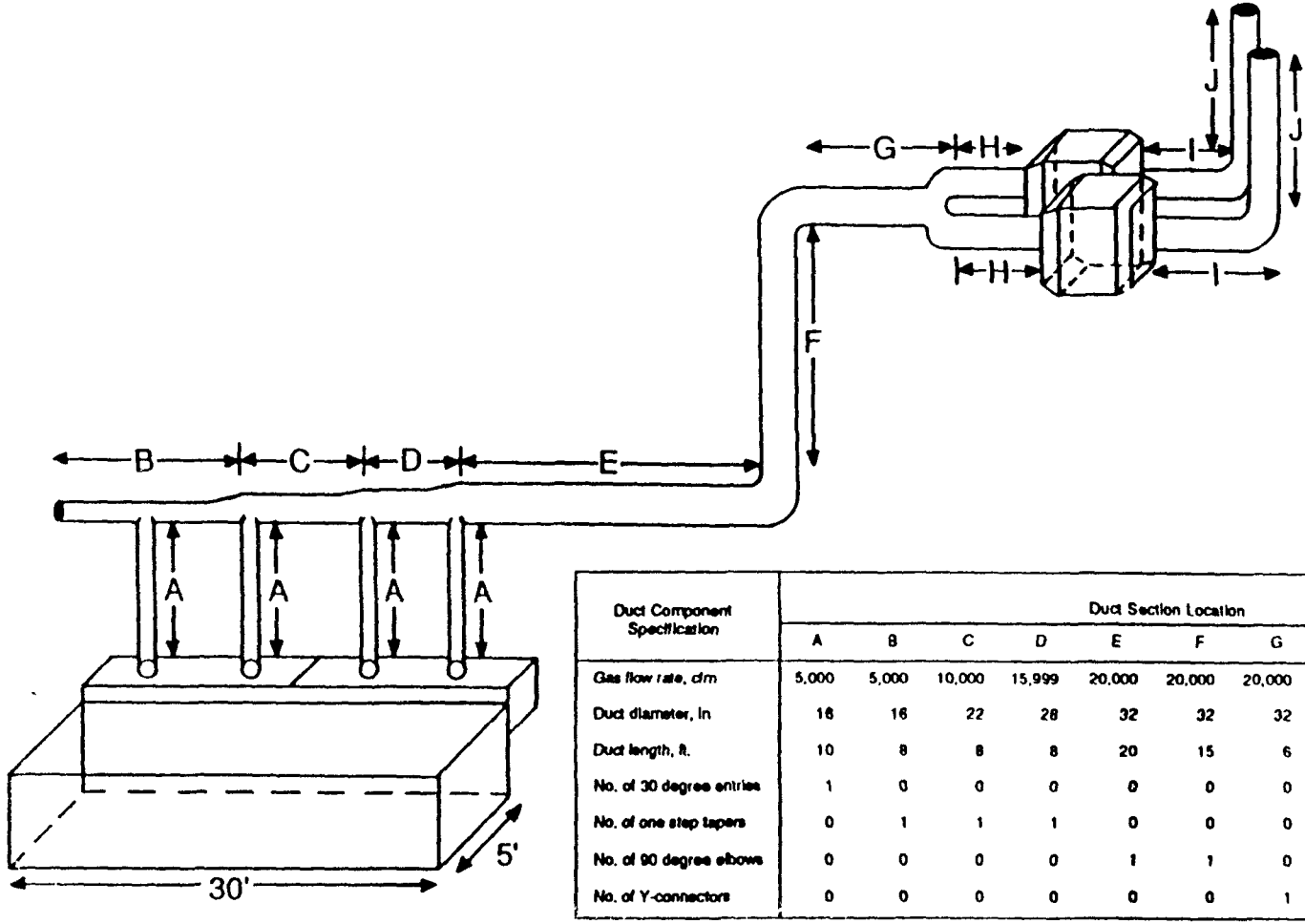
Duct Component Specification	Duct Section Location								
	A	B	C	D	E	F	G	H	I
Gas flow rate, cfm	3,000	3,000	6,000	2,000	8,000	8,000	8,000	8,000	8,000
Duct diameter, in.	12	12	18	10	20	20	20	20	20
Duct length, ft	10	8	12	10	15	15	6	4	10
No. of 30 degree entries	1	0	0	1	0	0	0	0	0
No. of one step tapers	0	1	1	0	1	0	0	0	0
No. of 90 degree elbows	0	0	0	0	1	1	0	1	0

Figure 5-8. Schematic and ductwork specifications for the 12-ft and 4-ft model tanks used in the medium and large hard chromium model plants (Configuration 2).



Duct Component Specification	Duct Section Location								
	A	B	C	D	E	F	G	H	I
Gas flow rate, cfm	2,500	2,500	5,000	7,500	10,000	10,000	10,000	10,000	10,000
Duct diameter, in.	12	12	16	20	22	22	22	22	22
Duct length, ft.	10	8	5	5	20	15	6	4	10
No. of 30 degree entries	1	0	0	0	0	0	0	0	0
No. of one step tapers	0	1	1	1	0	0	0	0	0
No. of 90 degree elbows	0	0	0	0	1	1	0	1	0

Figure 5-9. Schematic and ductwork specifications for the 25-ft model tank used in the medium and large hard chromium plating model plants (Configuration 2).



Duct Component Specification	Duct Section Location									
	A	B	C	D	E	F	G	H	I	J
Gas flow rate, cfm	5,000	5,000	10,000	15,999	20,000	20,000	20,000	10,000	10,000	10,000
Duct diameter, in	16	16	22	28	32	32	32	22	22	22
Duct length, ft.	10	8	8	8	20	15	6	4	4	10
No. of 30 degree entries	1	0	0	0	0	0	0	0	0	0
No. of one step tapers	0	1	1	1	0	0	0	0	0	0
No. of 90 degree elbows	0	0	0	0	1	1	0	0	1	0
No. of Y-connectors	0	0	0	0	0	0	1	0	0	0

Figure 5-10. Schematic and ductwork specifications for the 30-ft model tank used in the large chromic acid anodizing model plant (Configuration 2).

TABLE 5-1. PARAMETERS FOR MODEL HARD CHROMIUM ELECTROPLATING PLANTS[a]

Parameters	Plant size		
	Small	Medium	Large
A. Production rate			
Total ampere-hours per year	5.0×10^6	42×10^6	160×10^6
Time electrodes are energized, percent	70	70	80
Chromic acid usage, kg/yr (lb/yr)	1,130 (2,500)	5,670 (12,500)	14,700 (32,500)
B. Operating time			
Hours/day	8	14	24
Days/week	5	5	5
Weeks/year	50	50	50
Hours/year	2,000	3,500	6,000
C. Process			
No. of tanks	1	4	8
Tank dimensions (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 2 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 4 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 2 @ 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)
Total tank capacity, L (gal)[b]	6,550 (1,730)	30,930 (8,170)	61,850 (16,340)
Total tank surface area, m^2 (ft^2)	4.0 (42)	17 (187)	35 (374)
Chromic acid concentration, g/L (oz/gal)	250 (33)	250 (33)	250 (33)
Catalyst	Sulfuric acid	Sulfuric acid	Sulfuric acid
Catalyst concentration, g/L (oz/gal)	2.5 (0.33)	2.5 (0.33)	2.5 (0.33)
Temperature of plating solution, °C (°F)	49-65 (120-150)	49-65 (120-150)	49-65 (120-150)
Tank operating voltage, V	6-9	6-9	6-9
Tank operating current, amperes	3,625	2,330, 2 @ 4,145 6,475	2 @ 2,330, 4 @ 4,145 2 @ 6,475
Current density, A/m^2 (A/ft^2)	2,800 (260)	2,800 (260)	2,800 (260)

[a]Parameter values for the small, medium, and large plant sizes are based on information obtained from an industry survey and site visits.
[b]Tank freeboard space = 15.2 cm (6 in.).

TABLE 5-2. PARAMETERS FOR MODEL DECORATIVE CHROMIUM ELECTROPLATING PLANTS[a]

Parameters	Plant size		
	Small	Medium	Large
A. Production rate			
Total ampere-hours per year	3.0×10^6	12×10^6	120×10^6
Time electrodes are energized, percent	60	60	60
Chromic acid usage, kg/yr (lb/yr)	900 (2,000)	6,800 (15,000)	68,000 (150,000)
B. Operating time			
Hours/day	8	16	24
Days/week	5	5	5
Weeks/year	50	50	50
Hours/year	2,000	4,000	6,000
C. Process			
No. of tanks	1	2	5
Tank dimensions (l,w,d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 3.6, 1.1, 1.8 (12.0, 3.5 6.0)	5 @ 3.6, 1.8, 2.7 (12.0, 6.0, 9.0)
Total tank capacity, L (gal)[b]	6,550 (1,730)	13,100 (3,460)	86,650 (22,890)
Total tank surface area, m^2 (ft^2)	4.0 (42)	80 (84)	33 (360)
Chromic acid concentration, g/L (oz/gal)	300 (40)	300 (40)	300 (40)
Catalyst	Sulfuric acid or fluoride	Sulfuric acid or fluoride	Sulfuric acid or fluoride
Chromic acid-to-catalyst ratio	100:1	100:1	100:1
Temperature of plating solution, °C (°F)	38-46 (100-115)	38-46 (100-115)	38-46 (100-115)
Tank operating voltage, V	6	6	10
Tank operating current, amperes	2,600	2 @ 2,600	5 @ 6,800
Current density, A/m^2 (A/ft^2)	1,330 (124)	1,330 (124)	1,330 (124)

[a]Parameter values for the small, medium, and large plant sizes are based on information obtained from an industry survey and site visits.
[b]Tank freeboard space = 15.2 cm (6 in.).

TABLE 5-3. PARAMETERS FOR MODEL CHROMIC ACID ANODIZING PLANTS[a]

Parameters	Plant size	
	Small	Large
A. Production rate		
Time electrodes are energized, percent	70	40
Chromic acid usage, kg/yr (lb/yr)	430 (1,000)	5,900 (13,000)
B. Operating time		
Hours/day	8	24
Days/week	5	5
Weeks/year	50	50
Hours/year	2,000	6,000
C. Process		
No. of tanks	1	2
Tank dimensions (l, w, d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 9.1, 1.5, 2.7 (30.0, 5.0, 9.0)
Total tank capacity, L (gal)[b]	6,550 (1,730)	72,190 (19,070)
Total tank surface area, m^2 (ft^2)	4.0 (42)	28 (300)
Chromic acid concentration, g/L (oz/gal)	75 (10)	75 (10)
Temperature of plating solution, °C (°F)	32-35 (90-95)	32-35 (90-95)
Tank operating voltage, V	20 or 40	20 or 40

[a]Parameter values for the small and large plant sizes are based on information obtained from an industry survey and site visits.
[b]Tank freeboard space = 15.2 cm (6 in.).

TABLE 5-4. MINIMUM VENTILATION RATES FOR VENTILATION HOODS USED TO CAPTURE EMISSIONS OF CHROMIC ACID MIST FROM CHROMIUM PLATING AND CHROMIC ACID ANODIZING TANKS[a,5]

	Hood along one side or two parallel sides of free-standing tank not against wall or baffled	
Tank width-to-length ratio	Lateral hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)[b c]	Push-pull hoods, $m^3/min/m^2$ ($ft^3/min/ft^2$)
0.0-0.09	69 (225)	35 (115)
0.1-0.24	76 (250)	38 (125)
0.25-0.49	76 (250)	38 (125)
0.5-0.99	76 (250)	38 (125)
1.0-2.0	76 (250)	38 (125)

[a]Ventilation rates are based on the minimum control velocity of 46 m/min (150 ft/min) recommended for chromic acid mist.

[b]For lateral hoods along centerline or two parallel sides of tank, tank width-to-length ratio equals tank width divided by 2.

[c]Although a ventilation rate of 76 $m^3/min/m^2$ (250 $ft^3/min/ft^2$) may not produce a control velocity of 46 m/min (150 ft/min) at all aspect ratios, the ventilation rate is considered adequate for control.

TABLE 5-5. VENTILATION SPECIFICATIONS FOR MODEL TANKS

	Model tank dimensions (l, w, d), m (ft)					
	1.2, 1 2, 3.0 (4 0, 4 0, 10.0)	3.6, 1 1, 1 8 (12.0, 3 5, 6 0)	3 6, 1.2, 1.8 (12 0, 4 0, 6.0)	3.6, 1.8, 2.7 (12 0, 6.0, 9.0)	7 6, 0.9, 1.8 (25.0, 3 0, 6 0)	9.1, 1.5, 2.7 (30 0, 5.0, 9.0)
A. Ventilation hoods						
Type of hood	Push-pull	Double-sided lateral	Push-pull	Push-pull	Double-sided lateral	Push-pull
Ventilation rate,[a] m^3/min (ft^3/min)	Pull--57 (2,000) Push--<2.3 (<80)	297 (10,500)	Pull--170 (6,000) Push--<6 8 (<240)	Pull--255 (9,000) Push--<10 (<360)	531 (18,750)	Pull--531 (18,750) Push--<21 (<750)
B Takeoffs						
No. per hood[b]	1	4	2	2	8	4 or 5
Gas flow rate per takeoff, m^3/min (ft^3/min)	57 (2,000)	74 (2,625)	85 (3,000)	127 (4,500)	66 (2,344)	142 (5,000) or 106 (3,750)
Diameter of each takeoff, cm (in)[c]	25.4 (10)	30 5 (12)	30.5 (12)	40.6 (16)	30.5 (12)	40.6 (16) or 35.6 (14)
Length of each takeoff, m (ft)	3 (10)	3 (10)	3 (10)	3 (10)	3 (10)	3 (10)
No. of 30°-elbows	1	4	2	2	8	4 or 5

[a]Ventilation rates are based on American National Standards Institute guidelines and the following assumptions: (1) all tanks are free-standing, not against a wall or baffle; (2) push-pull hoods are used on tanks wider than 1.1 m (3.5 ft); and (3) all hoods are installed along the length of the tank.
[b]Takeoffs are spaced 1.8 m (6 ft) apart. For double-sided lateral hoods, takeoffs are assumed to be located downward along the sides of the tank to prevent obstructing the movement of parts.
[c]Assumed gas velocity = 1,070 m/min (3,500 ft/min).

TABLE 5-6. CONTROL DEVICE VENTILATION SPECIFICATIONS FOR MODEL PLANTS

Model plant	Model tanks: No.	Model tanks: Tank dimensions (l, w, d), m (ft)	Total ventilation rate per control device, m^3/min (ft^3/min)	Figure for plan view and ductwork specification
Scrubbers or chevron-blade mist eliminators				
Hard plating				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Medium (Configuration 1)[a]	1	1.2, 1.2, 3.0 (4.0, 4.0, 10.0)		
	2	3.6, 1.2, 1.8 (12.0, 4.0, 6.0)		
	1	7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	990 (35,000)	Figure 5-4
Large (Configuration 1)[b]	2	1.2, 1.2, 3.0 (4.0, 4.0, 10.0)		
	4	3.6, 1.2, 1.8 (12.0, 4.0, 6.0)		
	2	7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 990 (35,000)	Figure 5-4
Decorative plating				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Medium[c]	2	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 340 (12,000)	Figure 5-3
Large (Configuration 1)[d]	5	3.6, 1.8, 2.7 (12.0, 6.0, 9.0)	283 (10,000)	Figure 5-5a
			2 @ 510 (18,000)	Figure 5-5b
Anodizing				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Large (Configuration 1)[a]	2	9.1, 1.5, 2.7 (30.0, 5.0,. 9.0)	1,130 (40,000)	Figure 5-6
Mesh-pad mist eliminators				
Hard plating				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Medium (Configuration 2)[e]	1	1.2, 1.2, 3.0 (4.0, 4.0, 10.0)	170 (6,000)	Figure 5-7
	2	3.6, 1.2, 1.8 (12.0, 4.0, 6.0)	227 (8,000)	Figure 5-8
	1	7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 283 (10,000)	Figure 5-9
Large (Configuration 2)[f]	2	1.2, 1.2, 3.0 (4.0, 4.0, 10.0)	2 @ 170 (6,000)	Figure 5-7
	4	3.6, 1.2, 1.8 (12.0, 4.0, 6.0)	2 @ 227 (8,000)	Figure 5-8
	2	7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	4 @ 283 (10,000)	Figure 5-9
Decorative plating				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Medium[c]	2	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 340 (12,000)	Figure 5-3
Large (Configuration 2)[g]	5	3.6, 1.8, 2.7 (12.0, 6.0, 9.0)	5 @ 283 (10,000)	Figure 5-5a
Anodizing				
Small[a]	1	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	340 (12,000)	Figure 5-3
Large (Configuration 2)[h]	2	9.1, 1.5, 2.7 (30.0, 5.0, 9.0)	4 @ 283 (10,000)	Figure 5-10

[a]All tanks are vented to one control device.
[b]Two control devices are used to control emissions from all tanks. Each control device is used to control four tanks.
[c]Each of the tanks is vented to a separate control device.
[d]One tank is vented to one control device, and two tanks each are vented to a second and a third control device.
[e]Four control devices are used to control emissions from the plating tanks.
[f]Eight control devices are used to control emissions from the plating tanks.
[g]Each of the five tanks is vented to a separate control device.
[h]Each plating tank is controlled by two devices.

TABLE 5-7. CONTROL DEVICE AND STACK PARAMETERS FOR THE MODEL HARD CHROMIUM ELECTROPLATING PLANTS

Type of operation/control device	Plant size: Small	Medium	Large
Hard chromium plating			
I. Packed-bed scrubbers and chevron-blade mist eliminators			
A. Control device parameters			
No. of control devices	1	1	2
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	990 (35,000)	2 @ 990 (35,000)
Inlet gas temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2	2
1. Single packed-bed scrubber, ΔP, kPa (in. w.c)	0.5 (2)	0.5 (2)	0.5 (2)
Liquid-to-gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	400 (3)	400 (3)	400 (3)
2. Double packed-bed scrubber, ΔP, kPa (in. w.c.)	0.75 (3)	0.75 (3)	0.75 (3)
Liquid to gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	800 (6)	800 (6)	800 (6)
3. Chevron-blade mist eliminators with single set of blades, ΔP, kPa (in. w.c.)	0.19 (0.75)	0.19 (0.75)	0.19 (0.75)
4. Chevron-blade mist eliminators with double set of blades, ΔP, kPa (in. w.c.)	0.5 (2)	0.5 (2)	0.5 (2)
B. Stack parameters			
No of stacks	1	1	2
Height, m (ft)[b]	9.1 (30)	9.1 (30)	9.1 (30)
Diameter, m (ft)	0 7 (2.3)	1.1 (3.8)	2 @ 1.1 (3.8)
Temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Moisture, percent	2	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2 @ 990 (35,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)	910 (3,000)
II. Mesh-pad mist eliminators			
A. Control device parameters			
No. of control devices	1	4	8
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	170 (6,000) 227 (8,000) 2 @ 283 (10,000)	2 @ 170 (6,000) 2 @ 227 (8,000) 4 @ 283 (10,000)
Inlet gas temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2	2
Mesh-pad eliminator, ΔP, kPa (in. w.c.)	0.75 (3.0)	0.75 (3.0)	0.75 (3.0)
B. Stack parameters			
No. of stacks	1	4	8
Height, m (ft)[b]	9.1 (30)	9.1 (30)	9.1 (30)
Diameter, m (ft)	0.7 (2.3)	0.5 (1.5) 0.5 (1.8) 2 @ 0.6 (2.1)	2 @ 0.5 (1.5) 2 @ 0.5 (1.8) 4 @ 0.6 (2.1)
Temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Moisture, percent	2	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	170 (6,000) 227 (8,000) 2 @ 283 (10,000)	2 @ 170 (6,000) 2 @ 227 (8,000) 4 @ 283 (10,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)	910 (3,000)

[a]Ventilation rates were rounded to the gas flow rates for which factory-assembled control devices are available.
[b]Stack height is the distance from ground level to the point of discharge.

TABLE 5-8. CONTROL DEVICE AND STACK PARAMETERS FOR THE MODEL DECORATIVE CHROMIUM ELECTROPLATING PLANTS

Type of operation/control device	Plant size		
	Small	Medium	Large
Decorative chromium plating			
I. Packed-bed scrubbers and chevron-blade mist eliminators			
A. Control device parameters			
No of control devices	1	2	3
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	2 @ 340 (12,000)	280 (10,000) 2 @ 510 (18,000)
Inlet gas temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2	2
1. Single packed-bed scrubber, ΔP, kPa (in. w.c)	0.5 (2)	0.5 (2)	0.5 (2)
Liquid-to-gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	400 (3)	400 (3)	400 (3)
2. Double packed-bed scrubber, ΔP, kPa (in. w.c.)	0.75 (3)	0.75 (3)	0.75 (3)
Liquid to gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	800 (6)	800 (6)	800 (6)
3. Chevron-blade mist eliminator with single set of blades, ΔP, kPa (in. w.c.)	0.19 (0.75)	0.19 (0.75)	0.19 (0.75)
4. Chevron-blade mist eliminator with double set of blades, ΔP, kPa (in. w.c.)	0.5 (2)	0.5 (2)	0.5 (2)
B. Stack parameters			
No. of stacks	1	2	3
Height, m (ft)[b]	9.1 (30)	9.1 (30)	9.1 (30)
Diameter, m (ft)	0.7 (2.3)	2 @ 0.7 (2.3)	0.6 (2.1) 2 @ 0.8 (2.8)
Temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Moisture, percent	2	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	2 @ 340 (12,000)	280 (10,000) 2 @ 510 (18,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)	910 (3,000)
II. Mesh-pad mist eliminators			
A. Control device parameters			
No. of control devices	1	2	5
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	2 @ 340 (12,000)	5 @ 283 (10,000)
Inlet gas temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2	2
Mesh-pad mist eliminator, ΔP, kPa (in. w.c.)	0.75 (3.0)	0.75 (3.0)	0.75 (3.0)
B. Stack parameters			
No. of stacks	1	2	5
Height, m (ft)[b]	9.1 (30)	9.1 (30)	9.1 (30)
Diameter, m (ft)	0.7 (2.3)	2 @ 0.7 (2.3)	5 @ 0.6 (2.1)
Temperature, °C (°F)	27 (80)	27 (80)	27 (80)
Moisture, percent	2	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	2 @ 340 (12,000)	5 @ 283 (10,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)	910 (3,000)
III. Fume suppressants			
Annual usage, kg/yr or L/yr (lb/yr or gal/yr)	17 or 120 (37 or 32)	67 or 480 (148 or 128)	295 or 2,080 (650 or 550)

[a]Ventilation rates were rounded to the gas flow rates for which factory-assembled control devices are available.
[b]Stack height is the distance from ground level to the point of discharge.

TABLE 5-9. CONTROL DEVICE AND STACK PARAMETERS FOR THE MODEL CHROMIC ACID ANODIZING PLANTS

Type of operation/control device	Plant size: Small	Plant size: Large
Chromic acid anodizing		
I. Packed-bed scrubbers and chevron-blade mist eliminators		
A. Control device parameters		
No. of control devices	1	1
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	1,130 (40,000)
Inlet gas temperature, °C (°F)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2
1. Single packed-bed scrubber, ΔP, kPa (in. w.c)	0.5 (2)	0.5 (2)
Liquid-to-gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	400 (3)	400 (3)
2. Double packed-bed scrubber, ΔP, kPa (in. w.c.)	0.75 (3)	0.75 (3)
Liquid to gas ratio, L/min/1,000 m^3/min (gal/min/1,000 ft^3/min)	800 (6)	800 (6)
3. Chevron-blade mist eliminator with single set of blades, ΔP, kPa (in. w.c.)	0.19 (0.75)	0.19 (0.75)
4. Chevron-blade mist eliminator with double set of blades, ΔP, kPa (in. w.c.)	0.5 (2)	0.5 (2)
B. Stack parameters		
No. of stacks	1	1
Height, m (ft)[b]	9.1 (30)	9.1 (30)
Diameter, m (ft)	0.7 (2.3)	1.2 (4.1)
Temperature, °C (°F)	27 (80)	27 (80)
Moisture, percent	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	1,130 (40,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)
II. Mesh-pad mist eliminators		
A. Control device parameters		
No. of control devices	1	4
Inlet gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	4 @ 283 (10,000)
Inlet gas temperature °C (°F)	27 (80)	27 (80)
Inlet gas moisture, percent	2	2
Mesh-pad mist eliminator, ΔP, kPa (in. w.c)	0.75 (3.0)	0.75 (3.0)
B. Stack parameters		
No. of stacks	1	4
Height, m (ft)[b]	9.1 (30)	9.1 (30)
Diameter, m (ft)	0.7 (2.3)	4 @ 0.6 (2.1)
Temperature, °C (°F)	27 (80)	27 (80)
Moisture, percent	2	2
Gas flow rate, m^3/min (ft^3/min)	340 (12,000)	4 @ 283 (10,000)
Gas velocity, m/min (ft/min)	910 (3,000)	910 (3,000)
III. Fume suppressants		
Annual usage, kg/yr	9.0 (20)	72 (160)

[a]Ventilation rates were rounded to the gas flow rates for which factory-assembled control devices are available.
[b]Stack height is the distance from ground level to the point of discharge.

TABLE 5-10. BASELINE CONTROL LEVELS FOR CHROMIUM PLATING AND CHROMIC ACID ANODIZING OPERATIONS

Operation/control technique	Percent of total operations	Associated level of control, percent Cr^{+6} reduction
Hard plating		
Uncontrolled	30	0
Chevron-blade mist eliminator with a single set of blades	30	90
Packed-bed scrubber	40	97
Total	100	
Decorative plating		
Uncontrolled	15	0
Fume suppressant	40	97
Fume suppressant combined with a packed-bed scrubber	40	97
Packed-bed scrubber	5	95
Total	100	
Chromic acid anodizing		
Uncontrolled	40	0
Chevron-blade mist eliminator with a single set of blades	10	90
Fume suppressant	30	97
Packed-bed scrubber	20	95
Total	100	

TABLE 5-11. NUMBER OF OPERATIONS NATIONWIDE

Type of operation	No. of operations nationwide	Percentage of total (by type)
1. Hard chromium plating		
Small	1,080	70
Medium	310	20
Large	150	10
Total	1,540	100
2. Decorative chromium plating		
Small	2,240	80
Medium	420	15
Large	140	5
Total	2,800	100
3. Chromic acid anodizing		
Small	515	75
Large	165	25
Total	680	100

TABLE 5-12. SUMMARY OF CONTROL OPTIONS

Type of operation/ Control option	Control technique
Hard chromium plating	
Option I (no action)[a]	Existing (baseline level of control) • 30 percent of operations uncontrolled • 30 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent • 40 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 97 percent
Option II[b]	Chevron-blade mist eliminators that reduce uncontrolled emissions by 95 percent
Option III[b]	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent
Decorative chromium plating	
Option I (no action)[a]	Existing (baseline) level of control • 15 percent of operations uncontrolled • 40 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 40 percent of operations controlled by a combination of chemical fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent • 5 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II[b]	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III[b]	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent
Option IV[b]	Trivalent chromium plating processes that reduce hexavalent chromium emissions by 100 percent (technology forcing)
Chromic acid anodizing	
Option I (no action)[a]	Existing (baseline) level of control • 40 percent of operations uncontrolled • 30 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 10 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent • 20 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II[b]	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III[b]	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent

[a] The emission reductions presented here are based on the application of control techniques under representative baseline conditions, recognizing that control devices currently in use are often poorly operated and maintained.

[b] The emission reductions presented here reflect the application of control techniques under good operation and maintenance conditions.

5.4 REFERENCES FOR CHAPTER 5

1. Industrial Ventilation: A Manual of Recommended Practice. American Conference of Governmental Industrial Hygienists. 19th edition. 1986. pp. 5-68 to 5-70.

2. American National Standard Practices for Ventilation and Operation of Open-Surface Tanks. ANSI 29.1-1977. New York, American National Standards Institute, Inc. 1977.

3. Reference 2, p. 13.

4. Reference 3, pp. 13 and 22.

5. Reference 3, pp. 13 and 14.

6. Reference 3, pp. 13 and 15.

7. U.S. Department of Labor. Code of Federal Regulations. 29 CFR 1910.1000. Washington, D.C. July 1, 1986. p. 659.

8. U.S. Department of Commerce, Bureau of Census. Census of Manufacturers--Selected Metalworking Operations. Washington, D.C. Publication No. MC82-S-8. September 1985.

9. Finishers' Management Media/Market Bulletin. Metal Finishing Job Shop Industry Profile . . . . 1985/86. Glenview, Illinois. 1986. p. 2

6. ENVIRONMENTAL IMPACTS

6.1 INTRODUCTION

The purpose of this chapter is to present the air pollution, energy, water pollution, and solid waste impacts associated with the control options for reducing hexavalent chromium emissions from hard and decorative chromium electroplating and chromic acid anodizing operations. All impacts are based on the model plant parameters and control options presented in Chapter 5 and on industry profile data and growth projections presented in Chapter 8. Table 6-1 summarizes the control options upon which the environmental impacts are based. Incremental impacts are calculated by comparing the projected nationwide impacts under Option II, Option III, and Option IV to the impacts at baseline conditions (Option I). Control Option I represents the existing level of control currently being achieved by chromium plating and chromic acid anodizing operations in the absence of a NESHAP for chromium.

6.2 AIR POLLUTION IMPACTS

This section presents estimates of nationwide hexavalent chromium emissions under each control option for hard and decorative plating and chromic acid anodizing operations. Nationwide emission estimates for each control option are based on estimates of annual uncontrolled emissions ascribed to each model plant, estimates of the number of chromium plating or chromic acid anodizing operations within each model plant size category, and the control levels associated with the control option. For example, there are an estimated 1,080 small hard chromium plating operations nationwide. Under Option I (no action), 30 percent (324 operations) are uncontrolled, 30 percent

(324 operations) are controlled by chevron-blade mist eliminators with an average emission reduction of 90 percent, and 40 percent (432 operations) are controlled by packed-bed scrubbers with an average emission reduction of 97 percent. The estimated nationwide chromium emission rate for small hard chromium plating operations can be calculated by multiplying the number of operations at each control level by the annual uncontrolled small model plant emission rate of 0.05 Mg/yr (0.055 ton/yr), as follows:

(324)(0.05 Mg/yr) = 16 Mg/yr (18 tons/yr)

(324)(0.05 Mg/yr)(1 - 0.90) = 1.6 Mg/yr (1.8 tons/yr)

(432)(0.05 Mg/yr)(1 - 0.97) = 0.65 Mg/yr (0.71 ton/yr)

Total emissions for small operations are 18 Mg/yr (20 tons/yr). Emissions were calculated in this manner for each of the model plant sizes for hard and decorative chromium plating and chromic acid anodizing operations. The total nationwide hexavalent chromium emission rate for each type of operation under each control option is the sum of the nationwide totals for each model plant size.

6.2.1 Hard Chromium Electroplating

6.2.1.1 Nationwide Emissions. Nationwide hexavalent chromium emission estimates for each control option are presented in Table 6-2. The total nationwide emission rate for all hard chromium plating operations under Option I (no action) is 145 Mg/yr (160 tons/yr), which is the sum of the nationwide totals for each model plant size.

Control Option II is based on the use of a chevron-blade mist eliminator that reduces uncontrolled emissions by 95 percent. Application of Option II would reduce emissions by 95 percent for the 30 percent of operations that are uncontrolled under Option I and would increase the control level from 90 to 95 percent for the 30 percent of operations that currently use a chevron-blade mist eliminator. This increased level of control is achievable with good operation and maintenance practices. Emissions from the 40 percent of operations that are controlled by packed-bed scrubbers with control efficiencies greater than

95 percent would remain the same. Total nationwide chromium emissions associated with Option II are 18 Mg/yr (20 tons/yr).

Emission estimates associated with Option III for hard chromium plating operations are based on the use of a packed-bed scrubber or a mesh-pad mist eliminator that reduces uncontrolled emissions by 99 percent. Application of Option III would reduce emissions by 99 percent for the 30 percent of operations that are uncontrolled under Option I and increase the control level for the 30 percent of operations that currently use a chevron-blade mist eliminator from 90 to 99 percent. Implementation of Option III would also increase the control level from 97 to 99 percent at the 40 percent of operations that currently used packed-bed scrubbers. This improved level of control for packed-bed scrubbers is achievable with improved operating and maintenance practices. Total nationwide chromium emissions associated with Option III are 4.2 Mg/yr (4.7 tons/yr).

6.2.1.2 Emission Reductions. Table 6-3 presents nationwide emission reductions for the control options for hard chromium electroplating. Control levels associated with Option II would reduce nationwide emissions over Option I by 88 percent, or 127 Mg/yr (140 tons/yr). The average control level associated with Option III would reduce nationwide emissions over Option I by 97 percent or 141 Mg/yr (155 tons/yr) and reduce nationwide emissions over Option II by 76 percent, or 14 Mg/yr (15 tons/yr).

6.2.2 Decorative Chromium Electroplating

6.2.2.1 Nationwide Hexavalent Chromium Emissions. Nationwide hexavalent chromium emission estimates for each control option are presented in Table 6-4. Under Option I, about 15 percent of the operations are uncontrolled, 40 percent are controlled by fume suppressants that reduce uncontrolled emissions by 97 percent, 40 percent are controlled by a combination of fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent, and 5 percent are controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent. Total nationwide chromium emissions under Option I are 10 Mg/yr (11 tons/yr).

Control Option II is based on the use of a packed-bed scrubber or a mesh-pad mist eliminator to reduce uncontrolled emissions by 97 percent. For the 15 percent of operations that are uncontrolled under Option I, application of Option II would reduce emissions by 97 percent. Emissions from the 40 percent of operations controlled by fume suppressants and the 40 percent of operations controlled by a combination of fume suppressants and packed-bed scrubbers would remain the same. For the 5 percent of operations that are controlled by packed-bed scrubbers, Option II would increase the control level from 95 percent to 97 percent. This improved level of control for packed-bed scrubbers is achievable with improved operating and maintenance practices. Total nationwide chromium emissions associated with Option II are 1.7 Mg/yr (1.9 tons/yr).

Control Option III is based on the proper addition and use of fume suppressants. When vendor directions are strictly observed, this control technique will achieve 99.5 percent control, significantly improving upon the control level typically achieved when vendor recommendations are not strictly followed. Implementation of Option III would reduce emissions by 99.5 percent for the 15 percent of the operations that are uncontrolled under Option I, increase the control level at the 5 percent of operations that currently use packed-bed scrubbers, and increase the level of control from 97 percent to 99.5 percent for the 40 percent of operations that currently use fume suppressants and the 40 percent of operations that currently use a combination of fume suppressants and packed-bed scrubbers. Nationwide chromium emissions associated with Option III are 0.29 Mg/yr (0.32 ton/yr).

Control Option IV is based on the substitution of a trivalent chromium plating bath for a conventional hexavalent chromium plating bath. **This is a technology-forcing option.** Because there is no hexavalent chromium associated with trivalent processes, implementation of Option IV would eliminate hexavalent chromium emissions, resulting in a nationwide hexavalent chromium emissions level of zero.

6.2.2.2 Emission Reductions. Table 6-5 presents nationwide emission reductions for the control options for decorative chromium electroplating. The control level associated with Option II would reduce nationwide emissions over Option I by 83 percent or about 8.4 Mg/yr (9.2 tons/yr). The control level associated with Option III would reduce nationwide emissions over Option I and Option II by 97 and 83 percent, or 9.8 Mg/yr (11 tons/yr) and 1.4 Mg/yr (1.6 tons/yr), respectively. The control level associated with Option IV would reduce nationwide emissions over Option I, Option II, and Option III by 100 percent, or 10 Mg/yr (11 tons/yr), 1.7 Mg/yr (1.9 tons/yr), and 0.29 Mg/yr (0.32 ton/yr), respectively.

6.2.3 Chromic Acid Anodizing

6.2.3.1 Nationwide Hexavalent Chromium Emissions. Nationwide hexavalent chromium emission estimates for each control option are presented in Table 6-6. Under Option I, about 40 percent of the operations are uncontrolled, 10 percent are controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent, 20 percent are controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent, and 30 percent are controlled by fume suppressants that reduce uncontrolled emissions by 97 percent. Total nationwide chromium emission rates from chromic acid anodizing operations under Option I are about 3.6 Mg/yr (3.9 tons/yr).

Control Option II is based on the use of a packed-bed scrubber or a mesh-pad mist eliminator that reduces uncontrolled emissions by 97 percent. Under Option II, emissions from the 40 percent of operations that are uncontrolled under Option I would be reduced by 97 percent. The control level at the 10 percent of operations that are currently controlled by chevron-blade mist eliminators at a level of 90 percent would be increased by 7 percent. Control Option II would increase the control level from 95 to 97 percent at the 20 percent of operations that are controlled by packed-bed scrubbers under Option I. This improved level of control for packed-bed scrubbers is achievable with improved operating and maintenance

practices. Emissions from the 30 percent of operations that use fume suppressants and already have an emission reduction of 97 percent would remain the same. Total nationwide chromium emissions associated with Option II are 0.25 Mg/yr (0.27 ton/yr).

Control Option III is based on the use of fume suppressants consistent with vendor recommendations. Implementation of Option III would reduce emissions by 99.5 percent for the 40 percent of the operations that are uncontrolled under Option I. The levels of control would be increased by 9.5 percent at the 10 percent of operations that currently use chevron-blade mist eliminators and 4.5 percent at the 20 percent of operations that use packed-bed scrubbers. Control Option III would increase the level of control from 97 percent to 99.5 percent for the 30 percent of operations that currently use fume suppressants. When vendor recommendations are strictly observed, this control technique will achieve a 99.5 percent emissions reduction, improving upon the efficiencies typically achieved when vendor recommendations are not followed. Nationwide chromium emissions associated with Option III are 0.04 Mg/yr (0.05 ton/yr).

6.2.3.2 Emission Reductions. Table 6-7 presents nationwide emission reductions for the control options. The control level associated with Option II would reduce nationwide emissions over Option I by 93 percent, or 3.4 Mg/yr (3.7 tons/yr). The control level associated with Option III would reduce emissions over Options I and II by 99 and 83 percent, or 3.6 Mg/yr (3.9 tons/yr) and 0.21 Mg/yr (0.23 ton/yr), respectively.

6.3 ENERGY IMPACTS

This section presents the energy impacts associated with each control option. Electrical energy is needed to provide fan horsepower for operating exhaust ventilation systems and overcoming the pressure drop across control devices and to operate recirculation pumps on the packed-bed scrubbers and mesh-pad mist eliminators. The fan horsepower requirements for exhaust ventilation only are presented in Table 6-8. The electrical requirements shown in the table are based on the

number of fans, the individual fan sizes for each model plant, and the number of hours the plant operates each year. For example, the estimated energy requirements for the basic capture system for the small hard chromium model plant, as shown in Table 6-8, is calculated as follows:

$$(1\ \text{fan})(10\ \text{hp/fan})(0.746\ \text{kW/hp})(2{,}000\ \text{hr/yr}) = 14{,}900\ \text{kWh/yr}.$$

The basic capture system is applicable for use with scrubbers and chevron-blade mist eliminators, which can handle airflow rates up to 1,680 m^3/min (60,000 ft^3/min). The modified capture system shown in the table is intended to accommodate mesh-pad mist eliminators. These control devices are designed to handle a maximum airflow rate of 340 m^3/min (12,000 ft^3/min), which is considerably lower than the maximum design airflow rates for scrubbers and chevron-blade mist eliminators. The energy requirements for this system are calculated in the same way as for the basic capture system.

The increases in annual energy requirements for the control devices, compared to the ventilation systems alone, are presented in Table 6-9. These increases in electrical requirements are based on the numbers and sizes of fans and pumps for each model plant, and the number of hours the plant operates each year. Fan and pump horsepower requirements vary according to the control device being used. For example, the increase in energy requirements for the small model plant when a mesh-pad mist eliminator is used is determined as follows:

Mesh-pad mist eliminators require a modified capture system, and the fan horsepower requirement for the small hard chromium plating model plant for that system (as shown in Table 6-8) is 7.5 hp. Table 6-9 shows that the mesh-pad mist eliminator used in this model plant requires an additional 7.5 hp to operate the fans and an additional 0.75 hp to operate the pumps. Therefore, the increase in electrical use over that required for the modified capture system alone is:

$$(7.5 \text{ hp} + 0.75 \text{ hp})(0.746 \text{ kW/hp})(2{,}000 \text{ hr/yr}) = 11{,}200 \text{ kWh/yr}.$$

Fan and pump horsepower requirements were provided by Vendors A and I.[1,2]

6.3.1 Hard Chromium Electroplating

Table 6-10 presents the nationwide energy impacts associated with each control option for hard chromium plating operations. (Note that in this table, Option III is divided into two parts--Option IIIa is based on the use of packed-bed scrubbers, and Option IIIb is based on the use of mesh-pad mist eliminators.) The nationwide energy requirement for Option I (no action) is calculated below.

There are 310 medium hard chromium plating operations, of which 30 percent (93 operations) are uncontrolled, 30 percent are controlled by chevron-blade mist eliminators with single sets of blades, and 40 percent (124 operations) are controlled by packed-bed scrubbers. The energy requirements for the 93 uncontrolled operations are attributable only to the basic capture system. As shown in Table 6-8, the energy requirement for a basic capture system for a medium hard chromium plating operation is 104,400 kWh/yr. Therefore, the nationwide energy requirement for uncontrolled medium-size hard chromium plating operations is:

$$(93 \text{ operations})(104{,}400 \text{ kWh/yr}) =$$
$$9.70 \times 10^6 \text{ kWh/yr, or } 9{,}700 \text{ MWh/yr}.$$

The energy requirements for the 93 operations controlled by chevron-blade mist eliminators with single sets of blades include energy for the basic capture system plus additional fan horsepower to operate the mist eliminator. As shown in Table 6-9, the increase in electrical use over the basic capture system alone is 26,100 kWh/yr for a medium hard chromium plating model plant. The nationwide energy requirement for these operations is, therefore:

$$(93 \text{ operations})(26{,}100 \text{ kWh/yr} + 104{,}400 \text{ kWh/hr}) = 1.21 \times 10^7 \text{ kWh/yr or } 12{,}100 \text{ MWh/yr.}$$

As shown in Table 6-9, the energy requirements for a medium hard chromium plating operation controlled by a packed-bed scrubber increase by 60,100 kWh/yr over the requirements for the basic capture system. The nationwide energy requirement for these operations is:

$$(124 \text{ operations})(60{,}100 \text{ kWh/yr} + 104{,}400 \text{ kWh/yr}) = 2.04 \times 10^7 \text{ kWh/yr or } 20{,}400 \text{ MWh/yr.}$$

The estimated nationwide energy requirement for medium hard chromium model plants is, therefore:

$$9{,}700 \text{ MWh/yr} + 12{,}100 \text{ MWh/yr} + 20{,}400 \text{ MWh/yr} = 42{,}200 \text{ MWh/yr.}$$

Similar calculations were performed for the small and large model plants. The total nationwide energy requirement for hard chromium plating operations under Option I is the sum of the totals for each plant size, or 132,600 MWh/yr.

The energy requirement under Option II is based on the use of a chevron-blade mist eliminator with a double set of blades. The nationwide energy requirement for Option II is greater than that for Option I because additional fan horsepower (compared to the basic capture system) is required to operate chevron-blade mist eliminators with a double set of blades in all sizes of model plants. The number of operations controlled by packed-bed scrubbers remains constant under both options and, therefore, there is no additional energy requirement for those operations. The total nationwide energy requirement for Option II is equal to the nationwide energy requirement for Option I plus 24,200 MWh/yr, or 156,800 MWh/yr.

The energy requirement under Option IIIa (based on the use of packed-bed scrubbers) is greater than that for Options I and II because the number of operations controlled by scrubbers

increases above the levels in Options I and II, and scrubbers require additional energy to operate the fans and recirculation pumps compared to mist eliminators. The increase in the energy requirements for the additional fan and recirculation pump horsepower for scrubbers was calculated based on the increase in the number of operations controlled by scrubbers (60 percent) and the incremental fan and recirculation pump horsepower requirements for each plant size. The incremental increase in energy requirements for the medium hard chromium plating model plant is calculated as follows:

The additional energy requirement for the 30 percent of operations uncontrolled under Option I that would be controlled by packed-bed scrubbers under Option IIIa is:

$$(0.30)(310 \text{ operations})(60{,}100 \text{ kWh/yr}) = 5.59 \times 10^6 \text{ kWh/yr or } 5{,}600 \text{ MWh/yr.}$$

As shown in Table 6-9, operations using chevron-blade mist eliminators already have an increase in energy requirements (26,100 kWh/yr per plant) over the basic capture system. This must be subtracted from the energy increase due to the use of packed-bed scrubbers (60,100 kWh/yr per plant). The additional energy requirement for the 30 percent of operations controlled by chevron-blade mist eliminators with a single set of blades under Option I that would be controlled by packed-bed scrubbers under Option IIIa is:

$$(0.30)(310 \text{ operations})(60{,}100 \text{ kWh/yr} - 26{,}100 \text{ kWh/yr}) = 3.16 \times 10^6 \text{ kWh/yr or } 3{,}200 \text{ MWh/yr.}$$

No additional energy is required for the 40 percent of operations controlled by packed-bed scrubbers under Option I. The total increase in energy requirement for the medium model plant under Option IIIa is 5,600 MWh/yr plus 3,200 MWh/yr, or 8,800 MWh/yr. Similar calculations were performed for the small and large model plants. The total

increase in energy requirements under Option IIIa is equal to the sum of the nationwide totals for each model plant size, which is 29,500 MWh/yr. The total nationwide energy requirement for Option IIIa is then equal to the nationwide energy requirement for Option I plus 29,500 MWh/yr, which is 162,200 MWh/yr.

The energy requirement for Option IIIb is based on the use of mesh-pad mist eliminators. As with Option IIIa, there is an increase in nationwide energy requirements over Option I, attributable to an increase in the fan horsepower and recirculation pump horsepower requirements for the 30 percent of operations uncontrolled under Option I. However, for the 30 percent of medium and large plants using chevron-blade mist eliminators with a single set of blades under baseline conditions (Option I), the use of mesh-pad mist eliminators results in an incremental decrease in the energy requirement. The total fan plus total pump horsepower requirements required for the medium and large plants using mesh-pad mist eliminators are the same as the total fan horsepower requirements for the same plants using chevron-blade mist eliminators with a single set of blades (50 hp and 100 hp, respectively). However, the recirculation pumps required for mesh-pad mist eliminators are operated only 5 minutes in each 8-hour time period. Therefore, the total increase in electrical use over the basic capture system is less for mesh-pad mist eliminators than it is for chevron-blade mist eliminators for these operations. Energy requirements for the 40 percent of operations controlled by packed-bed scrubbers under Option I do not increase. The total nationwide energy requirement for Option IIIb is equal to the nationwide energy requirement for Option I plus 8,100 MWh/yr, or 140,800 MWh/yr.

6.3.2 Decorative Chromium Electroplating

Table 6-11 presents the nationwide energy requirements associated with each control option for decorative chromium electroplating. The nationwide energy requirement for Option I (baseline) is based on the basic capture systems for 55 percent of the plants because these plants are either uncontrolled

(15 percent) or use fume suppressants only (40 percent). The 45 percent of operations controlled by packed-bed scrubbers alone or fume suppressants used in conjunction with packed-bed scrubbers have additional fan horsepower and pump electrical requirements over those of the basic capture system. The estimated energy requirement for decorative chromium plating operations under Option I is 106,100 MWh/yr, which is calculated from the values given in Tables 6-8 and 6-9 as described in Section 6.3.1.

The energy requirement under Option IIa is based on the use of packed-bed scrubbers. The nationwide energy requirement for Option IIa increases over that for Option I because the number of operations controlled by scrubbers increases from 45 percent in Option I to 60 percent in Option IIa. This is due to the number of operations uncontrolled under Option I becoming controlled by packed-bed scrubbers under Option IIa. The increase in the fan and pump energy requirements is calculated as follows:

$$(336 \text{ small plants})(9{,}700 \text{ kWh/yr}) + (63 \text{ medium plants})(38{,}800 \text{ kWh/yr}) + (21 \text{ large plants})(134{,}300 \text{ kWh/yr}) = 8.52 \times 10^6 \text{ kWh/yr or } 8{,}500 \text{ MWh/yr.}$$

Therefore, the total nationwide energy requirement for Option IIa is equal to the nationwide energy requirement for Option I plus 8,500 MWh/yr, which is 114,600 MWh/yr.

The energy requirement under Option IIb is based on the use of mesh-pad mist eliminators. As with Option IIa, the increase in fan and pump horsepower energy requirements results in incremental energy increases only for the 15 percent of operations that are uncontrolled under Option I and have only basic capture systems. The total increase in fan energy requirements (see Table 6-9) is determined for each model plant size using calculations similar to those presented for Option IIa. Additional energy required for recirculation pumps is determined in a similar manner but calculations are adjusted to reflect the use of these pumps for only 5 minutes in each

8-hour time period. The total incremental energy increase for Option IIb is 8,200 MWh/yr. Therefore, the total nationwide energy requirement for Option IIb is equal to the nationwide energy requirement for Option I plus 8,200 MWh/yr, which is 114,300 MWh/yr.

The energy requirement under Option III is based on the use of fume suppressants. The nationwide energy requirement for Option III is the same as the nationwide energy requirement for Option I for 97.5 percent of the operations because no modifications to the basic capture systems at these operations are needed for the purpose of this control technology. For the 5 percent of the operations using packed-bed scrubbers under Option I, it is assumed that half will retain their packed-bed scrubbers in addition to using fume suppressants. For the remaining 2.5 percent, an incremental energy decrease is realized when fume suppressants alone are used. This is attributable to the elimination of scrubbers in these operations and the associated fan and pump energy requirements. The total incremental energy decrease for Option III is 1,400 MWh/yr. Therefore, the total nationwide energy requirement for Option III is equal to the nationwide energy requirement for Option I less 1,400 MWh/yr, which is 104,700 MWh/yr.

The energy requirement under Option IV is based on the use of the trivalent chromium process as a substitute for the hexavalent chromium process. The nationwide energy requirement for Option IV is zero because no ventilation systems are required for trivalent chromium plating tanks. This represents a reduction of 106,100 MWh/yr.

6.3.3 Chromic Acid Anodizing

Table 6-12 presents nationwide estimates of the annual energy use associated with the control options. The nationwide energy requirement for Option I (baseline) is based on the basic capture systems for all operations and the additional fan horsepower and pump electrical requirement for all sizes of operations that operate scrubbers. The operation of chevron-blade mist eliminators at these plants does not increase the fan

horsepower requirement over that of the basic capture system. Based on the fan and pump horsepower requirements, the number of operations nationwide, and the percentage of all operations controlled by scrubbers, the estimated energy requirement for chromic acid anodizing operations under Option I is 47,800 MWh/yr.

The energy requirement under Option IIa is based on the use of packed-bed scrubbers. The nationwide energy requirement for Option IIa increases over that for Option I because the number of operations controlled by scrubbers increases above the number for Option I, and these operations require additional fan horsepower and energy to operate the recirculation pumps. The total incremental energy increase for Option IIa over Option I is 8,000 MWh/yr. The total nationwide energy requirement for Option IIa is 55,800 MWh/yr.

The energy requirement for Option IIb is based on the use of mesh-pad mist eliminators. For 50 percent of the operations there is an increase in fan energy requirements, and additional energy is required to operate the recirculation pumps for 5 minutes in each 8-hour time period for the mesh-pad mist eliminators. The total incremental energy increase for Option IIb over Option I is 5,600 MWh/yr. The total nationwide energy requirement for Option IIb is 53,400 MWh/yr.

The energy requirement under Option III is based on the use of fume suppressants. There is no increase in the energy requirement for Option III over that for Option I because no modifications to the basic capture systems of any operations are needed for this control technology. For 20 percent of the operations there is an incremental decrease in electrical use attributable to the incremental fan and pump horsepower requirements associated with the packed-bed scrubbers used in those operations. The total incremental energy decrease for Option III is 3,200 MWh/yr. The total nationwide energy requirement for Option III is 44,600 MWh/yr.

6.4 WATER POLLUTION IMPACTS

Wet scrubbers and mist eliminators generate wastewater that requires reuse, treatment, or disposal. Some hard and most decorative plating operations install systems to treat wastes from plating baths. Some of these operations also drain the control device effluent to the treatment system. The amount of control device effluent relative to the total amount of wastewater associated with plating operations is low (less than 10 percent).

Hard chromium plating and chromic acid anodizing operations that use scrubbers typically avoid wastewater treatment costs and minimize water consumption by continuously recirculating scrubber liquor. The scrubber liquor is recirculated for a period ranging from several hours to several days and then is drained to the plating bath to make up for plating solution evaporation losses. The scrubber is recharged with clean water after being drained. This practice also permits the recovery of chromic acid. Operations using chevron-blade mist eliminators also recover chromic acid by draining the washdown water to the plating tank to make up for plating solution evaporation losses.

Decorative chromium plating operations that use scrubbers typically do not use scrubber liquor to make up for plating solution evaporation losses because fume suppressants are used to minimize evaporation losses. Many decorative plating operations avoid wastewater treatment costs and minimize water consumption by recirculating the water from the rinse tanks following the chromium plating tank through the scrubber.

Under Option IV for decorative chromium plating, operations would be faced with the problem of disposal of the hexavalent chromium plating solution as a part of the conversion to the trivalent process. Because this is considered to be a one-time occurrence, it is treated as a component of the capital cost of conversion rather than a continuing impact of the control option. More details on the impact of disposing of the plating solution are presented in Chapter 7. The long-term impacts of Option IV

on water pollution would be beneficial because the use of the more toxic hexavalent solution is eliminated.

6.5 SOLID WASTE IMPACTS

One potential source of solid waste from hard and decorative plating and chromic acid anodizing operations is the sludge produced by wastewater treatment systems. As noted in Section 6.4, wastewater from plating baths and control devices is typically recirculated. This minimizes wastewater treatment system throughput, and, therefore, the quantities of sludge generated are not significant.

Implementation of the control options based on the use of packed-bed scrubbers or mesh-pad mist eliminators will have some solid waste impacts. Vendors estimate that bed packing materials used in scrubbers may need to be replaced every 10 years and that mesh pads used in mesh-pad mist eliminators should be replaced every 4 years. Hexavalent chromium-contaminated materials such as these are accepted for disposal in hazardous waste landfills. The costs for disposal of these materials are addressed in Chapter 7. The total volumes of solid wastes attributable to the disposal of scrubber packing material and mesh pads for the model plants are presented in Tables 6-13 through 6-15. The quantities of spent scrubber packing material and mesh pads generated annually under Option I (baseline conditions) would be 44 m^3 (1,600 ft^3) for hard chromium plating operations, 67 m^3 (2,400 ft^3) for decorative chromium plating operations, and 8 m^3 (280 ft^3) for chromic acid anodizing operations. Control options based on the use of single packed-bed scrubbers would increase this to 110 m^3 (3,900 ft^3) for hard chromium plating operations, 89 m^3 (3,100 ft^3) for decorative plating operations, and 29 m^3 (1,000 ft^3) for chromic acid anodizing operations. Control options based on the use of mesh-pad mist eliminators would increase the quantities from those in Option I to 100 m^3 (3,500 ft^3) for hard chromium plating operations, 82 m^3 (2,900 ft^3) for decorative plating operations, and 26 m^3 (920 ft^3) for chromic acid anodizing. These increases are not considered to represent significant solid waste impacts.

Another source of solid waste is the retrofitting or replacement of control devices at existing operations. Disposal of replaced systems represents a one-time occurrence for each operation, and the extent of the impact depends on the type of modification involved. Costs pertinent to disposal of control device systems are discussed in Chapter 7.

The conversion to a trivalent chromium plating process involves the disposal of the hexavalent solution as a hazardous waste. This is a one-time impact and is covered in Chapter 7 as a cost item. Therefore, there are no significant solid waste impacts associated with this or other options for the three source categories.

As a result of legislation proposed at the time of this writing, the solid waste impacts described above may increase significantly.

6.6 OTHER ENVIRONMENTAL IMPACTS

No other beneficial or adverse environmental impacts are expected to arise from the implementation of the standards, regardless of the control option selected as the basis of the standards.

6.7 OTHER ENVIRONMENTAL CONCERNS

6.7.1 Irreversible and Irretrievable Commitment of Resources

As discussed in Section 6.3, the control options will result in an increase in the irreversible and irretrievable commitment of energy resources. However, this increased energy demand for pollution control is insignificant compared to the existing energy demand for the electroplating and anodizing processes and capture systems.

6.7.2 Environmental Impact of Delayed Regulatory Action

The only detrimental environmental impact associated with a delay in proposing and promulgating the standard would be the continued generation of hexavalent chromium emissions at the rates described earlier in this chapter. The Administrator has determined that this may reasonably be anticipated to endanger public health or welfare.

Delaying the standard would result in possible solid waste and energy impact reductions. However, the related reductions would be minimal compared with the air quality benefits attributable to promulgation of the standard.

TABLE 6-1. CONTROL TECHNIQUES UPON WHICH THE CONTROL OPTION ENVIRONMENTAL IMPACTS ARE BASED

Type of operation/ Control option	Control technique
Hard chromium plating	
Option I (no action)	Existing (baseline) level of control • 30 percent of operations uncontrolled • 30 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent • 40 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 97 percent
Option II	Chevron-blade mist eliminators that reduce uncontrolled emissions by 95 percent
Option III	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent
Decorative chromium plating	
Option I (no action)	Existing (baseline) level of control • 15 percent of operations uncontrolled • 40 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 40 percent of operations controlled by a combination of chemical fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent • 5 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent
Option IV	Trivalent chromium plating processes that reduce hexavalent chromium emissions by 100 percent (technology-forcing)
Chromic acid anodizing	
Option I (no action)	Existing (baseline) level of control • 40 percent of operations uncontrolled • 30 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 10 percent of operations controlled by chevron-blade mist eliminators that reduce uncontrolled emissions by 90 percent. • 20 percent of operations controlled by packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II	Packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent

TABLE 6-2. NATIONWIDE HEXAVALENT CHROMIUM EMISSION ESTIMATES ASSOCIATED WITH CONTROL OPTIONS FOR HARD CHROMIUM PLATING OPERATIONS

	Plant size			
	Small	Medium	Large	Total
Model plant production rate, Ah/yr (x 10^6)	5	42	160	
Uncontrolled emission factor, mg/Ah (gr/Ah)	10.0 (0.15)	10.0 (0.15)	10.0 (0.15)	
Model plant uncontrolled emission rate, kg/yr (lb/yr)	50 (110)	420 (926)	1,600 (3,530)	
Model plant uncontrolled emission rate, Mg/yr (tons/yr)	0.05 (0.055)	0.42 (0.46)	1.60 (1.76)	
No. of operations nationwide[a]	1,080	310	150	1,540
Nationwide emission estimates, Mg/yr (tons/yr)[a]				
Option I (no-action)[b]				
30 percent UNC[c]	16 (18)	39 (43)	72 (79)	
30 percent CBME at 90 percent[d]	1.6 (1.8)	3.9 (4.3)	7.2 (7.9)	
40 percent PBS at 97 percent[e]	0.65 (0.71)	1.6 (1.7)	2.9 (3.2)	
TOTAL[a]	18 (20)	45 (49)	82 (90)	145 (160)
Option II (95 percent)[f]				
Emissions for:[g]				
30 percent CBME at 95 percent	0.81 (0.89)	2.0 (2.2)	3.6 (4.0)	
30 percent CBME at 95 percent	0.81 (0.89)	2.0 (2.2)	3.6 (4.0)	
40 percent PBS at 97 percent	0.65 (0.71)	1.6 (1.7)	2.9 (3.2)	
TOTAL[a]	2.3 (2.5)	5.5 (6.0)	10 (11)	18 (20)
Option III (99 percent)[h]				
Emission for:[g]				
30 percent PBS or MPME at 99 percent	0.16 (0.18)	0.39 (0.43)	0.72 (0.79)	
30 percent PBS or MPME at 99 percent	0.16 (0.18)	0.39 (0.43)	0.72 (0.79)	
40 percent PBS or MPME at 99 percent	0.22 (0.24)	0.52 (0.57)	0.96 (1.1)	
TOTAL[a]	0.5 (0.6)	1.3 (1.4)	2.4 (2.6)	4.2 (4.7)

[a]Note: Numbers may not add exactly due to independent rounding.
[b]Option I is based on the existing level of control.
[c]UNC = Uncontrolled.
[d]CBME = Chevron-blade mist eliminator that reduces uncontrolled emissions by 90 percent.
[e]PBS = Packed-bed scrubber that reduces uncontrolled emissions by 97 percent.
[f]Based on the use of chevron-blade mist eliminators that reduce uncontrolled emissions by 95 percent.
[g]Percentage of plants nationwide for which emission reduction will be achieved by use of the control technique upon which the control option is based.
[h]Based on the use of packed-bed scrubbers or mesh-pad mist eliminators (MPME) that reduce uncontrolled emissions by 99 percent.

TABLE 6-3. NATIONWIDE EMISSION REDUCTIONS ATTRIBUTABLE TO EACH CONTROL OPTION FOR HARD CHROMIUM PLATING

Control options	Hexavalent chromium emission reductions, Mg/yr (tons/yr)			
	Plant size			
	Small	Medium	Large	Total
Option II vs. Option I				
Emissions under Option I	18 (20)	45 (49)	82 (90)	145 (160)
Emissions under Option II	2.3 (2.5)	5.5 (6.0)	10 (11)	18 (20)
Emission reduction for Option II	16 (18)	39 (43)	72 (79)	127 (140)
Percent reduction over Option I	88	88	88	88
Option III vs. Option I				
Emissions under Option I	18 (20)	45 (49)	82 (90)	145 (160)
Emissions under Option III	0.5 (0.6)	1.3 (1.4)	2.4 (2.6)	4.2 (4.7)
Emission reduction for Option III	18 (20)	43 (48)	80 (88)	141 (155)
Percent reduction over Option I	97	97	97	97
Option III vs. Option II				
Emissions under Option II	2.3 (2.5)	5.5 (6.0)	10 (11)	18 (20)
Emissions under Option III	0.5 (0.6)	1.3 (1.4)	2.4 (2.6)	4.2 (4.7)
Emission reduction for Option III	1.7 (1.9)	4.2 (4.6)	7.7 (8.5)	14 (15)
Percent reduction over Option II	76	76	76	76

TABLE 6-4. NATIONWIDE HEXAVALENT CHROMIUM EMISSION ESTIMATES ASSOCIATED WITH CONTROL OPTIONS FOR DECORATIVE CHROMIUM PLATING OPERATIONS

	Plant size			
	Small	Medium	Large	Total
Model plant production rate, Ah/yr (x 10^6)	3	12	120	
Uncontrolled emission factor, mg/Ah (gr/Ah)	2.0 (0.031)	2.0 (0.031)	2.0 (0.031)	
Model plant uncontrolled emission rate, kg/yr (lb/yr)	6.0 (13)	24 (53)	240 (530)	
Model plant uncontrolled emission rate, Mg/yr (tons/yr)	0.006 (0.0065)	0.024 (0.027)	0.24 (0.27)	
No. of plants nationwide	2,240	420	140	2,800
Nationwide emission estimates, Mg/yr (tons/yr)[a]				
Option I (no-action)[b]				
15 percent UNC[c]	2.0 (2.2)	1.5 (1.7)	5.0 (5.5)	
40 percent FS at 97 percent[d]	0.16 (0.18)	0.12 (0.13)	0.40 (0.44)	
40 percent FS and PBS at 97 percent[e]	0.16 (0.18)	0.12 (0.13)	0.40 (0.44)	
5 percent PBS at 95 percent[f]	0.03 (0.04)	0.03 (0.03)	0.08 (0.09)	
TOTAL[a]	2.4 (2.6)	1.8 (2.0)	5.9 (6.5)	10 (11)
Option II (97 percent)[g]				
Emissions for:[h]				
15 percent PBS or MPME at 97 percent	0.06 (0.07)	0.05 (0.05)	0.15 (0.17)	
40 percent FS at 97 percent	0.16 (0.18)	0.12 (0.13)	0.40 (0.44)	
40 percent FS and PBS at 97 percent	0.16 (0.18)	0.12 (0.13)	0.40 (0.44)	
5 percent PBS at 97 percent	0.02 (0.02)	0.02 (0.02)	0.05 (0.06)	
TOTAL[a]	0.40 (0.44)	0.30 (0.33)	1.0 (1.1)	1.7 (1.9)
Option III (99.5 percent)[i]				
Emissions for:[h]				
15 percent FS at 99.5 percent	0.01 (0.01)	0.01 (0.01)	0.03 (0.03)	
42.5 percent FS at 99.5 percent	0.03 (0.03)	0.02 (0.02)	0.07 (0.08)	
42.5 percent FS and PBS at 99.5 percent	0.03 (0.03)	0.02 (0.02)	0.07 (0.08)	
TOTAL[a]	0.07 (0.07)	0.05 (0.06)	0.17 (0.19)	0.29 (0.32)
Option IV (100 percent)[j]				
Emissions for:[h]				
15 percent TVC at 100 percent	0	0	0	
40 percent TVC at 100 percent	0	0	0	
40 percent TVC at 100 percent	0	0	0	
5 percent TVC at 100 percent	0	0	0	
TOTAL[a]	0	0	0	0

[a]Note: Numbers may not add exactly due to independent rounding.
[b]Option I is based on the existing level of control.
[c]UNC = Uncontrolled.
[d]FS = Fume suppressant that reduces uncontrolled emissions by 97 percent.
[e]FS and PBS = Combination of fume suppressant and packed-bed scrubber that reduces emissions by 97 percent.
[f]PBS = Packed-bed scrubber that reduces uncontrolled emissions by 95 percent.
[g]Based on the use of packed-bed scrubbers or mesh-pad mist eliminators (MPME) that would reduce uncontrolled emissions by 97 percent.
[h]Percentage of plants nationwide for which emission reduction will be achieved by use of the control technique upon which the control option is based.
[i]Based on the use of fume suppressants consistent with vendor recommendations. Uncontrolled emissions would be reduced by 99.5 percent.
[j]Based on the substitution of a trivalent chromium (TVC) plating bath for the conventional hexavalent chromium plating bath. Uncontrolled hexavalent chromium emissions would be reduced by 100 percent.

TABLE 6-5. NATIONWIDE EMISSION REDUCTIONS ATTRIBUTABLE TO EACH CONTROL OPTION FOR DECORATIVE CHROMIUM PLATING

Control options	Hexavalent chromium emission reductions, Mg/yr (tons/yr)			
	Plant size			
	Small	Medium	Large	Total
Option II vs. Option I				
Emissions under Option I	2.4 (2.6)	1.8 (2.0)	5.9 (6.5)	10 (11)
Emissions under Option II	0.40 (0.44)	0.30 (0.33)	1.0 (1.1)	1.7 (1.9)
Emission reduction for Option II	2.0 (2.2)	1.5 (1.7)	4.9 (5.4)	8.4 (9.2)
Percent reduction over Option I	83	83	83	83
Option III vs. Option I				
Emissions under Option I	2.4 (2.6)	1.8 (2.0)	5.9 (6.5)	10 (11)
Emissions under Option III	0.07 (0.07)	0.05 (0.06)	0.17 (0.19)	0.29 (0.32)
Emission reduction for Option III	2.3 (2.5)	1.7 (1.9)	5.8 (6.3)	9.8 (11)
Percent reduction over Option I	97	97	97	97
Option IV vs. Option I				
Emissions under Option I	2.4 (2.6)	1.8 (2.0)	5.9 (6.5)	10 (11)
Emissions under Option IV	0	0	0	0
Emission reduction for Option IV	2.4 (2.6)	1.8 (2.0)	5.9 (6.5)	10 (11)
Percent reduction over Option I	100	100	100	100

TABLE 6-5. (Continued)

Control options	Hexavalent chromium emission reductions, Mg/yr (tons/yr)			
	Plant size			
	Small	Medium	Large	Total
Option III vs. Option II				
Emissions under Option II	0.40 (0.44)	0.30 (0.33)	1.0 (1.1)	1.7 (1.9)
Emissions under Option III	0.07 (0.07)	0.05 (0.06)	0.17 (0.19)	0.29 (0.32)
Emission reduction for Option III	0.33 (0.37)	0.25 (0.27)	0.84 (0.92)	1.4 (1.6)
Percent reduction over Option II	83	83	83	83
Option IV vs. Option II				
Emissions under Option II	0.40 (0.44)	0.30 (0.33)	1.0 (1.1)	1.7 (1.9)
Emissions under Option IV	0	0	0	0
Emission reduction for Option IV	0.40 (0.44)	0.30 (0.33)	1.0 (1.1)	1.7 (1.9)
Percent reduction over Option II	100	100	100	100
Option IV vs. Option III				
Emissions under Option III	0.07 (0.07)	0.05 (0.06)	0.17 (0.19)	0.29 (0.32)
Emissions under Option IV	0	0	0	0
Emission reduction for Option IV	0.07 (0.07)	0.05 (0.06)	0.17 (0.19)	0.29 (0.32)
Percent reduction over Option III	100	100	100	100

TABLE 6-6. NATIONWIDE HEXAVALENT CHROMIUM EMISSION ESTIMATES ASSOCIATED WITH CONTROL OPTIONS FOR CHROMIC ACID ANODIZING OPERATIONS

	Plant size		
	Small	Large	Total
Uncontrolled emission factor, kg/hr/m^2 (lb/hr/ft^2)(10^{-4})	6 (1.2)	6 (1.2)	
Model plant uncontrolled emission rate, kg/yr (lb/yr)	3.3 (7.2)	40 (88)	
Model plant uncontrolled emission rate, Mg/yr (tons/yr)	0.0033 (0.0036)	0.04 (0.044)	
No. of plants nationwide	515	165	680
----------Nationwide emission estimates, Mg/yr (tons/yr)[a]----------			
Option I (no-action)[b]			
40 percent UNC[c]			
10 percent CBME at 90 percent[d]	0.68 (0.74)	2.7 (2.9)	
20 percent PBS at 95 percent[e]	0.02 (0.02)	0.06 (0.07)	
30 percent FS at 97 percent[f]	0.02 (0.02)	0.07 (0.07)	
TOTAL[a]	0.02 (0.02)	0.06 (0.07)	
	0.74 (0.80)	2.8 (3.1)	3.6 (3.9)
Option II (97 percent)[g]			
Emissions for:[h]			
40 percent PBS or MPME at 97 percent			
10 percent PBS or MPME at 97 percent	0.02 (0.02)	0.08 (0.09)	
20 percent PBS or MPME at 97 percent	0.01 (0.01)	0.02 (0.02)	
30 percent FS at 97 percent	0.01 (0.01)	0.04 (0.04)	
TOTAL[a]	0.02 (0.02)	0.06 (0.07)	
	0.05 (0.06)	0.20 (0.22)	0.25 (0.27)
Option III (99.5 percent)[i]			
Emissions for:[g]			
40 percent FS at 99.5 percent			
10 percent FS at 99.5 percent	0.003 (0.004)	0.013 (0.015)	
20 percent FS at 99.5 percent	0.001 (0.001)	0.003 (0.004)	
30 percent FS at 99.5 percent	0.002 (0.002)	0.007 (0.008)	
TOTAL[a]	0.003 (0.003)	0.010 (0.011)	
	0.01 (0.01)	0.03 (0.04)	0.04 (0.05)

[a]Note: Numbers may not add exactly due to independent rounding.
[b]Option I is based on the existing level of control.
[c]UNC = Uncontrolled.
[d]CBME = Chevron-blade mist eliminator that reduces uncontrolled emissions by 90 percent.
[e]PBS = Packed-bed scrubber that reduces uncontrolled emissions by 95 percent.
[f]FS = Fume suppressant that reduces uncontrolled emissions by 97 percent.
[g]Based on the use of packed-bed scrubbers or mesh-pad mist eliminators that would reduce uncontrolled emissions by 97 percent.
[h]Percentage of plants nationwide for which emission reduction will be achieved by use of the control technique upon which the control options are based.
[i]Based on the use of fume suppressants consistent with vendor recommendations. Uncontrolled emissions would be reduced by 99.5 percent.

TABLE 6-7. NATIONWIDE EMISSION REDUCTIONS ATTRIBUTABLE TO EACH CONTROL OPTION FOR CHROMIC ACID ANODIZING OPERATIONS

Control options	Hexavalent chromium emission reductions, Mg/yr (tons/yr)		
	Small	Large	Total
Option II vs. Option I			
Emissions under Option I	0.74 (0.80)	2.8 (3.1)	3.6 (3.9)
Emissions under Option II	0.05 (0.06)	0.20 (0.22)	0.25 (0.27)
Emission reduction for Option II	0.69 (0.76)	2.6 (2.9)	3.4 (3.7)
Percent reduction over Option I	93	93	93
Option III vs. Option I			
Emissions under Option I	0.74 (0.80)	2.8 (3.1)	3.6 (3.9)
Emissions under Option III	0.01 (0.01)	0.03 (0.04)	0.04 (0.05)
Emission reduction for Option III	0.73 (0.80)	2.8 (3.1)	3.6 (3.9)
Percent reduction over Option I	99	99	99
Option III vs. Option II			
Emissions under Option II	0.05 (0.06)	0.20 (0.22)	0.25 (0.27)
Emissions under Option III	0.01 (0.01)	0.03 (0.04)	0.04 (0.05)
Emission reduction for Option III	0.04 (0.04)	0.17 (0.19)	0.21 (0.23)
Percent reduction over Option II	83	83	83

TABLE 6-8. ANNUAL ENERGY REQUIREMENTS TO OPERATE EACH CAPTURE SYSTEM USED FOR THE PLATING AND ANODIZING MODEL PLANTS

	Hard chromium plating			Decorative chromium plating			Anodizing	
	Model plant size			Model plant size			Model plant size	
	Small	Medium	Large	Small	Medium	Large	Small	Large
Operating parameters								
Total ventilation rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2,000 (70,000)	340 (12,000)	680 (24,000)	1,300 (46,000)	340 (12,000)	1,100 (40,000)
Operating time, hr/yr	2,000	3,500	6,000	2,000	4,000	6,000	2,000	6,000
Basic capture system[a]								
No of fans	1	1	2	1	2	3	1	1
Individual fan sizes, hp	10	40	2 @ 40	10	2 @ 10	5, 2 @ 15	10	50
Total fan size, hp	10	40	80	10	20	35	10	50
Electrical use, kWh/yr	14,900	104,400	358,100	14,900	59,700	156,700	14,900	223,800
Modified capture system[b]								
No of fans	1	4	8	1	2	5	1	4
Individual fan sizes, hp	7.5	2 @ 5, 2 @ 7.5	4 @ 5, 4 @ 7 5	7.5	2 @ 7.5	5 @ 7.5	7.5	4 @ 7.5
Total fan size, hp	7.5	25	50	7.5	15	37.5	7.5	30
Electrical use, kWh/yr	11,200	65,300	223,800	11,200	44,800	167,900	11,200	134,300
Increase in electrical use over basic capture system, kWh/yr	(3,700)	(39,100)	(134,300)	(3,700)	(14,900)	11,200	(3,700)	(89,500)

[a]Capture system applicable when scrubbers or chevron-blade mist eliminators are used to control emissions. Standard scrubbers and chevron-blade mist eliminators can handle airflow rates up to 1,680 m^3/min (60,000 ft^3/min).

[b]Capture system modified to handle lower airflow rates for mesh-pad mist eliminators. The maximum airflow rate for a mesh-pad mist eliminator is 340 m^3/min (12,000 ft^3/min).

TABLE 6-9. INCREASE IN ANNUAL ENERGY REQUIREMENTS ATTRIBUTABLE TO CONTROL DEVICES USED FOR THE PLATING AND ANODIZING MODEL PLANTS

	Hard chromium plating			Decorative chromium plating			Anodizing	
	Model plant size			Model plant size			Model plant size	
	Small	Medium	Large	Small	Medium	Large	Small	Large
Operating parameters								
Total ventilation rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2,000 (70,000)	340 (12,000)	680 (24,000)	1,300 (46,000)	340 (12,000)	1,100 (40,000)
Operating time, hr/yr	2,000	3,500	6,000	2,000	4,000	6,000	2,000	6,000
Control device								
Scrubber								
No. of control devices	1	1	1	1	1	3	1	1
Individual fan sizes, hp	15	60	2 @ 60	15	2 @ 15	10, 2 @ 25	15	60
Total fan size, hp	15	60	120	15	30	60	15	60
Increase in energy requirements over basic capture system to operate fans, hp	5	20	40	5	10	25	5	10
Individual pump sizes, hp	1.5	3.0	2 @ 3 0	1.5	2 @ 1.5	1.0, 2 @ 2.0	1.5	5.0
Total pump size, hp	1.5	3.0	6 0	1.5	3 0	5.0	1.5	5 0
Total additional energy requirement, hp	6.5	23	46	6.5	13	30	6.5	15
Increase in electrical use over basic capture system to operate fan, hp	9,700	60,100	205,900	9,700	38,800	134,300	9,700	67,100
Chevron-blade mist eliminator with a single set of blades								
No. of control devices	1	1	2	1	2	3	1	1
Individual fan sizes, hp	10	50	2 @ 50	10	2 @ 10	7.5, 2 @ 20	10	50
Total fan size, hp	10	50	100	10	20	47.5	10	50
Increase in energy requirement over basic capture system to operate fan, hp	0	10	20	0	0	12.5	0	0
Increase in electrical use over basic capture system alone, kWh/yr[a]	0	26,100	89,500	0	0	56,000	0	0
Chevron-blade mist eliminator with a double set of blades								
No. of control devices	1	1	2	1	2	3	1	1
Individual fan sizes, hp	15	60	2 @ 60	15	2 @ 15	10, 2 @ 25	15	60
Total fan size, hp	15	60	120	15	30	60	15	60

TABLE 6-9. (Continued)

	Hard chromium plating			Decorative chromium plating			Anodizing	
	Model plant size			Model plant size			Model plant size	
	Small	Medium	Large	Small	Medium	Large	Small	Large
Increase in energy requirement over basic capture system to operate fans, hp	5	20	40	5	10	25	5	10
Increase in electrical use over basic capture system alone, kWh/yr[a]	7,500	52,200	179,000	7,500	29,800	111,900	7,500	44,800
Mesh-pad mist eliminator								
No. of control devices	1	4	8	1	2	5	1	4
Individual fan sizes, hp	15	7.5, 10, 2 @ 15	2 @ 7.5, 2 @ 10, 4 @ 15	15	2 @ 15	5 @ 15	15	4 @ 15
Total fan size, hp	15	47.5	95	15	30	75	15	60
Increase in energy requirement over modified capture system to operate fans, hp	7.5	22.5	45	7.5	15	37.5	7.5	30
Increase in electrical use over modified capture system use to operated fans, kWh/yr[a]	11,200	58,700	201,400	11,200	44,800	167,900	11,200	134,300
Increase in energy requirement over basic capture system to operate fans, hp	5	7.5	15	5	10	40	5	10
Increase in electrical use over basic capture system to operate fans, kWh/yr[a]	7,500	19,600	67,100	7,500	29,800	179,000	7,500	44,800
Individual pump size, hp	0.75	2 @ 0.5 2 @ 0.75	4 @ 0.5 4 @ 0.75	0.75	2 @ 0.75	5 @ 0.75	0.75	4 @ 0.75
Total pump size, hp	0.75	2.5	5.0	0.75	1.5	3.75	0.75	3.0
Increase in electrical use to operate pumps, kWh/yr[a]	0	100	200	0	0	200	0	100
Total increase in electrical system alone, kWh/yr[a]	11,200	58,800	201,600	11,200	44,800	168,100	11,200	134,400
Total increase in electrical use over basic capture system alone, kWh/yr[a]	7,500	19,700	67,300	7,500	29,900	179,200	7,500	44,900

[a]Numbers were rounded to the nearest 100 kWh.
[b]Calculations for electrical use for pumps are based on the use of the pumps for 5 minutes in each 8-hour time period.

TABLE 6-10. NATIONWIDE ANNUAL ENERGY REQUIREMENTS ASSOCIATED WITH CONTROL OPTIONS FOR HARD CHROMIUM PLATING OPERATIONS

	Plant size			
	Small	Medium	Large	Total
No. of operations nationwide:				
30 percent UNC[a]	324	93	45	
30 percent CBME(1) at 90 percent[b]	324	93	45	
40 percent PBS at 97 percent[c]	432	124	60	
TOTAL[d]	1,080	310	150	1,540
Option I (no-action)[e f]				
30 percent UNC, MWh/yr	4,800	9,700	16,100	
30 percent CBME(1) at 90 percent, MWh/yr	4,800	12,100	20,100	
40 percent PBS at 97 percent, MWh/yr	10,600	20,400	33,800	
Nationwide energy use, MWh/yr[d]	20,300	42,200	70,100	132,600
Option II (95 percent)[f g]				
Increased electrical usage over Option I:				
30 percent CBME(2) at 95 percent, MWh/yr	2,400	4,900	8,100	
30 percent CBME(2) at 95 percent, MWh/yr	2,400	2,400	4,000	
40 percent PBS at 97 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[d]	4,800	7,300	12,100	24,200
Nationwide energy use, MWh/yr[d] (Option I total + total increase for Option II)	25,100	49,500	82,200	156,800
Option IIIa (99 percent)[f h]				
Increased electrical usage over Option I:				
30 percent PBS at 99 percent, MWh/yr[j]	3,100	5,600	9,300	
30 percent PBS at 99 percent, MWh/yr	3,100	3,200	5,200	
40 percent PBS at 99 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[d]	6,300	8,800	14,500	29,500
Nationwide energy use, MWh/yr[d] (Option I total + total increase for Option IIIa)	26,600	51,000	84,600	162,200
Option IIIb (99 percent)[f,i]				
Increased electrical usage over Option I:				
30 percent MPME at 99 percent, MWh/yr[j]	2,400	1,800	3,000	
30 percent MPME at 99 percent, MWh/yr	2,400	(600)	(1,000)	
40 percent PBS at 99 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[d]	4,900	1,200	2,000	8,100
Nationwide energy use, MWh/yr[d] (Option I total + total increase for Option IIIb)	25,100	43,500	72,100	140,800

[a]UNC = Uncontrolled. Energy use based on capture system only.
[b]CBME(1) = Chevron-blade mist eliminators with single sets of blades that reduce uncontrolled emissions by 90 percent.
[c]PBS = Packed-bed scrubbers that reduce uncontrolled emissions by 97 percent.
[d]Note: Numbers may not add exactly due to independent rounding.
[e]Option I is based on the existing level of control.
[f]Numbers were rounded to the nearest 100 MWh.
[g]Control Option II is based on the use of chevron-blade mist eliminators with a double set of blades (CBME(2)).
[h]Control Option IIIa is based on the use of single packed-bed scrubbers.
[i]Control Option IIIb is based on the use of mesh-pad mist eliminators.
[j]MPME = Mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent.

TABLE 6-11. NATIONWIDE ANNUAL ENERGY REQUIREMENTS ASSOCIATED WITH CONTROL OPTIONS FOR DECORATIVE CHROMIUM PLATING OPERATIONS

	Plant size			
	Small	Medium	Large	Total
No. of operations nationwide:				
15 percent UNC[a]	336	63	21	
40 percent FS at 97 percent[b]	896	168	56	
40 percent FS + PBS at 97 percent[c]	896	168	56	
5 percent PBS at 95 percent[d]	112	21	7	
TOTAL[e]	2,240	420	140	2,800
Option I (no-action)[f g]				
15 percent UNC, MWh/yr	5,000	3,800	3,300	
40 percent FS at 97 percent, MWh/yr	13,400	10,000	8,800	
40 percent FS + PBS at 97 percent, MWh/yr	22,000	16,600	16,300	
5 percent PBS at 95 percent, MWh/yr	2,800	2,100	2,000	
Nationwide energy use, MWh/yr[e]	43,200	32,500	30,400	106,100
Option IIa (97 percent)[h i]				
Increased electrical usage over Option I:				
15 percent PBS at 97 percent, MWh/yr	3,300	2,400	2,800	
40 percent FS at 97 percent, MWh/yr	0	0	0	
40 percent FS + PBS at 97 percent, MWh/yr	0	0	0	
5 percent PBS at 97 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[e]	3,300	2,400	2,800	8,500
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option IIa)	46,500	34,900	33,200	114,600
Option IIb (97 percent)[g i]				
Increased electrical usage over Option I:				
15 percent MPME at 97 percent, MWh/yr[j]	2,500	1,900	3,800	
40 percent FS at 97 percent, MWh/yr	0	0	0	
40 percent FS + PBS at 97 percent, MWh/yr	0	0	0	
5 percent PBS at 97 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[e]	2,500	1,900	3,800	8,200
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option IIb)	45,700	34,400	34,200	114,300
Option III (99.5 percent)[g k]				
Increased electrical usage over Option I:				
15 percent FS at 99.5 percent, MWh/yr	0	0	0	
40 percent FS at 99.5 percent, MWh/yr	0	0	0	
40 percent FS + PBS at 99.5 percent, MWh/yr	0	0	0	
2.5 percent FS at 99.5 percent, MWh/yr	(500)	(400)	(500)	
2.5 percent FS + PBS at 99.5 percent, MWh/yr	0	0	0	
TOTAL INCREASE, MWh/yr[e]	(500)	(400)	(500)	(1,400)
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option III)	42,700	32,100	29,900	104,700

TABLE 6-11. (Continued)

	Plant size			
	Small	Medium	Large	Total
Option IV (100 percent)[g] [l]				
Increased electrical usage over Option I				
15 percent TVC at 100 percent, MWh/yr[m]	(5,000)	(3,800)	(3,300)	
40 percent TVC at 100 percent, MWh/yr	(13,400)	(10,000)	(8,800)	
40 percent TVC at 100 percent, MWh/yr	(22,000)	(16,600)	(16,300)	
5 percent TVC at 100 percent, MWh/yr	(2,800)	(2,100)	(2,000)	
TOTAL INCREASE, MWh/yr[e]	(43,200)	(32,500)	(30,400)	(106,100)
Nationwide energy use, MWh/yr (Option I total + total increase for Option IV)	0	0	0	0

[a]UNC = Uncontrolled. Energy use based on capture system only.
[b]FS = Fume suppressant that reduces uncontrolled emissions by 97 percent.
[c]FS + PBS = Fume suppressant and packed-bed scrubber that reduce uncontrolled emissions by 97 percent.
[d]PBS = Packed-bed scrubbers that reduce uncontrolled emissions by 95 percent.
[e]Note: Numbers may not add exactly due to independent rounding.
[f]Option I is based on the existing level of control.
[g]Numbers are rounded to nearest 100 MWh.
[h]Based on the use of packed-bed scrubbers that reduce uncontrolled emissions by 97 percent.
[i]Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
[j]MPME = Mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
[k]Based on use of fume suppressants that reduce uncontrolled emissions by 99.5 percent.
[l]Based on the substitution of a trivalent chromium plating bath for the conventional hexavalent chromium plating bath that would reduce uncontrolled emissions by 100 percent. Energy use is zero because capture and control systems are not required.
[m]TVC = Trivalent chromium process.

TABLE 6-12. NATIONWIDE ANNUAL ENERGY REQUIREMENTS ASSOCIATED WITH CONTROL OPTIONS FOR CHROMIC ACID ANODIZING OPERATIONS

	Plant size		
	Small	Large	Total
No. of plants nationwide:			
40 percent UNC[a]	206	66	
10 percent CBME(1) at 90 percent[b]	51	16	
20 percent PBS at 95 percent[c]	103	33	
30 percent FS at 97 percent[d]	155	50	
TOTAL[e]	515	165	680
Option I (no-action)[f g]			
40 percent UNC, MWh/yr	3,100	14,800	
10 percent CBME(1) at 90 percent, MWh/yr	800	3,600	
20 percent PBS at 95 percent, MWh/yr	2,500	9,600	
30 percent FS at 97 percent, MWh/yr	2,300	11,200	
Nationwide energy use, MWh/yr[e]	8,700	39,100	47,800
Option IIa (97 percent)[g h]			
Increased electrical usage over Option I:			
40 percent PBS at 97 percent, MWh/yr	2,000	4,400	
10 percent PBS at 97 percent, MWh/yr	500	1,100	
20 percent PBS at 97 percent, MWh/yr	0	0	
30 percent FS at 97 percent, MWh/yr	0	0	
TOTAL INCREASE, MWh/yr[e]	2,500	5,500	8,000
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option IIa)	11,200	44,600	55,800
Option IIb (97 percent)[g i]			
Increased electrical usage over Option I:			
40 percent MPME at 97 percent, MWh/yr[j]	1,500	3,000	
10 percent MPME at 97 percent, MWh/yr	400	700	
20 percent PBS at 97 percent, MWh/yr	0	0	
30 percent FS at 97 percent, MWh/yr	0	0	
TOTAL INCREASE, MWh/yr[e]	1,900	3,700	5,600
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option IIb)	10,600	42,800	53,400
Option III (99.5 percent)[g k]			
Increased electrical use over Option I:			
40 percent FS at 99.5 percent, MWh/yr	0	0	
10 percent FS at 99.5 percent, MWh/yr	0	0	
20 percent FS at 99.5 percent, MWh/yr	(1,000)	(2,200)	
30 percent FS at 99.5 percent, MWh/yr	0	0	
TOTAL INCREASE, MWh/yr[e]	(1,000)	(2,200)	(3,200)
Nationwide energy use, MWh/yr[e] (Option I total + total increase for Option III)	7,700	36,900	44,600

[a]UNC = Uncontrolled. Energy use based on capture system only.
[b]CBME(1) = Mist eliminator with single set of blades that reduces uncontrolled emissions by 90 percent.
[c]PBS = Energy use based on basic capture system and packed-bed scrubber that reduces uncontrolled emissions by 97 percent.
[d]FS = Fume suppressant that reduces uncontrolled emissions by 97 percent.
[e]Note: Numbers may not add exactly due to independent rounding.
[f]Option I is based on the existing level of control.
[g]Numbers were rounded to nearest 100 MWh.
[h]Based on the use of packed-bed scrubbers that reduce uncontrolled emissions by 97 percent.
[i]Based on the use of mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
[j]MPME = Mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent.
[k]Based on the use of fume suppressants consistent with vendor recommendations.

TABLE 6-13. NATIONWIDE SOLID WASTE IMPACTS ASSOCIATED WITH THE USE OF SINGLE PACKED-BED SCRUBBERS AND MESH-PAD MIST ELIMINATORS FOR HARD CHROMIUM PLATING OPERATIONS

	Plant size			
	Small[a]	Medium[b]	Large[c]	Total
Single packed-bed scrubbers				
Total volume of packing material, m^3 (ft^3)	0.82 (29)	2.1 (74)	4.2 (148)	
Frequency of replacement, yr	10	10	10	
Mesh-pad mist eliminators				
Total volume of pads, m^3 (ft^3)	0.26 (9.2)	0.72 (26)	1.4 (51)	
Frequency of replacement, yr	4	4	4	
No. of operations nationwide	1,080	310	150	1,540
Nationwide solid waste disposal estimates, m^3 (ft^3)[d e]				
Option I (baseline)				
30 percent UNC[f]	0	0	0	
30 percent CBME(1)[g]	0	0	0	
40 percent PBS[h]	180 (6,400)	130 (4,600)	130 (4,600)	
TOTAL	180 (6,400)	130 (4,600)	130 (4,600)	440 (15,500)
TOTAL ANNUALIZED[i]	18 (6,400)	13 (460)	13 (460)	44 (1,600)
Option II				
30 percent CBME(2)[j]	0	0	0	
30 percent CBME(2)	0	0	0	
40 percent PBS	180 (6,400)	130 (4,600)	130 (4,600)	
TOTAL	180 (6,400)	130 (4,600)	130 (4,600)	440 (15,500)
TOTAL ANNUALIZED[i]	18 (640)	13 (460)	13 (460)	44 (1,600)
Option IIIa				
30 percent PBS	130 (4,600)	100 (3,500)	90 (3,200)	
30 percent PBS	130 (4,600)	100 (3,500)	90 (3,200)	
40 percent PBS	180 (6,400)	130 (4,600)	130 (4,600)	
TOTAL	440 (15,500)	330 (11,700)	310 (10,900)	1,100 (38,800)
TOTAL ANNUALIZED[i]	44 (1,600)	33 (1,200)	31 (1,100)	110 (3,900)
Option IIIb				
30 percent MPME[k]	42 (1,500)	33 (1,200)	32 (1,100)	
30 percent MPME	42 (1,500)	33 (1,200)	32 (1,100)	
40 percent PBS	180 (6,400)	130 (4,600)	130 (4,600)	
TOTAL FROM MPME	84 (3,000)	66 (2,300)	64 (2,300)	210 (7,400)
TOTAL FROM PBS	180 (6,400)	130 (4,600)	130 (4,600)	440 (15,500)
TOTAL ANNUALIZED[i]	39 (1,400)	30 (1,100)	29 (1,000)	100 (3,500)

[a]The small model plant has one control device using 0.82 m^3 (29 ft^3) of disposable packing material for the scrubber or 0.26 m^3 (9.2 ft^3) of disposable material for the mesh-pad mist eliminator.

[b]The medium model plant has one control device using 2.1 m^3 (74 ft^3) of disposable packing material for the scrubber or four control devices (one using 0.13 m^3 [4.7 ft^3], one using 0.17 m^3 [6.0 ft^3], and two using 0.21 m^3 [7.4 ft^3] each of disposable material) for the mesh-pad mist eliminator.

[c]The large model plant has two control devices (each using 2.1 m^3 [74 ft^3] of disposable packing material) for the scrubber or eight control devices (two using 0.13 m^3 [4.7 ft^3] each, two using 0.17 m^3 [6.0 ft^3] each, and four using 0.21 m^3 [7.4 ft^3] each of disposable material) for the mesh-pad mist eliminator.

[d]Calculations made using the assumption that waste material is compacted to 50 percent of its original volume.

[e]Numbers may not add exactly due to independent rounding.

[f]UNC = Uncontrolled.

[g]CBME(1) = Chevron-blade mist eliminator with a single set of blades.

[h]PBS = Single packed-bed scrubber.

[i]Costs for plants using mesh-pad mist eliminators are annualized by dividing by 4; costs for plants using packed-bed scrubbers are annualized by dividing by 10.

[j]CBME(2) = Chevron-blade mist eliminator with a double set of blades.

[k]MPME = Mesh-pad mist eliminator.

TABLE 6-14. NATIONWIDE SOLID WASTE IMPACTS ASSOCIATED WITH THE USE OF SINGLE PACKED-BED SCRUBBERS AND MESH-PAD MIST ELIMINATORS FOR DECORATIVE CHROMIUM PLATING OPERATIONS

	Plant size			
	Small[a]	Medium[b]	Large[c]	Total
Single packed-bed scrubbers				
Total volume of packing material, m^3 (ft^3)	0.82 (29)	1.6 (58)	3.1 (108)	
Frequency of replacement, yr	10	10	10	
Mesh-pad mist eliminators				
Total volume of pads, m^3 (ft^3)	0.26 (9.2)	0.52 (18.4)	1.0 (37)	
Frequency of replacement, yr	4	4	4	
No. of operations nationwide	2,240	420	140	2,800
---------- Nationwide solid waste disposal estimates, m^3 (ft^3)[d e] ----------				
Option I (baseline)				
15 percent UNC[f]	0	0	0	
40 percent FS[g]	0	0	0	
40 percent FS + PBS[h]	370 (13,100)	130 (4,600)	87 (3,100)	
5 percent PBS[i]	46 (1,600)	17 (600)	11 (390)	
TOTAL	420 (14,800)	150 (5,300)	98 (3,500)	670 (23,700)
TOTAL ANNUALIZED[j]	42 (1,500)	15 (530)	10 (350)	67 (2,400)
Option IIa				
15 percent PBS	140 (4,900)	50 (1,800)	33 (1,200)	
40 percent FS	0	0	0	
40 percent FS + PBS	370 (13,100)	130 (4,600)	87 (3,100)	
5 percent PBS	46 (1,600)	17 (600)	11 (390)	
TOTAL	560 (19,800)	200 (7,100)	130 (4,600)	890 (31,400)
TOTAL ANNUALIZED[j]	56 (2,000)	20 (710)	13 (460)	89 (3,100)
Option IIb				
15 percent MPME[k]	44 (1,600)	16 (570)	11 (390)	
40 percent FS	0	0	0	
40 percent FS + PBS	370 (13,100)	130 (4,600)	87 (3,100)	
5 percent PBS	46 (1,600)	17 (600)	11 (390)	
TOTAL FOR PBS	44 (1,600)	16 (570)	11 (390)	71 (2,500)
TOTAL FOR MPME	420 (14,800)	150 (5,300)	98 (3,500)	670 (23,700)
TOTAL ANNUALIZED[j]	53 (1,900)	19(670)	10 (350)	82 (2,900)
Option III				
15 percent FS	0	0	0	
40 percent FS	0	0	0	
40 percent FS + PBS	370 (13,100)	130 (4,600)	87 (3,100)	
2.5 percent FS	0	0	0	
2.5 percent FS + PBS	23 (810)	8 (280)	5 (180)	
TOTAL	390 (13,800)	140 (4,900)	90 (3,200)	620 (21,900)
TOTAL ANNUALIZED	39 (1,400)	14 (490)	9 (320)	62 (2,200)

TABLE 6-14. (Continued)

	Plant size			
	Small[a]	Medium[b]	Large[c]	Total
Option IV				
15 percent TVC[l]	0	0	0	
40 percent TVC	0	0	0	
40 percent TVC	0	0	0	
5 percent TVC	0	0	0	
TOTAL	0	0	0	0
TOTAL ANNUALIZED	0	0	0	0

[a]The small model plant has one control device using 0.82 m^3 (29 ft^3) of disposable packing material for the scrubber or 0.26 m^3 (9.2 ft^3) of disposable material for the mesh-pad mist eliminator.
[b]The medium model plant has two control devices, each using 0.82 m^3 (29 ft^3) of disposable packing material for the scrubber or 0.26 m^3 (9.2 ft^3) of disposable material for the mesh-pad mist eliminator.
[c]The large model plant has three control devices (one using 0.68 m^3 [24 ft^3] and two using 1.2 m^3 [42 ft^3] each of disposable packing material) for the scrubber or five control devices (each using 0.21 m^3 [7.4 ft^3] of disposable material) for the mesh-pad mist eliminator.
[d]Calculations made using the assumption that waste material is compacted to 50 percent of its original volume.
[e]Numbers may not add exactly due to independent rounding.
[f]UNC = Uncontrolled.
[g]FS = Fume suppressant.
[h]FS + PBS = Fume suppressant used in conjunction with packed-bed scrubber.
[i]PBS = Single packed-bed scrubber.
[j]Costs for plants using mesh-pad mist eliminators are annualized by dividing by 4; costs for plants using packed-bed scrubbers are annualized by dividing by 10.
[k]MPME = Mesh-pad mist eliminator.
[l]TVC = Trivalent chromium process.

TABLE 6-15. NATIONWIDE SOLID WASTE IMPACTS ASSOCIATED WITH THE USE OF SINGLE PACKED-BED SCRUBBERS AND MESH-PAD MIST ELIMINATORS FOR CHROMIC ACID ANODIZING OPERATIONS

	Plant size		
	Small[a]	Large[b]	Total
Single packed-bed scrubbers			
Total volume of packing material, m^3 (ft^3)	0.82 (29)	2.4 (86)	
Frequency of replacement, yr	10	10	
Mesh-pad mist eliminators			
Total volume of packing material, m^3 (ft^3)	0.26 (9.2)	0.84 (29.6)	
Frequency of replacement, yr	4	4	
No. of operations nationwide	515	165	680
Nationwide solid waste disposal estimates, m^3 (ft^3)[d e]			
Option I (baseline)			
40 percent UNC[e]	0	0	
10 percent CBME(1)[f]	0	0	
20 percent PBS[g]	42 (1,500)	40 (1,400)	
30 percent FS[h]	0	0	
TOTAL	42 (1,500)	40 (1,400)	80 (2,800)
TOTAL ANNUALIZED[i]	4 (140)	4 (140)	8 (280)
Option IIa			
40 percent PBS	84 (3,000)	79 (2,800)	
10 percent PBS	21 (740)	20 (700)	
20 percent PBS	42 (1,500)	40 (1,400)	
30 percent FS	0	0	
TOTAL	150 (5,300)	140 (4,900)	290 (10,200)
TOTAL ANNUALIZED[i]	15 (530)	14 (490)	29 (1,000)
Option IIb			
40 percent MPME[j]	27 (950)	28 (990)	
10 percent MPME	7 (250)	7 (250)	
20 percent PBS	42 (1,500)	40 (1,400)	
30 percent FS	0	0	
TOTAL FROM MPME	34 (1,200)	35 (1,200)	69 (2,400)
TOTAL FROM PBS	42 (1,500)	40 (1,400)	82 (2,900)
TOTAL ANNUALIZED[i]	13 (460)	13 (460)	26 (920)
Option III			
40 percent FS	0	0	
10 percent FS	0	0	
20 percent FS	0	0	
30 percent FS	0	0	
TOTAL	0	0	0
TOTAL ANNUALIZED	0	0	0

[a]The small model plant has one control device using 0.82 m^3 (29 ft^3) of disposable packing material for the scrubber or 0.26 m^3 (9.2 ft^3) of disposable material for the mesh-pad mist eliminator.
[b]The large model plant has one control device using 2.4 m^3 (86 ft^3) of disposable packing material for the scrubber or four control devices (each using 0.21 m^3 [7.4 ft^3] of disposable material) for the mesh-pad mist eliminator.
[c]Numbers may not add exactly due to independent rounding.
[d]Calculations made using the assumption that waste material is compacted to 50 percent of its original volume.
[e]UNC = Uncontrolled.
[f]CBME(1) = Chevron-blade mist eliminator with a single set of blades.
[g]PBS = Single packed-bed scrubber.
[h]FS = Fume suppressant.
[i]Costs for plants using mesh-pad mist eliminators are annualized by dividing by 4; costs for plants using packed-bed scrubbers are annualized by dividing by 10.
[j]MPME = Mesh-pad mist eliminator.

6.8 REFERENCES FOR CHAPTER 6

1. Cost Enclosure for Control Equipment Vendors: Vendor A. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. December 31, 1986. p. 1-2.

2. Telecon. Barker, R., MRI, with Vendor I. February 21, 1989. Cost information for mesh-pad mist eliminators.

7. COST ANALYSIS OF CONTROL OPTIONS

7.1 INTRODUCTION

This chapter presents cost estimates for various control options for controlling hexavalent chromium emissions from hard and decorative chromium electroplating and chromic acid anodizing operations. Control costs were based on the application of the control options to the model plants presented in Chapter 5. The bases for the cost estimates for each of the control options are presented in Section 7.2. Capital and annualized costs estimated for the model hard chromium plating plants are presented in Section 7.3, for the model decorative chromium plating plants in Section 7.4, and for the model chromic acid anodizing plants in Section 7.5. Aggregate nationwide capital and annualized costs and cost-effectiveness values are presented in Section 7.6. Table 7-1 presents the control techniques upon which the cost impacts are based for each control option. Other cost considerations (e.g., water pollution, hazardous waste, and occupational safety and health) are discussed in Section 7.7. Unit costs (costs for individual control systems) that are used in the model plants are presented in Appendix F. The economic impacts associated with the control options are presented in Chapter 8.

7.2 BASES FOR COSTS OF EMISSION CONTROL TECHNIQUES

7.2.1 New Operations

Cost information was obtained from several major vendors of the control techniques typically used to reduce chromium emissions from chromium plating and chromic acid anodizing operations. Each vendor provided cost estimates based on the model plant parameters presented in Chapter 5 to ensure a common

basis for the cost estimates. Capital costs for ventilation systems, including exhaust hoods and ductwork, are reported separately from those for control devices. Plants typically have to install ventilation systems to comply with occupational health standards that limit potential employee exposure to chromium emissions in the work place. Section 7.7.3 presents the capital costs of ventilation hoods and ductwork for the model plants as costs associated with the OSHA Act. All cost data presented in this chapter are in November 1988 dollars. Sources of data used to calculate capital and annualized costs of the emissions control techniques are listed in Table 7-2. Cost factors used to calculate annualized costs are presented in Table 7-3.

7.2.1.1 Chevron-Blade Mist Eliminators and Packed-Bed Scrubbers. Information on capital costs for each of five different sizes of chevron-blade mist eliminators and packed-bed scrubbers specified in the model plants were obtained from three control device vendors (designated as Vendors A, B, and C).[1,20,21] The vendors also provided operating parameters for mist eliminators and scrubbers (e.g., fan and recirculation pump motor horsepower [hp] requirements; water consumption rates; labor and maintenance hours; and the life expectancy of control devices) that were used to calculate annualized costs.

Vendor A provided the most complete and highest cost estimates of the three vendors. Vendor B provided installed capital cost estimates for mist eliminators and scrubbers that ranged from $10,000 to $20,000 lower than those provided by Vendor A. Annualized cost estimates calculated from the control device operating parameters provided by Vendor B ranged from $1,000 to $10,000 lower than the annualized cost estimates calculated from the control device operating parameters provided by Vendor A. Capital cost estimates provided by Vendor C were incomplete because this vendor did not provide installation costs. Therefore, cost estimates presented in this section are based on the more complete cost data provided by Vendor A.

Capital and annualized cost estimates for chevron-blade mist eliminators with single and double sets of blades and for single

packed-bed scrubbers are presented and discussed in this chapter. Costs for double packed-bed scrubbers are presented in Appendix F.

7.2.1.1.1 Capital costs. The capital costs for chevron-blade mist eliminators and packed-bed scrubbers include the purchase cost of the control device and auxiliaries such as exhaust fans, motors, inlet and outlet transitions, and stacks; direct installation costs for electrical panels and wiring, instrumentation and controls, and piping; indirect costs for erection, engineering services, contractor fees, and contingencies; and startup costs. Installation costs are based on the assumption that the control device would be installed on the roof of the plating shop, which is 6.1 m (20 ft) high and would require no major structural modifications to support the weight of the control device. Erection costs include the cost of renting a crane to hoist the control device onto the roof of the shop. The purchased equipment cost includes taxes and freight costs as well, which are assumed to be 3 and 5 percent of the base equipment cost, respectively.[14] The startup cost is assumed to be 1 percent of the purchased equipment cost.[14]

7.2.1.1.2 Annualized costs. The annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and materials; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs. The annualized costs of packed-bed scrubbers also include the costs of scrubber packing replacement and disposal.

A. Utility costs. Utility costs include the costs of electricity and water required to operate chevron-blade mist eliminators and packed-bed scrubbers. The annual electrical cost attributable to pollution control results from the additional fan horsepower needed to overcome the pressure drop added to the ventilation system by the control device and (in the case of packed-bed scrubbers) the horsepower needed to operate scrubber recirculation pumps. Both the incremental fan and recirculation

pump electrical costs were calculated using the following equation:

$$\text{Electrical cost, } \$/\text{yr} = \left[\left(\frac{0.746\ \text{kW}}{\text{hp}}\right)(\text{hp})(t)\right][C]$$

where:

kW = kilowatt;

hp = horsepower of pump motor or incremental horsepower of fan motor;

t = operating time, hr/yr; and

C = electricity cost, \$0.0461/kWh.[9]

Example: For a single packed-bed scrubber whose fan requires an additional 5 hp to overcome the additional pressure drop and that operates 6,000 hr/yr, the incremental annual electrical cost to operate the fan is:

$$\left[\frac{0.746\ \text{kW}}{\text{hp}}\right][5\ \text{hp}]\left[\frac{6{,}000\ \text{hr}}{\text{yr}}\right]\left[\frac{\$0.0461}{\text{kWh}}\right] = \$1{,}030/\text{yr}.$$

In addition, the single packed-bed scrubber requires a 1-hp pump to recirculate the scrubber water. The annual electrical cost to operate the pump is:

$$\left[\frac{0.746\ \text{kW}}{\text{hp}}\right][5\ \text{hp}]\left[\frac{6{,}000\ \text{hr}}{\text{yr}}\right]\left[\frac{\$0.0461}{\text{kWh}}\right] = \$210/\text{yr}.$$

Therefore, the total annual electrical cost for the scrubber is \$1,240/yr.

Water consumption costs are associated with the washdown of chevron-blade mist eliminators and the operation of packed-bed scrubbers. For the purposes of this analysis, it was assumed that washdown occurs every 8 hours and the water for washdown of mist eliminators is recycled to the process, as is typically the case. Scrubber water also was assumed to be recirculated for 8 hours of operation, at which time the water in the recirculation basin is drained to the process and the basin is

replenished with clean water. Water costs were calculated using the following equations:

(1) Chevron-blade mist eliminators

Water cost, $/yr = [(V)(N)(S)][C]

where:

V = volume of water per washdown, L (gal);

N = number of washdowns per 8-hr shift;

S = number of 8-hour shifts per year; and

C = water cost, $0.20/1,000 L ($0.77/1,000 gal).[10]

(2) Packed-bed scrubbers

Water cost, $/yr = [(V)(f)+(FR)(60 min/hr)(t)][C]

where:

V = recirculation tank volume, L (gal);

f = frequency of washdowns, number per year;

FR = makeup water flow rate, L/min (gal/min);

t = operating time, hr/yr; and

C = water cost, $0.20/1,000 L ($0.77/1,000 gal).[10]

Example: If, for the single packed-bed scrubber used in the examples above, the recirculation tank volume is 120 gal, the makeup water flow rate is 1.5 gal/min, the scrubber is operated 6,000 hr/yr, and the scrubber water is drained to the process and replaced with clean water after 8 hours of operation, or 750 times per year, the annual water cost for this unit is:

$$[(120\ \text{gal})(750) + (1.5\ \text{gal/min})(60\ \text{min/hr})(6{,}000\ \text{hr/yr})]\left[\frac{\$0.77}{1{,}000\ \text{gal}}\right] = \$490/\text{yr}.$$

The total annual cost of utilities for the scrubber is equal to the sum of the annual electrical and water costs, which is $1,730/yr.

B. Replacement costs. Scrubber packing replacement costs were included in annualized scrubber costs because the life of the packing material is less than the life of the control device. Vendor A estimates that most operations will probably need to replace the packing material every 10 years. The packing

material costs approximately \$620/m^3 (\$17.50/ft^3) of material.[22] Annualized packing material replacement costs include the replacement cost of the packing and the transportation and disposal costs associated with the used packing. The replacement costs of the packing material were calculated based on the following equation:

$$\text{Replacement cost, \$/yr} = [(V)(c)](CRF_p)$$

where:

V = volume of packing required for each control device, m^3 (ft^3);

c = cost of packing material, \$620/m^3 (\$17.50/ft^3);[22] and

CRF_p = capital recovery factor of 0.1628, based on an interest rate of 10 percent and a depreciable life of 10 years for the packing.

The transportation and disposal costs for the packing material were calculated based on the following equation:

$$\text{Disposal and transportation cost, \$/yr} = [(N)(dc) + (N)(tc)](CRF_p)$$

where:

N = number of 55-gal drums, V/V_d, rounded to the nearest whole number;

V = volume of packing material disposed for each control device, m^3 (ft^3);

V_d = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3);

dc = disposal cost, \$50.00/drum plus 10 percent tax;[23]

tc = transportation cost, \$40.00/drum;[23] and

CRF_p = capital recovery factor of 0.1628, based on an interest rate of 10 percent and a depreciable life of 10 years for the packing material.

C. <u>Labor costs</u>. The annual cost of operating labor is based on the amount of labor required to operate the control device, plus supervision. The operator labor is based on vendor estimates for labor hours required for each day of operation and a labor rate of \$8.37/hour.[12] It was assumed that 0.25 hour per day of operator labor is required for chevron-blade mist eliminators, and 0.5 hour per day of operator labor is required

for packed-bed scrubbers. The operator labor is independent of the control device size and the number of operating hours per day because the amount of time required to inspect and start up the control device is not a function of its size or how long it operates. The supervisor labor cost is assumed to be 15 percent of the operator labor cost.[14]

The annual cost of maintenance labor for each control device is based on vendor estimates of the maintenance hours required per 2,000 hours of control device operation and a maintenance labor rate of $9.21/hr.[12,13] Maintenance labor is independent of the control device size. The amount of labor does not vary according to the size of the control device because the amount of time to repair damaged parts (spray nozzles, water pumps, etc.) is independent of the size of those parts for these systems.

The operator, supervisor, and maintenance labor requirements for each model plant were calculated based on the assumption that the labor required to operate and maintain more than one control device increased the labor requirement by only 30 percent instead of by 100 percent for each additional control device. For example, for the large hard chromium plating model plant with chevron-blade mist eliminators with a single set of blades (which requires a total of two control devices), the operator and maintenance labor requirement was calculated as follows:

Operator and maintenance labor, $/yr = ($1,430)(1.3) = $1,900 instead of ($1,430)(2) = $2,860.

D. Material costs. The material cost is based on 100 percent of the maintenance labor for each control device.[14] This cost is assumed to increase 100 percent for each additional control device for the model plants.

E. Indirect costs. The indirect costs for each model plant include overhead, property taxes, insurance, and administration. The overhead cost is based on 60 percent of the sum of the operator and maintenance labor plus the material costs.[14] The property taxes, insurance, and administration are equal to 4 percent of the total capital cost.[14] For example, for the large hard chromium plating model plant with chevron-blade mist

eliminators with a single set of blades, the indirect costs were calculated as follows:

Indirect costs, \$/yr = 0.60 [(1.3)(\$1,430) + 3(\$830)] + 0.04[2(45,500)] = \$2,110 + \$3,640 = \$5,800.

F. Capital recovery costs. Capital recovery costs, which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[14]

$$CRC = [TCC][(i\{1 + i\}^n)/(\{1 + i\}^n - 1)]$$

where:

CRC = capital recovery cost, \$/yr;

TCC = total capital cost, \$;

i = annual interest rate, 10 percent; and

n = depreciable life, 20 years.

For example, for the large hard chromium plating model plant with chevron-blade mist eliminators with a single set of blades, the capital recovery costs were calculated as follows:

$$CRC = [\$91,000][(0.10\{1 + 0.10\}^{20})/(\{1 + 0.10\}^{20} - 1)]$$

$$CRC = \$10,600.$$

G. Chromic acid recovery credits. The chromic acid recovery credits are calculated based on the estimated removal efficiency for chevron-blade mist eliminators and packed-bed scrubbers and the assumption that 100 percent of the chromic acid captured by the control device is recovered. The chromic acid recovery credit is calculated using the following equation:

Chromic acid recovery credit, \$/yr = (ER)(Eff)(1.923)(C)

where:

ER = uncontrolled hexavalent chromium emission rate per plant, kg/yr (lb/yr);

Eff = efficiency of control device, decimal percent;

1.923 = ratio of chromic acid molecular weight (100) to hexavalent chromium molecular weight (52); and

C = cost of chromic acid (CrO_3), \$3.28/kg (\$1.49/lb).[11]

7.2.1.2 Mesh Pad Mist Eliminators. Capital cost estimates and operating parameters for the four different sizes of mesh-pad mist eliminators specified for the model plants were obtained from the control device vendor designated as Vendor I.[2-4]

Operating parameters used to calculate annualized costs provided by this vendor include the fan and washdown water pump horsepower, washdown frequency, water consumption rates, maintenance and operating labor hours required to operate and maintain the control device, and the life expectancy of the devices.

7.2.1.2.1 Capital costs. The capital costs include the purchase cost of the control device and auxiliaries such as inlet and outlet transition zones, exhaust fans and motors, washdown pumps and motors, and stacks; direct installation costs for electrical panels and wiring, instrumentation and controls, and piping; indirect costs for erection, engineering services, contractor fees, and contingencies; and startup costs. Installation costs are based on the assumptions that the control device would be installed on the roof of the plating shop, that the roof is 6.1 m (20 ft) high, and that the roof would require no major structural modifications to support the weight of the control device. The purchased equipment cost also includes taxes and freight costs, which are assumed to be 3 and 5 percent, respectively, of the base equipment cost.[14] The startup cost is assumed to be 1 percent of the purchased equipment cost.[14]

Ductwork requirements for mesh pad mist eliminator systems are greater than for other control devices. The type of mesh-pad mist eliminators upon which the cost estimates are based are designed to handle a maximum gas flow rate of 340 m^3/min (12,000 ft^3/min), whereas other control devices have maximum gas flow rates of approximately 1,700 m^3/min (60,000 ft^3/min). Because of this lower limit, control by mesh-pad mist eliminators requires the use of multiple small units rather than one large unit. Consequently, additional ductwork is required to connect these multiple units to the main ventilation system. Therefore, the cost estimates presented in this section include costs associated with the multiple units as well as an incremental ductwork cost to cover the additional ductwork expense. Schematics of the ventilation and ductwork configurations are presented in Chapter 5.

Installation costs for each model plant include the direct installation costs of each unit and an indirect fixed cost of $7,000 that covers the cost of engineering services, contractor fees, and contingencies. The indirect cost is a fixed fee that is applied on a per-plant basis and does not vary with the number of control systems. Therefore, model plant installation costs were computed as the direct installation cost of the unit plus $7,000.

7.2.1.2.2 Annualized costs. Annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and maintenance materials; mesh pad replacement (including disposal costs for old pads); indirect operating costs such as overhead, property taxes, insurance, and administration; and capital recovery costs.

A. Utility costs. Utility costs include the costs of electricity and water required to operate the mesh-pad mist eliminators. Annual electrical costs result from the additional fan horsepower needed to overcome the pressure drop added to the ventilation system by the control device in addition to the horsepower needed to operate the water pumps for the washdown system. The incremental fan electrical costs were calculated using the equation given in Section 7.2.1.1.2-A (annualized utility costs for chevron-blade mist eliminators and packed-bed scrubbers).

The washdown water pumps are assumed to operate about 5 minutes per 8-hr shift. The pump electrical costs were then calculated based on the following equation:

Pump electrical cost, $/yr = $[(0.746\ kW/hp)(hp)(t_p)(t_{cd})](c)$

where:

kW = kilowatt;

hp = horsepower requirement, hp;

t_p = operating time of pump per hour of control device operation, 0.010 hr/hr;

t_{cd} = operating time of control device, hr/yr; and

c = electrical cost, $0.0461/kWh.[9]

For the purposes of this analysis, it was assumed that the washdown water is recycled to the process, as is typically the case. The amount of washdown water required and the frequency of washdown was provided by Vendor I for each size of mesh-pad unit. The water costs for mesh-pad mist eliminators were calculated using the following equation:

$$\text{Water cost, } \$/\text{yr} = [(V)(f)(S)](c)$$

where:

V = volume of washdown water, L(gal);

f = frequency of washdown, No. of times/8-hr shift;

S = number of 8-hr shifts per year, No./yr; and

c = water cost, \$0.20/1,000 L (\$0.77/1,000 gal).[10]

B. Replacement costs. Mesh pad replacement costs were included because the life of the pads is less than the life of the control device. Vendor I estimated that most facilities will need to replace the mesh pads every 4 years. The mesh pad material is estimated to cost approximately \$10,600/m^3 (\$300/ft^3) of material.[4] Annualized mesh pad replacement costs include the replacement cost of the pads and the transportation and disposal costs associated with the used pads. The replacement costs of the pads were calculated based on the following equation:

$$\text{Replacement cost, } \$/\text{yr} = [(V)(c)](CRF_p)$$

where:

V = volume of pad material required for each control device, m^3 (ft^3);

c = cost of pad material, \$10,600/m^3 (\$300/ft^3)[4]; and

CRF_p = capital recovery factor of 0.3154, based on an interest rate of 10 percent and a depreciable life of 4 years for the mesh pads.

The transportation and disposal costs for the mesh pad material were calculated based on the following equation:

$$\text{Transportation and disposal cost, } \$/\text{yr} = [(N)(dc) + (N)(tc)](CRF_p)$$

where:

N = number of 55-gal drums, V/V_d, rounded to the nearest whole number;

V = volume of pad material disposed for each control device, m^3 (ft^3);

V_d = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3);

dc = disposal cost, \$50.00/drum plus 10 percent tax;[23]

tc = transportation cost, \$40.00/drum;[23] and

CRF_p = capital recovery factor of 0.3154, based on an interest rate of 10 percent and a depreciable life of 4 years for the pad material.

C. Labor costs. The annual cost of operating labor is based on the amount of labor required to operate the control device, plus supervision. The operator labor is based on vendor estimates for labor hours required for each day of operation and a labor rate of \$8.37/hr.[12] The operator labor is independent of the control device size and the number of operating hours per day because the amount of time required to inspect and start up the control device is not a function of its size or how long it operates. The supervisor labor cost is assumed to be 15 percent of the operator labor cost.[14]

The annual cost of maintenance labor for each control device is based on vendor estimates of the maintenance hours required per 2,000 hr of operation and a maintenance labor rate of \$9.21/hr.[12,13] Maintenance labor is independent of the control device size. The amount of maintenance labor does not vary according to the size of the control device because the amount of time to repair damaged parts (spray nozzles, water pumps, etc.) is independent of the size of those parts for these systems.

The operator, supervisor, and maintenance labor requirements for each model plant were calculated based on the assumption that the labor required to operate and maintain more than one control device increased the labor requirement by only 30 percent instead of by 100 percent for each additional control device. An example of a calculation for operator and maintenance labor is given in Section 7.2.1.1.2-C.

D. Material costs. The annual cost of materials is assumed to be 100 percent of the maintenance labor cost.[14] The material cost was assumed to increase 100 percent for each additional control device for the model plants.

E. Indirect costs. Indirect costs include overhead, property taxes, insurance, and administration. Overhead cost is set at 60 percent of the sum of the operator and maintenance labor plus the material costs.[14] Property taxes, insurance, and administration equal 4 percent of the total capital cost.[14] An example of a calculation for indirect costs is given in Section 7.2.1.1.2-E.

F. Capital recovery costs. Capital recovery costs, which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[14]

$$CRC = [TCC]\{[i(1 + i)^n]/[(1 + i)^n - 1]\}$$

where:

CRC = capital recovery cost, $/yr;

TCC = total capital cost, $;

i = annual interest rate, 10 percent; and

n = depreciable life, 10 yr.

For example, for the small hard chromium plating model plant with a mesh-pad mist eliminator, the capital recovery costs were calculated as follows:

$$CRC = [\$23,000]\{[0.10(1 + 0.10)^{10}]]/[(1 + 0.10)^{10} - 1]\}$$

$$CRC = \$3,800.$$

G. Chromic acid recovery credits. Chromic acid recovery credits are calculated based on the estimated removal efficiency for mesh-pad mist eliminators and the assumption that 100 percent of the chromic acid captured by the control device is recovered. The chromic acid recovery credit is calculated using the equation presented in Section 7.2.1.1.2-G.

7.2.1.3 Trivalent Chromium Process. Cost data were obtained from four vendors of trivalent chromium plating baths.[5-8] Two types (single cell and double cell) of trivalent chromium processes are currently marketed. The capital cost

estimates developed for the model plants are representative of both processes and are based on a compilation of cost data obtained from the four vendors.

7.2.1.3.1 Capital costs. Capital cost information was obtained for the two model tanks (42 ft^2 and 72 ft^2 of surface area) that are used to configure the model plants. Capital costs include direct costs for new equipment, installation, and startup plus indirect costs, taxes, and freight charges. New equipment requirements include ampere-hour controller(s), anode boxes, a plating bath filtering system, and chillers. The filtering system and chillers are optional equipment purchases. Chillers are required for some operations where parts are plated at high current densities and the production load is heavy or for operations where the temperature of the cooling water is too high to maintain the bath within its normal operating temperature range. Filtering systems are usually recommended to help control plating bath contaminants. The startup cost includes the cost of the initial trivalent chromium plating solution and the initial cost of the passivation solution. Installation costs, based on data obtained from plants, are estimated to be 15 percent of the purchased equipment cost for new operations. Indirect costs for new operations are estimated to be 31 percent of the purchased equipment cost and cover costs associated with engineering and supervision, process startup, and contingencies.[24] Taxes and freight charges were estimated at 3 and 5 percent, respectively, of the base equipment cost.[25]

7.2.1.3.2 Annualized costs. A cost model was developed to compare plating line costs (total cost to operate a plating line) for the hexavalent and trivalent chromium processes. In developing the model, emphasis was placed on operational factors that differ between the two processes and that affect overall production costs. These factors include differences in chemical usage and cost, production efficiency, operation and maintenance requirements, and wastewater treatment requirements. Information on these factors was obtained from facilities that use the hexavalent or trivalent chromium process, from vendors that

manufacture both processes, and from firms that supply wastewater treatment systems. The model, which is outlined in Table 7-4, consists of 10 sections.

The first four sections (A through D) allow for the specification of input parameters pertaining to the part being plated, the model plant size, unit cost factors, and production rates. The remaining six sections (E through J) contain the mathematical expressions used to calculate the cost estimates. A description of each section and its function in the cost model is given below.

A. End-product (part) parameters. In this section, the part and its plating parameters are specified. The parameters include surface area of the part, plating time, current density, and plating thickness. These parameters are used to calculate the required current, in ampere-hours, needed to plate each part or each square foot of part surface area. Ampere-hours are obtained by multiplying the current density (amperes per square foot) by the plating time (hours) and the surface area of the part (square feet). The required current (ampere-hours per square foot) is used to determine the chemical costs. For this analysis, the current density and plating time are assumed to be the same for both the hexavalent and trivalent chromium processes.

B. Model plant parameters. In this section, parameters that define the size of the plating facility are given. These parameters include number of plating lines, annual operating time, percent of time electrodes are energized, fan horsepower required for the ventilation system, and chromium wastewater flow rates. These parameters are used along with the part parameters to determine the production capacity as well as the wastewater treatment and fan electrical requirements.

C. Cost factors. This section specifies the cost factors, expressed in dollars per unit of consumption, for wastewater treatment, process chemicals, and electricity. These factors are used to estimate the cost of individual components that, combined, make up the total annual plating line costs.

D. Production parameter. This section identifies the parameters that establish the production efficiency. These parameters include the rework rate for both processes (the percentage of total parts produced per year that required replating because of flaws in the original finish) and the percent increase in productivity associated with the trivalent chromium process. The rework rates for each process are the most critical variables in the cost model.

Also identified in this section is the maximum annual production rate for the hexavalent chromium process. The maximum annual production rate is an ideal value based on the assumption that no parts require reworking. The maximum annual production rate considers the type of part plated and the size of the plating tank(s). The size of the plating tank(s) limits the number of racks that can be processed, while the part size and plating specifications limit the number of parts that can be put on a rack (rack population).

E. Production rates. This section of the model calculates the production rates. The maximum annual production rate for the trivalent chromium process is equal to the maximum annual production rate of the hexavalent chromium process plus the percent increase in productivity specified in Section D. The total number of parts a facility can sell or distribute as final end products is less than the maximum annual production rate because of reworked parts that are replated. The number of parts that are replated each year is equal to the maximum annual production rate times the rework rate. Once the number of reworked parts per year is known, the number of parts that were plated and did not require reworking (once-through parts) and the total annual production rate can be determined. The number of once-through parts is equal to the maximum annual production rate

minus twice the number of reworked parts, since all reworked parts are plated two times. The total annual production rate is then equal to the sum of the number of once-through parts and the number of reworked parts. A basic assumption used in determining the total annual production rate is that all reworked parts are replated only once.

F. Chemical cost. This section of the model calculates the chemical costs on a per-unit basis. Chemical costs are calculated by multiplying the chemical cost factor ($/Ah) for each process as specified in Section C by the amount of current required per square foot of part surface area (Ah/ft^2) as specified in Section A. This product, in terms of dollars per square foot, is then multiplied by the surface area of each part to obtain the chemical cost per part. The chemical cost difference between the two processes is then calculated and subsequently used to determine the unit plating costs (plating cost per part) for the trivalent chromium process.

G. Plating costs. This section provides estimates of annual plating costs for both processes. First, the unit plating costs are calculated. The plating cost factor ($\$/ft^2$) for hexavalent chromium plating is a known input for the type of part selected. The unit plating cost for hexavalent chromium plating is calculated by multiplying the plating cost factor ($\$/ft^2$) by the surface area ($ft^2$) of the part, or end product, to be plated. The unit plating cost includes costs associated with process chemicals, utilities, and maintenance and labor. The unit plating cost for trivalent chromium is assumed to equal the unit plating cost calculated for hexavalent chromium plus the incremental cost for chemicals associated with the trivalent chromium process (calculated in Section F). This assumption is valid because the only component of unit plating costs that differs between the two processes is the chemical cost. For both processes, the rework unit plating cost is twice the original plating cost because reworked parts are plated twice.

Annual plating costs for once-through and reworked parts are calculated by multiplying the unit plating costs for once-through

parts by the number of once-through parts and adding the result to the product of the unit plating cost for reworked parts times the number of reworked parts.

H. Wastewater treatment costs. In this section, the volume of wastewater to be treated and the associated treatment costs are calculated based on the size of the plating operations. The volume of wastewater treated per year is the product of the wastewater flow rate for each plating line (Section B), the number of plating lines (Section B), and the annual operating time (Section C). This value (gal/yr) is then multiplied by the wastewater treatment cost factor ($/gal), specified in Section C for each process, to yield the annual wastewater treatment costs.

I. Fan electrical costs. This section presents calculations for fan electrical costs associated with the operation of fans needed for exhaust ventilation. Fan electrical costs apply only to the hexavalent chromium process because trivalent chromium processes do not require ventilation. Annual fan electrical costs are calculated by multiplying annual fan electrical requirements (kWh) by the unit electrical cost ($/kWh) specified in Section C. The fan electrical requirements are based on the horsepower requirements for the exhaust ventilation system and the annual facility operating hours specified in Section B.

J. Plating line costs. Annual costs for plating, wastewater treatment, and fan electrical requirements are summed to obtain the total annual plating line cost. The total annual plating line costs are then divided by the total annual production rate for each process to obtain unit plating line costs for each process. The unit plating line cost for the trivalent chromium process is then subtracted from the unit plating line cost of the hexavalent chromium process to obtain the cost difference. This cost difference is then multiplied by the total number of parts produced per year with the hexavalent chromium process to yield the incremental annual cost or savings associated with the trivalent chromium process.

The key inputs in the cost model and the basis of these inputs are presented in Appendix G. The rework rates for both processes are the most critical variables influencing the total plating line cost. The analysis on the rework rate and its influence on the plating costs is also presented in Appendix G.

Capital recovery costs were calculated based on the estimates of capital costs associated with the installation of the trivalent chromium process at new facilities. Costs of capital recovery for equipment purchases were calculated based on the following equation:

$$CRC = TCC[i(1 + i)^n/(1 + i)^n - 1]$$

where:

CRC = capital recovery costs, $/yr;

TCC = total capital investment;

i = interest rate, 10 percent; and

n = equipment life, years.

The equipment life was estimated by a vendor of the trivalent and hexavalent chromium processes.[26] The capital recovery costs associated with the cost of the initial trivalent chromium solution were calculated by the same equation as above, but, instead of the life of the equipment, a loan life of 10 years was assumed.

The incremental capital cost to install the trivalent chromium process instead of the hexavalent chromium process includes a credit for not having to install certain components of the wastewater treatment system required for processing wastewater from the hexavalent chromium processes. These credits were spread over 10 years. These annual credits were then subtracted from the capital recovery costs to obtain a net capital recovery cost for each model plant.

7.2.1.4 Fume Suppressants. Cost information for the application and maintenance of a variety of fume suppressants was obtained from five major manufacturers.[15-19] Cost estimates were obtained for all three types of chemical fume suppressants (wetting agents, foam blankets, and combinations of wetting

agents and foam blankets). For cost purposes, the chemical fume suppressants were classified as either permanent or temporary. Permanent fume suppressants are those which are mainly depleted by drag-out of the plating solution, and temporary fume suppressants are those which are depleted mainly by decomposition of the fume suppressant in the plating bath and, to lesser extent, by drag-out.

Annual costs include both the material cost of the initial makeup addition and the material cost of maintenance additions of the fume suppressant in the plating bath(s). Initial makeup is the addition of a fume suppressant to a plating bath not using a fume suppressant. Maintenance additions are added periodically after startup to maintain the fume suppressant concentration in the bath at the recommended level. There is no capital investment in equipment associated with the use of fume suppressants. The makeup addition of the fume suppressant is not considered a capital cost because it is an expendable material and would only last a few days without frequent maintenance additions.

Each of the five vendors contacted provided cost information for applying their fume suppressants on the three model tanks (42 ft^2, 72 ft^2, and 150 ft^2 of surface area) that were used to develop model decorative chromium plating and chromic acid anodizing plants. Tank operating times were provided to the vendors to ensure a common basis for the cost estimates. For decorative chromium plating model plants, maintenance addition cost estimates were based on operating the 42-ft^2 model tank 1,600 hr/yr and the 72-ft^2 model tank 4,800 hr/yr. For chromic acid anodizing model plants, maintenance addition cost estimates were based on operating the 42-ft^2 model tank 500 hr/yr and the 150-ft^2 model tank 5,760 hr/yr. The average makeup and maintenance addition costs of both the permanent and temporary fume suppressants for each tank were used to compute the annual costs for the model plants.

Information received from the industry indicated that the operating times used to develop the cost estimates were not

representative of the tank operating times for decorative chromium plating and chromic acid anodizing operations. Adjustments were then made to the tank operating times, and, subsequently, to the maintenance addition costs obtained from vendors. An operating time adjustment ratio was developed to correct the difference between the revised operating time of the model tanks and the operating time upon which the maintenance cost data were originally based. This ratio was then multiplied by the maintenance cost calculated for each model tank to obtain the corrected cost estimates. For example, the average temporary fume suppressant maintenance addition cost supplied by vendors for the 42-ft^2 model tank for decorative chromium plating is $1,200, based on a tank operating time of 1,600 hr/yr. The revised 42-ft^2 model tank in the small decorative chromium plating model plant operates 1,200 hr/yr. Therefore, the operating time adjustment ratio is 1,200/1,600 or 0.75, and the annual maintenance addition cost is $900 (0.75 times $1,200). The annual cost for each model plant was then calculated by multiplying the number of model tanks used in the model plant by their respective makeup and maintenance cost estimates to obtain a total annual cost estimate for the model plant.

The annual costs do not include labor costs because the labor required to add fume suppressants to the bath is negligible. Chromic acid recovery credits are calculated based on the reduction in the chromic acid plating solution lost when chemical fume suppressants were used in the plating tank over that when the plating tank was uncontrolled.

7.2.2 Existing Operations

7.2.2.1 Chevron-Blade Mist Eliminators, Packed-Bed Scrubbers, and Mesh-Pad Mist Eliminators. Estimates for capital and annualized costs to retrofit chevron-blade mist eliminators with single and double sets of blades, single packed-bed scrubbers, and mesh-pad mist eliminators for each hard and decorative chromium electroplating and chromic acid anodizing model plant were developed based on information provided by vendors. The retrofit costs account for any necessary ductwork

modifications as well as the removal and disposal of any existing control device to be replaced at the facility. Actual retrofit costs vary and depend on the particular facility, its layout, and the presence or absence of an existing control device.

Three control device vendors provided estimates of retrofit costs.[27-29] Based on these estimates, a scaling factor of 20 percent of the installed capital costs of control for new facilities was used to estimate retrofit capital costs for existing facilities. The disposal and transportation costs for existing control devices were not included in the vendor estimates. Therefore, an additional 5 percent was added to cover these costs. The 5 percent was based on the estimated disposal and transportation costs for various sizes and types of control devices. The total retrofit scaling factor is, then, 25 percent of the installed capital cost of control for new facilities.

Annualized retrofit costs of chevron-blade mist eliminators, packed-bed scrubbers, and mesh-pad mist eliminators are higher than those for new facilities due to the higher capital recovery costs and higher indirect costs. These costs are both a function of the installed capital cost. Capital recovery costs for a retrofit situation are higher because the installed capital cost for retrofit is 25 percent higher. The taxes, insurance, and administration components of the indirect costs are higher because these costs are based on 4 percent of the capital costs.

7.2.2.2 Trivalent Chromium Process. Cost data were obtained from four manufacturers of trivalent chromium plating baths.[5-8] Capital costs for existing operations include the direct cost of new equipment, startup, and installation/ modification, indirect costs, taxes, and freight charges. New equipment consists of an ampere-hour controller, tank liner, replacement anodes and hangers, and anode boxes. The startup (tank conversion) costs include the initial makeup cost of the trivalent chromium plating solution, the initial makeup cost of the passivation solution, and the disposal cost (transportation and treatment) of the hexavalent chromium solution as a hazardous

waste. Disposal costs were obtained from a waste management facility.[30]

For existing operations, costs for installation/modification are estimated to be 20 percent of the purchased equipment cost.[24] Included in these costs are the costs for installing new equipment, tank cleaning, and modifying the plating line, electrical supply, or cooling system. Indirect costs are estimated to be 31 percent of the purchased equipment cost and include costs associated with engineering and supervision, process startup, and contingencies. Taxes and freight charges are estimated at 3 to 5 percent of the base equipment, respectively.[25]

Annual plating line costs associated with using the trivalent chromium plating process at existing operations are the same as the costs for new operations. However, the annualized costs are higher for existing facilities because of increased costs for capital recovery. Capital recovery costs were higher for existing operations because more capital was needed to modify the existing plating line(s) than was needed to install the trivalent chromium process rather than the hexavalent chromium process at new facilities.

7.2.2.3 Fume Suppressants. Costs associated with using fume suppressants at existing operations are the same as those at new operations.

7.3 MODEL PLANT COSTS FOR HARD CHROMIUM PLATING OPERATIONS

This section presents the installed capital and annualized costs of emission control techniques for new and existing hard chromium plating operations. Table 7-5 presents the model plant parameters on which the installed capital and annualized costs of control devices are based.

7.3.1 Chevron-Blade Mist Eliminators and Single Packed-Bed Scrubbers

7.3.1.1 Capital Costs. Table 7-6 presents total installed capital costs including equipment, installation, and startup for chevron-blade mist eliminators and single packed-bed scrubbers applied to the hard chromium plating model plants. These

estimates were compiled from information presented in Tables F-4 through F-7 of Appendix F on unit costs.

7.3.1.1.1 New operations. Installed capital costs for the model small plant range from $22,500 for the chevron-blade mist eliminator with a single set of blades to $36,700 for the single packed-bed scrubber. Capital costs for the model large plant range from $91,000 for the chevron-blade mist eliminator with a single set of blades to $148,400 for the single packed-bed scrubber. For a given control device, capital costs for the model large plant are about four times higher than capital costs for the model small plant. Capital costs for single packed-bed scrubbers are about 60 percent higher than capital costs for chevron-blade mist eliminators with a single set of blades and about 50 percent higher than capital costs for chevron-blade mist eliminators with a double set of blades.

7.3.1.1.2 Existing operations. Estimated capital costs to retrofit a chevron-blade mist eliminator with a double set of blades at the model small, medium, and large plants are $29,800, $62,400, and $124,800, respectively. For the single packed-bed scrubber, the costs are $45,900, $92,800, and $185,500, respectively.

7.3.1.2 Annualized Costs. The annualized costs for chevron-blade mist eliminators and single packed-bed scrubbers for the model hard chromium plating plants are presented in Table 7-7. The annualized cost estimates, with the exception of the labor requirements and indirect costs, were compiled from information presented in Tables F-8 through F-10 of Appendix F on unit costs. The procedures for calculating labor requirements, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.1.2.

7.3.1.2.1 New Operations. The net annualized costs (annualized costs less chromic acid recovery credits) for the model small plant range from $5,500 for the chevron-blade mist eliminator with a double set of blades to $9,800 for the single packed-bed scrubber. Net annualized costs for the model large plant range from $20,100 for the chevron-blade mist eliminator

with a double set of blades to $39,000 for the single packed-bed scrubber. Net annualized costs for chevron-blade mist eliminators with a double set of blades are 15 to 33 percent higher than mist eliminators with a single set of blades.

7.3.1.2.2 Existing operations. The net annualized costs for retrofitting the chevron-blade mist eliminator with a double set of blades at the model small, medium, and large plants are $6,400, $12,200, and $24,000, respectively. For the single packed-bed scrubber, the costs are $11,200, $21,600, and $44,800.

7.3.2 Mesh-Pad Mist Eliminators

7.3.2.1 Capital Costs. Table 7-8 presents the total installed capital costs including equipment, additional ductwork, installation, and startup for mesh-pad mist eliminators applied to the model hard chromium plating plants. These estimates, with the exception of the additional ductwork costs, were compiled from information presented in Table F-20 of Appendix F on the unit costs.

7.3.2.1.1 New operations. Installed capital costs for the mesh-pad mist eliminators range from $23,000 for the model small plant to $124,900 for the model large plant. Capital costs for the model large plant are about five times higher than capital costs for the model small plant. For the model small plant, capital costs for mesh-pad mist eliminators are 37 percent lower than the capital costs of single packed-bed scrubbers and 3 percent lower than the capital costs of chevron-blade mist eliminators with a double set of blades. For the model medium plant, capital costs for mesh-pad mist eliminators are 11 percent lower than for single packed-bed scrubbers and 33 percent higher than those for chevron-blade mist eliminators with a double set of blades. For the model large plant, capital costs for mesh-pad mist eliminators are 16 percent lower than capital costs for single packed-bed scrubbers and 25 percent higher than capital costs for chevron-blade mist eliminators with a double set of blades.

7.3.2.1.2 Existing operations. Estimated capital costs to retrofit mesh-pad mist eliminators at the model small, medium,

and large plants are $28,900, $82,500, and $156,300, respectively.

7.3.2.2 Annualized Costs. The annualized costs for mesh-pad mist eliminators for the model hard chromium plating plants are presented in Table 7-9. The annualized cost estimates, with the exception of the labor requirements and indirect costs, were compiled from information presented in Table F-21 of Appendix F on unit costs. The procedures for calculating labor requirements, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.2.2.

7.3.2.2.1 New operations. The net annualized costs (annualized costs less chromic acid recovery credits) for the mesh-pad mist eliminator range from $8,000 for the model small plant to $52,600 for the model large plant.

7.3.2.2.2 Existing operations. The net annualized costs for retrofitting mesh-pad mist eliminators at the model small, medium, and large plants are $9,200, $27,300, and $59,000, respectively.

7.4 MODEL PLANT COSTS FOR DECORATIVE CHROMIUM PLATING OPERATIONS

This section presents the installed capital and annualized costs of emission control techniques applied to new and existing decorative chromium plating operations. Table 7-10 presents the model plant parameters on which the installed capital and annualized cost estimates of control techniques are based.

7.4.1 Single Packed-Bed Scrubbers

7.4.1.1 Capital Costs. Table 7-11 presents the total installed capital costs including equipment, installation, and startup for single packed-bed scrubbers applied to the model decorative chromium plating plants. These estimates were compiled from information presented in Table F-6 of Appendix F on unit costs.

7.4.1.1.1 New operations. Installed capital costs for single packed-bed scrubbers range from $36,700 for the model small plant to $124,600 for the model large plant. Capital costs for the model large plant are about three times higher than capital costs for the model small plant.

7.4.1.1.2 Existing Operations. Estimated capital costs to retrofit single packed-bed scrubbers at the model small, medium, and large plants are $45,900, $91,800, and $155,900, respectively.

7.4.1.2 Annualized Costs. The annualized costs for single packed-bed scrubbers for the decorative chromium plating model plants are presented in Table 7-12. The annualized cost estimates, with the exception of the labor requirements and indirect costs, were compiled from information presented in Table F-10 of Appendix F on unit costs. The procedures for calculating labor requirements, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.1.2.

7.4.1.2.1 New operations. The net annualized costs (annualized costs less chromic acid recovery credits) for the single packed-bed scrubber range from $10,100 for the model small plant to $40,400 for the model large plant.

7.4.1.2.2 Existing operations. The net annualized costs for retrofitting single packed-bed scrubbers at the model small, medium, and large plants are $11,500, $24,400, and $45,200, respectively.

7.4.2 Mesh-Pad Mist Eliminators

7.4.2.1 Capital Costs. Table 7-13 presents total installed capital costs including the equipment, additional ductwork, installation, and startup for mesh-pad mist eliminators applied at the model decorative chromium plating plants. These estimates, with the exception of additional ductwork costs, were compiled from information presented in Table F-20 of Appendix F on unit costs.

7.4.2.1.1 New operations. Installed capital costs for mesh-pad mist eliminators range from $23,000 for the model small plant to $87,200 for the model large plant. Capital costs for the model large plant are about four times higher than capital costs for the model small plant. Capital costs of mesh-pad mist eliminators are 30 to 47 percent lower than the capital costs of single packed-bed scrubbers.

7.4.2.1.2 Existing operations. Estimated capital costs to retrofit mesh-pad mist eliminators at the model small, medium, and large plants are $28,900, $49,000, and $109,100, respectively.

7.4.2.2 Annualized Costs. The annualized costs for mesh-pad mist eliminators for the decorative chromium plating model plants are presented in Table 7-14. The annualized cost estimates, with the exception of the labor requirements and indirect costs, were compiled from information presented in Table F-21 of Appendix F on unit costs. The procedures for calculating labor requirements, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.2.2.

7.4.2.2.1 New operations. The net annualized costs (annualized costs less chromic acid recovery credits) for mesh-pad mist eliminators range from $8,300 for the model small plant to $42,800 for the model large plant.

7.4.2.2.2 Existing operations. The net annualized costs for retrofitting mesh-pad mist eliminators at the model small, medium, and large plants are $9,500, $18,900, and $47,300, respectively.

7.4.3 Chemical Fume Suppressants

Table 7-15 presents the net annualized costs (annualized costs less chromic acid recovery credits) of fume suppressants for the model decorative chromium electroplating plants. There is no capital investment associated with using fume suppressants as a control technique. For temporary fume suppressants, net annual costs range from $900 for the model small plant to $11,000 for the model large plant. Net annual costs for permanent fume suppressants range from $1,000 for the model small plant to $17,200 for the model large plant. Annual costs associated with using fume suppressants are the same for new and existing operations.

7.4.4 Trivalent Chromium Process

7.4.4.1 Capital Costs.

7.4.4.1.1 New operations. The incremental capital costs of installing the trivalent chromium plating process rather than the

conventional hexavalent chromium plating process at new facilities are presented in Table 7-16. Total capital costs are $44,800 for the model small plant and $306,000 for the model large plant. Since using the trivalent chromium process eliminates the need for a hexavalent chromium reduction step in the wastewater treatment system, a cost savings is achieved. The capital cost for the hexavalent chromium reduction step was obtained from a 1985 EPA document.[31] Treatment equipment and ancillary items no longer required for reduction purposes were identified, and their associated costs were estimated. In addition, the volume of process wastewater to be treated was estimated for each model plant based on information presented in the development document for effluent guidelines and standards.[32] The cost savings associated with eliminating the hexavalent chromium reduction step ranged from $19,600 for the model small plant to $41,400 for the model large plant. After adding in this savings, the net capital costs of a trivalent chromium process for the model small plant would be reduced to $25,200, and net capital costs for the model medium and large plants would be reduced to $60,000 and $264,600, respectively.

7.4.4.1.2 Existing operations. The capital costs associated with converting a hexavalent chromium process to a trivalent chromium process for each model plant are presented in Table 7-17. These costs range from $66,900 for the model small plant to $565,500 for the model large plant.

7.4.4.2 Annualized Costs. The difference in annual plating line costs between the hexavalent and trivalent chromium processes was calculated for three different end products using the cost model detailed in Table 7-4. These three end products were faucets, ratchets, and bumpers. For the purpose of this analysis, the model small plant was assumed to be plating the ratchets, the model medium plant the faucets, and the model large plant the bumpers. Because the plating line costs are highly dependent on the reject or rework rate for the hexavalent chromium processes (see Appendix G) and because of the wide range of rework rates encountered in the industry, three comparative

cost scenarios representative of the full range of rework rates were developed. In contrast, rework rates reported for the trivalent chromium process are fairly uniform. Consequently, for each scenario, the trivalent chromium rework rate was set at 1 percent, while the rework rate for the hexavalent chromium process varied. In the first scenario, the rework rates for the hexavalent chromium process were set at the values provided by individual plants that actually plate the parts selected. The corresponding hexavalent chromium rework rates for the first scenario were 1, 3, and 15 percent for faucets, ratchets, and bumpers, respectively. In the second scenario, the rework rate for all parts was set at the average rework rate (7 percent) provided by the hexavalent chromium plants. In the third scenario, the individual hexavalent chromium process rework rates were set at a value that yields a zero cost difference between the two processes. The hexavalent chromium rework rates for this third scenario were 2.85, 4.5, and 6.75 percent for ratchets, faucets, and bumpers, respectively. The results from the cost model for each of the three scenarios are presented in Tables 7-18 through 7-20.

The incremental annualized costs associated with the trivalent chromium process were calculated by adding the capital recovery costs to the total annual plating cost difference between the two processes. Since three different scenarios were used to determine the incremental annual plating cost difference associated with the trivalent chromium process, there are also three separate incremental annualized costs based on these scenarios. The capital recovery costs are presented in Table 7-21, and the resulting incremental annualized costs are presented in Table 7-22.

7.5 MODEL PLANT COSTS FOR CHROMIC ACID ANODIZING OPERATIONS

This section presents the installed capital and annualized costs of emission control techniques for new and existing chromic acid anodizing operations. Table 7-23 presents the model plant parameters on which the installed capital and annualized costs of control techniques are based.

7.5.1 Chevron-Blade Mist Eliminators and Single Packed-Bed Scrubbers

7.5.1.1 Capital Costs. Table 7-24 presents total installed capital costs including equipment, installation, and startup for chevron-blade mist eliminators with a single set of blades and single packed-bed scrubbers applied to the model chromic acid anodizing plants. These estimates were compiled from information presented in Tables F-4 and F-6 of Appendix F on unit costs.

7.5.1.1.1 New operations. Installed capital costs for the model small plant range from $22,500 for the chevron-blade mist eliminator with a single set of blades to $36,700 for the single packed-bed scrubber. Capital costs for the model large plant range from $48,600 for the chevron-blade mist eliminator with a single set of blades to $78,700 for the single packed-bed scrubber. Capital costs of either control device for the model large plant are about twice those of the model small plant.

7.5.1.1.2 Existing Operations. Estimated capital costs to retrofit single packed-bed scrubbers are $45,900 at the model small plant and $98,400 for the model large plant.

7.5.1.2 Annualized Costs. Table 7-25 presents the annualized costs for chevron-blade mist eliminators with a single set of blades and single packed-bed scrubbers for the model chromic acid anodizing plants. The cost estimates, with the exception of labor requirements and indirect costs, were compiled from information presented in Tables F-8 and F-10 of Appendix F on the unit costs. Procedures for calculating labor requirements, material cost, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.1.2.

7.5.1.2.1 New operations. The net annualized costs (annualized costs less chromic acid recovery credits) for the single packed-bed scrubber are $10,100 for the model small plant and $25,500 for the model large plant.

7.5.1.2.2 Existing operations. The net annualized costs for retrofitting single packed-bed scrubbers are $11,500 for the model small plant and $28,600 for the model large plant.

7.5.2 Mesh-Pad Mist Eliminators

7.5.2.1 Capital Costs. Table 7-26 presents the total installed capital costs of mesh-pad mist eliminators for the model chromic acid anodizing plants. These estimates, with the exception of the additional ductwork costs, were compiled from information presented in Table F-20 of Appendix F for unit costs. As discussed in Section 7.2.1.2.1, additional ductwork is required to accommodate the low air flows associated with mesh-pad mist eliminators.

7.5.2.1.1 New operations. Installed capital costs for mesh-pad mist eliminators range from $23,000 for the model small plant to $91,700 for the model large plant. Capital costs for the model large plant are about four times higher than capital costs for the model small plant. Capital costs of mesh-pad mist eliminators for the model small plant are about 40 percent lower than capital costs of single packed-bed scrubbers. For the model large plant, capital costs of mesh-pad mist eliminators are about 20 percent higher than capital costs of single packed-bed scrubbers.

7.5.2.1.2 Existing operations. Estimated capital costs to retrofit mesh-pad mist eliminators are $28,900 for the model small plant and $114,900 for the model large plant.

7.5.2.2 Annualized Costs. Table 7-27 shows the annualized costs for mesh-pad mist eliminators for the model chromic acid anodizing plants. The annualized cost estimates, except for labor requirements and indirect costs, were compiled from information presented in Table F-21 of Appendix F on unit costs. Procedures for calculating labor requirements, indirect costs, and chromic acid recovery credits are described in Section 7.2.1.2.2.

7.5.2.2.1 New operations. The net annualized costs (annualized costs less chromic acid recovery credits) for mesh-pad mist eliminators range from $8,300 for the model small plant to $39,800 for the model large plant.

7.5.2.2.2 Existing operations. The net annualized costs for retrofitting mesh-pad mist eliminators are $9,500 for the model small plant and $44,400 for the model large plant.

7.5.3 Chemical Fume Suppressants

Table 7-28 presents the net annualized costs (annualized costs less chromic acid recovery credits) of permanent fume suppressants for the chromic acid anodizing model plants. Cost data were provided only for permanent fume suppressants. There is no capital investment associated with using fume suppressants as a control technique. Net annual costs for permanent fume suppressants range from $1,600 for the model small plant to $4,300 for the model large plant. Annual costs associated with using fume suppressants for new and existing operations are the same.

7.6 TOTAL INDUSTRY COSTS

This section presents estimates of total aggregate costs, both capital and annualized, associated with applying each control option industrywide. Nationwide capital and annualized costs for each control option are based on a combination of new facility and existing facility costs for the model plants, the estimated number of operations nationwide of each size model plant, and the percentage of operations controlled by a specific control technique.

For operations controlled by a specific control technique under Option I, model plant costs representative of new facility costs were used to determine the nationwide baseline control costs. For the other control options, existing facility costs (retrofit costs) were used for operations that went from one control technique under Option I to another control technique under one of the other options. New facility costs were used for operations that went from uncontrolled under Option I to a specified control technique under one of the other options and for operations for which the specified control technique is the same under Option I as it would be under other options.

Cost effectiveness is the annual cost to control 1 Mg of hexavalent chromium. The cost effectiveness of a control option

is determined by dividing the incremental annualized cost estimate by the incremental annual hexavalent chromium emission reduction. Cost effectiveness values were computed for each control option compared to the baseline level and compared to each of the next-less-stringent control options.

The profile of this industry is dynamic, so no attempt was made to quantify fifth-year costs. It is anticipated that the total number of operations nationwide will not change in the next 5 years. If anything, a number of existing small operations may be replaced by new larger operations. Because new facility costs are less than existing facility (retrofit) costs, this replacement could result in lower nationwide costs in the fifth year.

7.6.1 Hard Chromium Electroplating

7.6.1.1 Capital and Annualized Costs Attributable to Each Control Option. Nationwide capital and annualized costs attributable to each control option are presented in Table 7-29. Control Option I is the no-action, or baseline, option that would require no additional controls over existing levels. Table 7-5 presents the hard chromium plating model plant parameters and baseline conditions upon which Option I was based.

Costs associated with Control Option I are based on new facility costs for the operations controlled by a specified control technique. For example, for the small hard chromium plating model plants under Option I, 30 percent of the operations (324 operations) are uncontrolled, 30 percent of the operations (324 operations) are controlled by chevron-blade mist eliminators with a single set of blades, and 40 percent (432 operations) are controlled by single packed-bed scrubbers. The total new facility capital cost of a chevron-blade mist eliminator with a single set of blades and a single packed-bed scrubber for the model small plant is $22,500 and $36,700, respectively. The net annualized costs for these control techniques are $4,800 and $9,800, respectively. The nationwide capital and net annualized costs for small hard chromium plating operations are calculated as follows:

Capital Costs:

(324 operations)($0.00) = $ 0.00

(324 operations)($22,500) = $ 7.29 million

(432 operations)($36,700) = $15.85 million

Total capital costs = $23.14 million

Annualized Costs:

(324 operations)($0.00) = $0.00

(324 operations)($4,800) = $1.56 million

(432 operations)($9,800) = $4.23 million

Total net annualized costs = $5.79 million

Similar calculations were performed for the model medium and large plants. The total nationwide capital and annualized costs for hard chromium plating operations under Control Option I are the sums of the nationwide totals for each plant size, which are $49.57 million and $11.93 million, respectively.

Costs associated with Control Option II are based on the use of chevron-blade mist eliminators with a double set of blades that reduce uncontrolled emissions by 95 percent. For the model small plants under Option II, the 30 percent (324 operations) that were uncontrolled under Option I would install chevron-blade mist eliminators with a double set of blades, and new facility costs would apply. For the 30 percent (324 operations) that were controlled under Option I by chevron-blade mist eliminators with a single set of blades, retrofit costs for chevron-blade mist eliminators with a double set of blades are used. The other 40 percent (432 operations) are controlled by single packed-bed scrubbers under Option I. Because scrubbers reduce uncontrolled emissions by 97 percent, these operations would not convert to chevron-blade mist eliminators with a double set of blades and, therefore, new facility costs for single packed-bed scrubbers are used.

For a chevron-blade mist eliminator with a double set of blades, the total new facility capital cost is $23,800, and the total retrofit capital cost is $29,800. The net annualized costs are $5,500 and $6,400, respectively. The total new facility capital cost for a single packed-bed scrubber is $36,700. The

net annualized costs are $9,800. Therefore, the nationwide capital and net annualized costs for small hard chromium plating operations under Control Option II are calculated as follows:

Capital Costs:

(324 operations)($23,800) = $ 7.71 million

(324 operations)($29,800) = $ 9.66 million

(432 operations)($36,700) = $15.85 million

Total capital costs = $33.22 million

Annualized Costs:

(324 operations)($5,500) = $1.78 million

(324 operations)($6,400) = $2.07 million

(432 operations)($9,800) = $4.23 million

Total net annualized costs = $8.09 million

Similar calculations were performed for the model medium and large plants.

Costs associated with Control Option IIIa are based on the use of single packed-bed scrubbers that reduce uncontrolled hexavalent chromium emissions by 99 percent. Costs associated with Control Option IIIb are based on the use of mesh-pad mist eliminators that also reduce uncontrolled emissions by 99 percent. These costs were calculated using the procedures described above.

7.6.1.2 Cost Effectiveness. The cost-effectiveness values for the control options are summarized in Table 7-30.

7.6.2 Decorative Chromium Electroplating

7.6.2.1 Capital and Annualized Costs Attributable to Each Control Option. Nationwide capital and annualized costs attributable to each control option are presented in Table 7-31. Table 7-10 presents the decorative chromium plating model plant parameters and baseline conditions upon which Option I was based. Costs associated with Option IIa are based on the use of single packed-bed scrubbers, and costs associated with Option IIb are based on the use of mesh-pad mist eliminators. Single packed-bed scrubbers and mesh-pad mist eliminators are assumed to reduce uncontrolled hexavalent chromium emissions from decorative chromium plating operations by 97 percent. Costs associated with

Option III are based on the use of chemical fume suppressants, which are assumed to reduce uncontrolled chromium emissions by 99.5 percent. Cost impacts for fume suppressants were based on the cost of the permanent fume suppressant presented for the model plants in Table 7-15. Costs associated with Option IV are based on the use of the trivalent chromium plating process, which reduces uncontrolled hexavalent chromium emissions by 100 percent. Costs for Option IV are presented for three production scenarios, each representing different rework rates.

7.6.2.2 Cost Effectiveness. The cost-effectiveness values for the control options are summarized in Table 7-32.

7.6.3 Chromic Acid Anodizing

7.6.3.1 Capital and Annualized Costs Attributable to Each Control Option. Nationwide capital and annualized costs attributable to each control option are presented in Table 7-33. Table 7-23 presents the chromic acid anodizing model plant and the baseline conditions upon which Option I was based. Costs associated with Option IIa are based on the use of single packed-bed scrubbers, and costs associated with Option IIb are based on the use of mesh-pad mist eliminators. These two control devices are assumed to reduce uncontrolled hexavalent chromium emissions from chromic acid anodizing operations by 97 percent. Costs associated with Option III are based on the use of chemical fume suppressants, which reduce uncontrolled emissions by 99.5 percent. Fume suppressant cost impacts are based on the cost of permanent fume suppressants (presented in Table 7-15).

7.6.3.2 Cost Effectiveness. The cost-effectiveness values for the control options are summarized in Table 7-34.

7.7 OTHER COST CONSIDERATIONS

7.7.1 Water Pollution Control Act

Water pollution control costs associated with the control options based on the use of mist eliminators and scrubbers are not expected to increase over those associated with the respective baseline options. The scrubber water and mist eliminator washdown water typically are discharged to the plating or anodizing tank to make up for evaporation losses. The

discharging of scrubber water and mist eliminator washdown water to the plating or anodizing tank reduces plant wastewater treatment costs and recovers chromic acid lost by misting. Some operations, especially decorative chromium plating operations, operate wastewater treatment systems. In decorative chromium plating operations, the scrubber often has two functions: (1) to reduce chromic acid emissions from the plating tank and (2) to evaporate rinse water. The rinse tank following the decorative chromium plating tank is used as the source of the scrubber water; as the water evaporates in the scrubber, the chromium concentration increases. This helps to keep the chromium concentration in the rinse tanks low but also increases the chromium concentration in the scrubber effluent before it goes to wastewater treatment, reducing the overall wastewater treatment burden of the plant. However, the amount of control device effluent relative to the total amount of wastewater associated with the plating operations is low (less than 2 percent).[1-3,32] Therefore, treatment costs attributable to the control options are considered to be insignificant.

7.7.2 Resource Conservation and Recovery Act

Under Control Option IV, decorative chromium plating operations would incur hazardous waste disposal costs as a result of replacing a hexavalent with a trivalent chromium plating process. Replacing of the hexavalent chromium process requires proper disposal of the hexavalent chromium plating solution. The hexavalent chromium plating solution is considered hazardous waste under the provisions of RCRA, and, therefore, the solution must be sent to a hazardous waste management facility for proper treatment and disposal. The hazardous waste disposal costs incurred by the model plants under Option IV are estimated to be:

Model small plant: $3,700 for 6,500 L (1,730 gal) of waste;

Model medium plant: $7,400 for 13,100 L (3,460 gal) of waste; and

Model large plant: $41,000 for 86,700 L (22,900 gal) of waste.

For decorative chromium electroplating operations, there are 2,240 small plants, 420 medium plants, and 140 large plants. Thus, the nationwide hazardous waste disposal cost attributable to Option IV is estimated to be $17.1 million.

Implementing the control options based on the use of packed-bed scrubbers or mesh-pad mist eliminators would also result in an increase in hazardous waste disposal costs. Scrubber packing materials are replaced approximately every 10 years and mesh pads every 4 years. The hexavalent chromium-contaminated packing and pads must be treated and disposed of by a hazardous waste management facility. The volumes of waste associated with disposal are shown in Chapter 6, Tables 6-13 through 6-15. Tables 7-35 through 7-37 present the annualized disposal costs attributable to these control options.

The following example shows how the transportation and disposal costs were estimated. This example uses Option IIIa (single packed-bed scrubbers) for the model large plant of the hard chromium electroplating operations:

The model large plant uses two 990 m^3/min (35,000 ft^3/min) single packed-bed scrubber units. These units each contain 2.1 m^3 (74 ft^3) of packing material. At 0.21 m^3 (7.35 ft^3) per 55-gal drum, 11 drums (considering void space) are needed to contain the bed packing material from each unit. Total disposal costs are $40 per drum for transportation and $50 (plus 10 percent tax) per drum for disposal, or $95 per drum.[23] The total transportation and disposal costs for scrubber packing material for the model large plant are:

(2 units)(11 drums/unit)($95/drum) = $2,090.

Assuming a 10-year life for packing material, the capital recovery factor is 0.1628. Under Option IIIa for hard chromium plating operations, there would be 150 large operations using single packed-bed scrubbers. Therefore, the nationwide annualized disposal costs for packing material for large operations would be:

$$(0.1628)(\$2,090/\text{operation})(150 \text{ operations}) = \$51,000.$$

Similar calculations were performed for each plant size in each control option for hard and decorative chromium plating operations and chromic acid anodizing operations for scrubber packing material. For operations using mesh-pad mist eliminators, calculations were similar, except that the capital recovery factor is based on a 4-year life and is equal to 0.3154.

At the time of this writing, RCRA legislation is being considered that would affect the disposal of chromium-contaminated waste in landfills. At this time, solid debris (e.g., scrubber bed packing and mesh-pad material) that is contaminated with chromium may be placed in a Class I landfill without pretreatment. Implementation of RCRA pretreatment standards for chromium-contaminated debris could significantly impact the costs associated with disposal of these material. In Chapter 6, estimates of solid waste generation associated with the use of packed-bed scrubbers and mesh-pad mist eliminators were made using the assumption that the waste material is compacted to 50 percent of its original volume. While compaction for disposal is typically practiced in the industry, disposal costs presented in this document have been estimated without the compaction assumption. These "worst-case" cost estimates were made in order to compensate for future increases in disposal costs attributable to the RCRA legislation.

For hard chromium electroplating operations, nationwide annualized disposal costs attributable to the use of packed-bed scrubbers or mesh-pad mist eliminators range from $76,000/yr for Option I to $190,100/yr for Option IIIa. Because Option I

represents baseline conditions (i.e., these operations already incur these disposal costs), costs for Option I are subtracted from the costs for other control options in order to determine disposal costs attributable to implementation of a particular control option. Therefore, disposal costs attributable to Option II are zero ($76,000/yr for Option II minus $76,000/yr for Option I). Disposal costs attributable to the implementation of Option IIIa or Option IIIb are $114,100/yr or $104,800/yr, respectively.

Nationwide annualized disposal costs attributable to the use of packed-bed scrubbers or mesh-pad mist eliminators for decorative chromium plating operations range from $126,000/yr for Option I to $168,000/yr for Option IIa. Subtracting the costs for Option I, incremental disposal costs attributable to the implementation of Option IIa are $42,000/yr and of Option IIb, $34,000/yr. For chromic acid anodizing operations, incremental disposal costs attributable to the implementation of Option IIa are $36,200/yr and of Option IIb, $35,100/yr.

There are hazardous waste transportation and disposal costs associated with retrofitting or replacing of control devices at existing operations. The cost to dispose of control devices at existing operations was estimated as 5 percent of the cost of a new control device.

No other control options considered in these analyses are expected to increase costs to the electroplating and anodizing operations under RCRA because the pollution control techniques upon which the control options are based will not increase the amount of hazardous wastes currently generated by electroplating or anodizing operations.

7.7.3 Occupational Safety and Health Administration Act

The chromium electroplating and anodizing shops considered in these analyses are subject to the OSHA general industrial health and safety standards as well as the OSHA regulation that limits concentrations of chromic acid and chromates inside the plant to a ceiling concentration of 0.1 mg/m^3 (4.4×10^{-5} gr/ft^3).[33] Most chromium electroplating and

anodizing shops already have installed ventilation systems to comply with OSHA standards.

Costs of capture systems and ductwork necessary to comply with the OSHA regulation for chromium are included in this chapter for information only and are not considered to be costs attributable to the control options. Table 7-38 presents the capital costs of ventilation hoods and takeoffs for each of the six tank sizes used in the model plants. Table 7-39 presents the capital costs of ventilation hoods, takeoffs, and ductwork for the tank(s) vented to each of the control devices. Vendor A provided these cost data based on the ventilation hood, takeoff, and ductwork specifications presented in Chapter 5. Table 7-40 presents the capital costs of ventilation hoods, takeoffs, and ductwork for the model plants. Vendors B and C did not provide cost estimates for capture systems and ductwork.

TABLE 7-1. CONTROL TECHNIQUES UPON WHICH THE CONTROL OPTION COST IMPACTS ARE BASED

Type of operation/ Control option	Control technique
Hard chromium plating	
Option I (no action)	Existing (baseline) level of control • 30 percent of operations uncontrolled • 30 percent of operations controlled by chevron-blade mist eliminators with single sets of blades that reduce uncontrolled emissions by 90 percent • 40 percent of operations controlled by single packed-bed scrubbers that reduce uncontrolled emissions by 97 percent
Option II	Chevron-blade mist eliminators with a double set of blades that reduce uncontrolled emissions by 95 percent
Option III	Single packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 99 percent
Decorative chromium plating	
Option I (no action)	Existing (baseline) level of control • 15 percent of operations uncontrolled • 40 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 40 percent of operations controlled by a combination of chemical fume suppressants and packed-bed scrubbers that reduces uncontrolled emissions by 97 percent • 5 percent of operations controlled by single packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II	Single packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent
Option IV	Trivalent chromium plating processes that reduce hexavalent chromium emissions by 100 percent (technology forcing)
Chromic acid anodizing	
Option I (no action)	Existing (baseline) level of control • 40 percent of operations uncontrolled • 30 percent of operations controlled by chemical fume suppressants that reduce uncontrolled emissions by 97 percent • 10 percent of operations controlled by chevron-blade mist eliminators with a single set of blades that reduce uncontrolled emissions by 90 percent • 20 percent of operations controlled by single packed-bed scrubbers that reduce uncontrolled emissions by 95 percent
Option II	Single packed-bed scrubbers or mesh-pad mist eliminators that reduce uncontrolled emissions by 97 percent
Option III	Chemical fume suppressants applied in accordance with vendor recommendations. Uncontrolled emissions reduced by 99.5 percent

TABLE 7-2. CAPITAL AND ANNUALIZED COST DATA SOURCES FOR POLLUTION CONTROL TECHNIQUES

Cost item	Source	Date of reference	Ref.
Capital Costs			
1. Chevron-blade mist eliminators	Vendor A	October 1986--Updated to November 1988[a]	1
2. Packed-bed scrubbers	Vendor A	October 1986--Updated to November 1988[a]	1
3. Mesh-pad mist eliminators	Vendor I	November 1988	2-4
4. Trivalent chromium process	Vendors D, E, F, and H	October 1986--Updated to November 1988[a]	5-8
Annualized Costs			
1. Electricity	Department of Energy	October 1988	9
2. Water	American Water Works Association	March 1989	10
3. Chromic acid	Ashland Chemical Company	August 1987--Updated to November 1988[a]	11
4. Labor			
a. Operator	Bureau of Labor Statistics	August 1988, January 1989	12, 13
b. Supervisor and maintenance	Bureau of Labor Statistics, EPA/OAQPS/EAB	August 1988, February 1987, January 1989	12-14
5. Chemical fume suppressants	Vendors D, E, F, G, and H	October 1986--Updated to November 1988[a]	15-19
6. Overhead, property tax, insurance, administration	EPA/OAQPS/EAB	February 1987	14
7. Capital recovery	EPA/OAQPS/EAB	February 1987	14

[a]Costs were updated using Chemical Engineering plant indices from the February 1989 issue of Chemical Engineering.

TABLE 7-3. ANNUAL OPERATING COST FACTORS

Cost categories	Cost factors
Direct operating costs	
1. Operating labor	
a. Operator[12,13]	$8.37/hr
b. Supervisor[14]	15 percent of 1a
2. Operating materials	As required
3. Maintenance	
a. Labor[12-14]	$9.21/hr[a]
b. Materials[14]	100 percent of 3a
4. Replacement parts	As required
5. Utilities	
a. Electricity[9]	$0.0461/kWh[13]
b. Water[10]	$0.77/1,000 gal[14]
Indirect operating costs	
6. Overhead[14]	60 percent of 1a + 1b + 3a
7. Property tax[14]	1 percent of capital cost
8. Insurance[14]	1 percent of capital cost
9. Administration[14]	2 percent of capital cost
10. Capital recovery[14]	11.7 percent of capital cost[b] or 16.3 percent of capital cost[c]
Credits	
Chromic acid recovery[11]	$3.28/kg

[a]Based on 110 percent of operating labor.
[b]Based on an interest rate of 10 percent and an equipment life of 20 years (for chevron-blade mist eliminators and packed-bed scrubbers).
[c]Based on an interest rate of 10 percent and an equipment life of 10 years (for mesh-pad mist eliminators).

TABLE 7-4. COMPARATIVE PLATING LINE COST MODEL USED TO DETERMINE COST DIFFERENTIAL BETWEEN THE HEXAVALENT AND TRIVALENT CHROMIUM PROCESSES.

PRODUCTION FACTORS	
A. END-PRODUCT PARAMETERS	
PART PLATED	INPUT
PLATING TIME, MIN	INPUT
CURRENT DENSITY, AMPS/FT2	INPUT
SURFACE AREA OF PART, FT2	INPUT
PLATING THICKNESS, MILS	INPUT
AMPERE-HOURS/FT2	(current density, A/ft2)(plating time, h)
AMPERE-HOURS/PART	(current density, A/ft2)(plating time, h)(surface area of part, ft2)
B. MODEL PLANT PARAMETERS	
NO. OF PLATING LINES	INPUT
OPERATING TIME, H/YR	INPUT
% TIME ELECTRODES ARE ENERGIZED, %	INPUT
FAN HORSEPOWER REQUIREMENT, HP	INPUT
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LIN	INPUT
C. COST FACTORS	
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	INPUT
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	INPUT
CR+6 CHEMICAL COSTS, $/AH	INPUT
CR+3 CHEMICAL COSTS, $/AH	INPUT

TABLE 7-4 (Continued)

PRODUCTION FACTORS	
FAN ELECTRICAL COSTS, $/KWH	INPUT
D PRODUCTION PARAMETERS	
1. Rework rates	
a Hexavalent Chromium Process, %	INPUT
b. Trivalent Chromium Process, %	INPUT
2. Trivalent Chromium Productivity Increase, %	INPUT
3 Hexavalent Chromium Maximum Production Rate, parts/yr	INPUT
E PRODUCTION RATES	
1. HEXAVALENT CHROMIUM PROCESS	
a. Maximum surface area per year, ft2/yr	(hexavalent chromium maximum production rate, parts/yr)(surface area of part, ft2)
b. Total # of parts produced, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1-rework decimal percent)
c. No. of once-through parts, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1-(2*rework decimal percent))
d. No. of rework parts (parts processed twice), parts/yr	(hexavalent chromium maximum production rate, parts/yr)(rework decimal percent)
2. TRIVALENT CHROMIUM PROCESS	
a. Maximum surface area per year, ft2/yr	(trivalent chromium maximum production rate, parts/yr)(surface area of part, ft2)
b. Maximum # of parts plated per year, parts/yr	(hexavalent chromium maximum production rate, parts/yr)(1+decimal percent increase in productivity)
c. Total # of parts produced, parts/yr	(trivalent chromium maximum production rate, parts/yr)(1-rework decimal percent)
d No. of once-through parts, parts/yr	(trivalent chromium maximum production rate, parts/yr)(1-(2*rework decimal percent))
e. No. of rework parts (parts processed twice), parts/yr	(trivalent chromium maximum production rate, parts/yr)(rework decimal percent)
F CHEMICAL COST	
HEXAVALENT CHROMIUM SOLUTION, $/FT2	(hexavalent chromium chemical cost, $/AH)(ampere-hours required per part surface area, AH/ft2)
HEXAVALENT CHROMIUM SOLUTION, $/PART	(hexavalent chromium chemical cost, $/ft2)(surface area of part, ft2)

TABLE 7-4 (Continued)

PRODUCTION FACTORS	
TRIVALENT CHROMIUM PROCESS, $/FT2	(trivalent chromium chemical cost, $/AH)(ampere-hours required per part surface area, AH/ft2)
TRIVALENT CHROMIUM PROCESS, $/PART	(trivalent chromium chemical cost, $/ft2)(surface area of part, ft2)
G. ANNUAL PLATING COST	
1. UNIT PLATING COSTS	
a. Hexavalent Chromium Process	
1)plating cost, $/part	(plating cost, $/ft2)(surface area of part, ft2)
2)plating cost, $/ft2	INPUT
3)rework plating cost, $/part	(plating cost, $/part)(2)
b. Trivalent Chromium Process	
1)plating cost, $/part	(plating cost, $/ft2)(surface area of part, ft2)
2)plating cost, $/ft2	(hexavalent chromium plating cost, $/ft2)+(CR+3 chemical cost, $/ft2 - CR+6 chemical cost, $/ft2)
3)rework plating cost, $/part	(plating cost, $/part)(2)
2. ANNUAL PLATING COSTS	
a. Hexavalent Chromium Process	
1)plating costs-once-through parts, $/yr	(No. of once-through parts)(original plating cost, $/part)
2)plating costs-rework, $/yr	(No. of rework parts)(rework plating cost, $/part)
3)annual plating costs, $/yr	Sum of annual plating costs for once-through and reworked parts
b. Trivalent Chromium Process	
1)plating costs-once-through parts, $/yr	(No of once-through parts)(original plating cost, $/part)
2)plating costs-rework, $/yr	(No. of rework parts)(rework plating cost, $/part)
3)annual plating costs, $/yr	Sum of annual plating costs for once-through and reworked parts
H. WASTEWATER TREATMENT COSTS	
1. HEXAVALENT CHROMIUM PROCESS	
a)WASTEWATER VOLUMES, GAL/YR	(number of plating lines)(wastewater volume per plating line, gpm/line)(60 min/hr)(operating hours per year)
b)TREATMENT COSTS, $/YR	(chromium wastewater treatment volume, gals/yr)(hexavalent chromium wastewater treatment costs, $/gal)

TABLE 7-4 (Continued)

PRODUCTION FACTORS	
2. TRIVALENT CHROMIUM PROCESS	
a)WASTEWATER VOLUMES, GAL/YR	(number of plating lines)(wastewater volume per plating line, gpm/line)(60 min/hr)(operating hours per year)
b)TREATMENT COSTS, $/YR	(chromium wastewater treatment volume, gals/yr)(trivalent chromium wastewater treatment costs, $/gal)
I. FAN ELECTRICAL COSTS	
HEXAVALENT CHROMIUM PROCESS	
a) FAN ELECTRICAL USAGE, KWH/YR	(fan horsepower requirements, hp)(0 746hp/kw)(operating time per year)
b) FAN ELECTRICAL COSTS, $/YR	(fan electrical requirements, kwh/yr)(electrical cost, $/kwh)
J. PLATING LINE COSTS	
1. HEXAVALENT CHROMIUM PROCESS	
a)annual plating costs, $/yr	sum of plating costs for once-through and reworked parts
b)wastewater treatment costs, $/yr	(chromium wastewater treatment volume, gals/yr)(hexavalent chromium wastewater treatment costs, $/gal)
c)fan electrical costs, $/yr	(fan electrical requirements, kwh/yr)(electrical cost, $/kwh)
d)total plating line costs, $/yr	(total plating costs + wastewater treatment costs + fan electrical costs)
e)total plating line costs, $/part	(total plating line costs, $/yr)/(total production, parts/yr)
2. TRIVALENT CHROMIUM PROCESS	
a)annual plating costs, $/yr	sum of plating costs for once-through and reworked parts
b)wastewater treatment costs, $/yr	(chromium wastewater treatment volume, gals/yr)(trivalent chromium wastewater treatment costs, $/gal)
c)total plating line cost, $/yr	(total plating costs + wastewater treatment costs + fan electrical costs)
d)total plating line costs, $/part	(total plating line costs, $/yr)/(total production, parts/yr)
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a	(trivalent chromium unit plating cost, $/part)-(hexavalent chromium unit plating cost, $/part)
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	(cost differential, $/part)(surface area of part, ft2)
ANNUAL COST DIFFERENTIAL, $/YR (c)	(cost differential, $/part)(total hexavalent chromium production rate, parts/yr)

TABLE 7-5. HARD CHROMIUM ELECTROPLATING MODEL PLANT PARAMETERS AND BASELINE CONDITIONS

	Model plant		
	Small	Medium	Large
Model plant parameters			
Operating time, hr/yr	2,000	3,500	6,000
Percent of operating time electrodes are energized, %	70	70	80
Time electrodes are energized, hr/yr	1,400	2,450	4,800
Production rate, Ah/yr[a]	5×10^6	42×10^6	160×10^6
Uncontrolled emission factor, mg/Ah	10	10	10
Uncontrolled emission rate per plant, kg/yr (lb/yr)[b]	50 (110)	420 (925)	1,600 (3,539)
No. of plating tanks	1	4	8
Tank dimensions (l, w, d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 2 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)	2 @ 1.2, 1.2, 3.0 (4.0, 4.0, 10.0) 4 @ 3.6, 1.2, 1.8 (12.0, 4.0, 6.0) 2 @ 7.6, 0.9, 1.8 (25.0, 3.0, 6.0)
Total tank surface area, m^2/min (ft^2/min)	4.0 (42)	17 (187)	35 (374)
Total tank capacity, L (gal)[c]	6,550 (1,730)	30,930 (8,170)	61,850 (16,340)
Operating current per tank, amperes	3,625	2,330 2 @ 4,145 6,475	2 @ 2,330 4 @ 4,145 2 @ 6,475
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)	57 (2,000) 2 @ 170 (6,000) 531 (18,750)	2 @ 57 (2,000) 4 @ 170 (6,000) 2 @ 531 (18,750)
Chevron-blade mist eliminators and packed-bed scrubbers			
No. of control devices	1	1	2
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2 @ 990 (35,000)

TABLE 7-5. (Continued)

	Model plant		
	Small	Medium	Large
Mesh pad mist eliminators			
No. of control devices	1	4	8
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	170 (6,000) 227 (8,000) 2 @ 283 (10,000)	2 @ 170 (6,000) 2 @ 227 (8,000) 4 @ 283 (10,000)
Baseline conditions[d]			
No. of operations nationwide	1,080	310	150
Level of control, percent:			
Uncontrolled	30	30	30
Chevron-blade mist eliminator with a single set of blades[e]	30	30	30
Packed-bed scrubber[f]	40	40	40
TOTAL	100	100	100
No. of operations nationwide:			
Uncontrolled	324	93	45
Chevron-blade mist eliminator with a single set of blades[e]	324	93	45
Packed-bed scrubber[f]	432	124	60
TOTAL	1,080	310	150

[a]Production rate = sum of operating current x time electrodes are energized for each tank.
[b]Uncontrolled emission rate [(production rate)(uncontrolled emission factor)]/1 x 10^6.
[c]Assumed 15.2 cm (6.0 in.) of freeboard space between the top of the tank and the surface of the plating solution.
[d]See Chapter 5 for derivation of number of operations nationwide and baseline level of control.
[e]Mist eliminator with a control efficiency of 90 percent.
[f]Packed-bed scrubber with a control efficiency of 97 percent.

TABLE 7-6. CAPITAL COSTS OF CHEVRON-BLADE MIST ELIMINATORS AND SINGLE PACKED-BED SCRUBBERS FOR HARD CHROMIUM PLATING MODEL PLANTS[a]
(November 1988 Dollars)

Model plant size	Chevron-blade mist eliminator: Single set of blades	Chevron-blade mist eliminator: Double set of blades	Single packed-bed scrubber
Small[b]			
Purchased equipment	10,100	11,400	19,500
Installation	12,300	12,300	17,000
Startup[c]	100	100	200
Total capital cost[d]	22,500	23,800	36,700
Medium[e]			
Purchased equipment	24,400	28,700	47,300
Installation	20,800	20,800	26,400
Startup[c]	200	300	500
Total capital cost[d]	45,400	49,800	74,200
Large[f]			
Purchased equipment	48,800	57,400	94,600
Installation	41,700	41,700	52,900
Startup[c]	500	600	900
Total capital cost[d]	91,000	99,700	148,400

[a]Capital costs for chevron-blade mist eliminators are from Tables F-4 and F-5, and capital costs for scrubbers are from Tables F-6 and F-7 in Appendix F.
[b]Small model plant costs for each control device type are from Column B in Tables F-4 through F-7 in Appendix F.
[c]Startup costs are based on 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of purchased equipment, installation, and startup costs. Cost data were rounded to the nearest $100.
[e]Medium model plant costs for each control device type are from Column D in Tables F-4 through F-7 in Appendix F.
[f]Large model plant costs for each control device type are two times medium model plant costs.

TABLE 7-7. ANNUALIZED COSTS OF CHEVRON-BLADE MIST ELIMINATORS AND SINGLE PACKED-BED SCRUBBERS FOR HARD CHROMIUM PLATING MODEL PLANTS (November 1988 Dollars)[a]

Model plant size	Chevron-blade mist eliminators: Single set of blades	Chevron-blade mist eliminators: Double set of blades	Single packed-bed scrubber
Small[b]			
Utilities[c]	0	400	600
Operator and maintenance labor[d]	800	800	1,700
Maintenance materials	200	200	500
Packing replacement[e]	–	–	200
Indirect costs[f]	1,500	1,600	2,800
Capital recovery	2,600	2,800	4,300
Annualized cost, $	5,100	5,800	10,100
Chromic acid recovery[g]	(300)	(300)	(300)
Net annualized costs, $[h]	4,800	5,500	9,800
Medium[i]			
Utilities[c]	1,200	2,400	3,800
Operator and maintenance labor[d]	1,100	1,100	2,300
Maintenance materials	500	500	1,100
Packing replacement[e]	–	–	400
Indirect costs[f]	2,800	2,900	5,000
Capital recovery	5,300	5,800	8,700
Annualized cost, $	10,900	12,700	21,300
Chromic acid recovery[g]	(2,400)	(2,500)	(2,600)
Net annualized costs, $[h]	8,500	10,200	18,700
Large[j]			
Utilities[c]	4,200	8,300	12,900
Operator and maintenance labor[d]	1,900	1,900	3,900
Maintenance materials	1,700	1,700	3,600
Packing replacement[e]	–	–	800
Indirect costs[f]	5,800	6,100	10,400
Capital recovery	10,600	11,700	17,400
Annualized cost, $	24,200	29,700	49,000
Chromic acid recovery[g]	(9,100)	(9,600)	(10,000)
Net annualized costs, $[h]	15,100	20,100	39,000

[a]Annualized costs for mist eliminators are from Tables F-8 and F-9, and annualized costs for the single packed-bed scrubber are from Table F-10 in Appendix F.
[b]Small model plant costs for each control device type are from Column B_1 in Tables F-8 through F-10 in Appendix F.
[c]Utility costs for mist eliminators were rounded to zero if utility costs were less than or equal to $50 per year.
[d]Includes operator, supervisor, and maintenance labor.
[e]Packing replacement costs include the cost associated with purchasing new packing material and disposal of the old material.
[f]Includes overhead, property tax, insurance, and administration.
[g]Chromic acid recovery credit for the mist eliminator with a single set of blades is based on a control efficiency of 95 percent. Chromic acid recovery credit for the mist eliminator with double sets of blades is based on a control efficiency of 95 percent. Chromic acid recovery credit for the packed-bed scrubbers is based on a control efficiency of 99 percent. Parentheses indicate negative values.
[h]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.
[i]Medium model plant costs for each control device type are from Column D_1 in Tables F-8 through F-10 in Appendix F.
[j]Large model plant costs for each control device type are two times the annualized costs from Column D_2 in Tables F-8 through F-10 in Appendix F.

TABLE 7-8. CAPITAL COSTS OF MESH-PAD MIST ELIMINATORS FOR HARD CHROMIUM PLATING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size		
	Small[b]	Medium[c]	Large[d]
Total purchased equipment (TPE)	13,900	45,600	91,200
Incremental ductwork cost[e]	0	4,900	9,800
Installation cost	9,000	15,000	23,000
Startup (1 percent of TPE)	100	500	900
Total capital cost, $	23,000	66,000	124,900

[a]Cost data were rounded to the nearest $100.
[b]Small model plant costs are from column D of Table F-20 in Appendix F.
[c]Medium model plant costs are equal to the sum of Columns A and B plus two times Column C in Table F-20 in Appendix F.
[d]Large model plant costs are twice the costs of the medium model plant.
[e]Estimated costs of additional ductwork required to modify existing capture system to accommodate installation of mesh-pad mist eliminator.

TABLE 7-9. ANNUALIZED COSTS FOR MESH-PAD MIST ELIMINATORS FOR HARD CHROMIUM PLATING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size		
	Small	Medium	Large
Hard chromium plating			
Utilities	500	2,700	9,400
Operator and maintenance labor[b]	1,000	2,400	5,300
Maintenance materials	400	2,600	8,900
Mesh pad replacement[c]	900	2,600	5,100
Indirect costs[d]	1,700	5,600	13,500
Capital recovery[e]	3,800	10,800	20,400
Annualized cost, $	8,300	26,700	62,600
Chromic acid recovery[f]	(300)	(2,600)	(10,000)
Net annualized cost, $	8,000	24,100	52,600

[a]Cost data are rounded to the nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs are based on a 4-year life for the pad material. Includes cost of mesh pad replacement and transportation and disposal costs of used pads.
[d]Includes overhead, property tax, insurance, and administration.
[e]Capital recovery includes cost of capital for mesh-pad mist eliminator unit(s) plus cost of capital for incremental ductwork.
[f]Chromic acid recovery credits are based on a removal efficiency of 99 percent for mesh-pad mist eliminators used in hard chromium plating processes. Parentheses indicate negative values.

TABLE 7-10. DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANT PARAMETERS AND BASELINE CONDITIONS

	Model plant		
	Small	Medium	Large
Model plant parameters			
Operating time, hr/yr	2,000	4,000	6,000
Percent of operating time electrodes are energized	60	60	60
Time electrodes are energized, hr/yr	1,200	2,400	3,600
Production rate, Ah/yr[a]	3.0×10^6	12×10^6	120×10^6
Uncontrolled emission factor, mg/Ah	2	2	2
Uncontrolled emission rate per plant, kg/yr (lb/yr)[b]	6.0 (13)	24 (53)	240 (530)
No. of plating tanks	1	2	5
Tank dimensions (l, w, d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	2 @ 3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	5 @ 3.6, 1.8, 2.7 (12.0, 6.0, 9.0)
Total surface area of tanks, m^2 (ft^2)	4.0 (42)	8.0 (84)	33 (360)
Total tank capacity, L (gal)[c]	6,550 (1,730)	13,100 (3,460)	86,650 (22,890)
Operating current per tank, amperes	2,600	2 @ 2,600	5 @ 6,800
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)	2 @ 297 (10,500)	5 @ 255 (9,000)
Plating solution drag-out rate, L/hr (gal/hr)	2.8 (0.75)	5.6 (1.50)	14 (3.75)
Packed-bed scrubbers			
No. of control devices	1	2	3
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	2 @ 340 (12,000)	283 (10,000) 2 @ 510 (18,000)
Mesh-pad mist eliminators			
No. of control devices	1	2	5
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	2 @ 340 (12,000)	5 @ 283 (10,000)

TABLE 7-10. (Continued)

	Model plant		
	Small	Medium	Large
Baseline conditions[d]			
No. of operations nationwide	2,240	420	140
Level of control, percent:			
Uncontrolled	15	15	15
Chemical fume suppressant[e]	40	40	40
Chemical fume suppressant combined with packed-bed scrubber[f]	40	40	40
Packed-bed scrubber[g]	5	5	5
TOTAL	100	100	100
No. of operations nationwide:			
Uncontrolled	336	63	21
Chemical fume suppressant[e]	896	168	56
Chemical fume suppressant combined with packed-bed scrubber[f]	896	168	56
Packed-bed scrubber[g]	112	21	7
TOTAL	2,240	420	140

[a]Production rate = sum of (operating current x time electrodes are energized) for each tank.
[b]Uncontrolled emission rate [(production rate)(uncontrolled emission factor)]/1 x 10^6.
[c]Assumed 15.2 cm (6.0 in.) of freeboard space between surface of tank and surface of plating solution.
[d]See Chapter 5 for derivation of number of operations nationwide and baseline level of control.
[e]Fume suppressant with control efficiency of 97 percent.
[f]Fume suppressant used in conjunction with packed-bed scrubber with combined control efficiency of 97 percent.
[g]Packed-bed scrubber with control efficiency of 95 percent.

TABLE 7-11. CAPITAL COSTS OF SINGLE PACKED-BED SCRUBBERS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS (November 1988 Dollars)[a]

Model plant size	Single packed-bed scrubber
Small[b]	
Purchased equipment	19,500
Installation	17,000
Startup[c]	200
Total capital cost[d]	36,700
Medium[e]	
Purchased equipment	39,100
Installation	34,000
Startup[c]	400
Total capital cost[d]	73,500
Large[f]	
Purchased equipment	70,200
Installation	53,700
Startup[c]	700
Total capital cost[d]	124,600

[a]Capital costs for single packed-bed scrubbers are from Table F-6 in Appendix F.
[b]Small model plant costs are presented in Column B in Table F-6 in Appendix F.
[c]Startup costs are based on 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of purchased equipment, installation, and startup costs. Cost data were rounded to the nearest $100.
[e]Medium model plant costs are two times small model plant costs.
[f]Large model plant costs are two times the control device costs in Column C plus the control device costs in Column A from Table F-6 in Appendix F.

TABLE 7-12. ANNUALIZED COSTS OF SINGLE PACKED-BED SCRUBBERS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS[a] (November 1988 Dollars)

Model plant size	Single packed-bed scrubber
Small[b]	
Utilities	600
Operator and maintenance labor[c]	1,700
Maintenance materials	500
Packing replacement[d]	200
Indirect costs[e]	2,800
Capital recovery	4,300
Annualized cost, $	10,100
Chromic acid recovery[f]	0
Net annualized cost, $[g]	10,100
Medium[h]	
Utilities	2,600
Operator and maintenance labor[c]	2,800
Maintenance materials	1,800
Packing replacement[d]	300
Indirect costs[e]	5,700
Capital recovery	8,600
Annualized cost, $	21,800
Chromic acid recovery[f]	(200)
Net annualized cost, $[g]	21,600
Large[i]	
Utilities	8,500
Operator and maintenance labor[c]	4,100
Maintenance materials	4,100
Packing replacement[d]	600
Indirect costs[e]	10,000
Capital recovery	14,600
Annualized cost, $	41,900
Chromic acid recovery[f]	(1,500)
Net annualized cost, $[g]	40,400

[a]Annualized costs for packed-bed scrubbers are from Table F-10 in Appendix F.
[b]Small model plant costs are from Column B_1 in Table F-10 in Appendix F.
[c]Includes operator, supervisor, and maintenance labor.
[d]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of the old material.
[e]Includes overhead, property tax, insurance, and administration.
[f]Chromic acid recovery credit for single blade chevron-blade mist eliminators is based on a control efficiency of 90 percent. Chromic acid recovery credit for double blade chevron-blade mist eliminators is based on a control efficiency of 95 percent. Chromic acid recovery credit for packed-bed scrubbers is based on a control efficiency of 97 percent. Parentheses indicate negative values. Costs were rounded to nearest $100.
[g]Numbers may not add exactly due to independent rounding. Costs were rounded to nearest $100.
[h]Medium model plant costs are two times the costs presented in Column B_2 in Table F-10 in Appendix F.
[i]Large model plant costs are two times the costs in Column C plus the costs in Column A in Table F-10 in Appendix F.

TABLE 7-13. CAPITAL COSTS OF MESH-PAD MIST ELIMINATORS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size		
	Small[b]	Medium[c]	Large[d]
Total purchased equipment (TPE)	13,900	27,900	62,700
Incremental ductwork cost[e]	0	0	6,800
Installation cost	9,000	11,000	17,000
Startup (1 percent of TPE)	100	300	700
Total capital cost, $	23,000	39,200	87,200

[a]Cost data were rounded to the nearest $100.
[b]Small model plant costs are equal to the costs presented in Column D of Table F-20 in Appendix F.
[c]Medium model plant costs are two times the costs presented in Column D of Table F-20 in Appendix F.
[d]Large model plant costs are equal to five times the costs presented in Column C in Table F-20 in Appendix F.
[e]Estimated cost of additional ductwork required to modify typical capture system to accommodate installation to mesh-pad mist eliminator

TABLE 7-14. ANNUALIZED COSTS OF MESH-PAD MIST ELIMINATORS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS[a] (November 1988 Dollars)

	Model plant size		
	Small	Medium	Large
Utilities	500	2,100	7,800
Operator and maintenance labor[b]	1,000	1,700	3,800
Maintenance materials	400	1,500	5,600
Mesh pad replacement[c]	900	1,900	3,800
Indirect costs[d]	1,700	3,500	9,100
Capital recovery[e]	3,800	6,400	14,200
Annualized cost, $	8,300	17,100	44,300
Chromic acid recovery[f]	0	(200)	(1,500)
Net annualized cost, $	8,300	16,900	42,800

[a]Cost data were rounded to the nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs are based on a 4-year life for the pad material. Includes cost of mesh pad replacement and transportation and disposal costs of used pads.
[d]Includes overhead, property tax, insurance, and administration.
[e]Capital recovery includes cost of capital for mesh-pad mist eliminator unit(s) plus cost of capital for incremental ductwork.
[f]Chromic acid recovery credits are based on a removal efficiency of 97 percent for mesh-pad mist eliminators used in decorative chromium and chromic acid anodizing operations.

TABLE 7-15. ANNUALIZED COSTS OF TEMPORARY AND PERMANENT FUME SUPPRESSANTS FOR DECORATIVE CHROMIUM ELECTROPLATING MODEL PLANTS
(November 1988 Dollars)

	Model plants		
	Small	Medium	Large
A. Model Tank Data[a]			
1. Surface area of tank, ft^2	42	42	72
2. Temporary fume suppressants			
a. Average makeup cost, $[b]	20	20	40
b. Average maintenance, cost, $/yr[b]	1,200	1,200	3,280
3. Permanent fume suppressants			
a. Average makeup cost, $[b]	170	170	460
b. Average maintenance cost, $/yr[b]	1,060	1,060	4,360
4. Operating time basis, hr/yr[c]	1,600	1,600	4,800
B. Model Plant Data			
1. No. of model tanks	1	2	5
2. Operating hours, hr/yr[c]	1,200	2,400	3,600
3. Temporary fume suppressants			
a. Makeup cost, $[b] (A2a x B1)	20	40	200
b. Maintenance cost, $yr[b d] (A2b x B1)(B2/A4)	900	3,600	12,300
c. Annual cost, $/yr[e] (B3a + B3b)	900	3,600	12,500
d. Chromic acid recovery, $/yr[e]	0	(200)	(1,500)
e. Net annual cost, $/yr	900	3,400	11,000
4. Permanent fume suppressants			
a. Makeup cost, $[b] (A3a x B1)	170	340	2,300
b. Maintenance cost, $/yr[b,d] (A3b x B1)(B2/A4)	800	3,180	16,350
c. Annual cost, $/yr[e] (B4a + B4b)	1,000	3,500	18,700
d. Chromic acid recovery, $/yr[e,f]	0	(200)	(1,500)
e. Net annual cost, $/yr[e]	1,000	3,300	17,200

[a] Fume suppressant cost basis (original model tank parameters).
[b] Cost data were rounded to the nearest $10.
[c] Operating time of tanks = (operating time of plant, hr/yr) multiplied by (percent time electrodes are energized).
[d] Maintenance cost is adjusted by applying a ratio that corrects for the difference between the operating time of the model tanks upon which the cost data are based and the revised operating time of the model tanks.
[e] Cost data were rounded to the nearest $10.
[f] Chromic acid recovery credits for fume suppressants are based on control efficiency of 99.5 percent. Parentheses indicate negative values.

TABLE 7-16. INCREMENTAL CAPITAL COST ASSOCIATED WITH INSTALLING A TRIVALENT CHROMIUM PROCESS INSTEAD OF A HEXAVALENT CHROMIUM PROCESS AT NEW DECORATIVE CHROMIUM ELECTROPLATING FACILITIES (November 1988 Dollars)

	Model plant size		
Component	Small	Medium	Large
Startup (plating tank[s]) cost[a,5]	2,800	5,500	27,500
Initial passivation solution[b,8]	500	1,000	6,500
Subtotal	3,300	6,500	34,000
Purchased equipment cost			
Ampere-hour controller[8]	1,600	3,200	8,000
Anode boxes[c,8]	7,800	15,600	39,000
Chillers[d,6]	9,300	18,600	71,000
Filter[d,5]	7,600	15,200	54,500
Subtotal	26,300	52,600	172,500
Taxes and freight[e,25]	2,100	4,200	13,800
TOTAL	28,400	56,800	186,300
Installation [f,24]	4,300	8,500	27,900
Indirect costs[g,25]	8,800	17,600	57,800
Total cost	44,800	89,400	306,000
Wastewater treatment cost savings[h,32]	-19,600[i]	-29,400[j]	-41,400[j]
Net cost[k]	25,200	60,000	264,600

[a]Startup cost for new plants would only consist of the incremental cost of the trivalent chromium bath solution over the hexavalent chromium bath solution. The cost differential between the trivalent chromium plating solution and the hexavalent plating solution is $1.60 per gallon of plating solution for the small and medium model plants and $1.20 per gallon for the large model plant.[5]
[b]Passivation solution is required for some trivalent chromium processes.
[c]Anode boxes are required for all double-cell processes.
[d]Optional equipment.
[e]Taxes and freight are estimated to be 3 and 5 percent, respectively, of the base equipment cost.
[f]Installation costs are based on 15 percent of the purchased equipment costs.
[g]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent) and are based on 31 percent of the purchased equipment costs.
[h]Represents the capital cost of a hexavalent chromium reduction unit for the wastewater volume associated with each model plant.
[i]Batch process.
[j]Continuous process.
[k]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE 7-17. CAPITAL COST OF CONVERTING A HEXAVALENT CHROMIUM PROCESS TO A TRIVALENT CHROMIUM PROCESS AT EXISTING DECORATIVE CHROMIUM ELECTROPLATING FACILITIES (November 1988 Dollars)

Component	Model plant size		
	Small	Medium	Large
Startup (tank conversion)[a]			
Initial trivalent chromium solution purchase[5]	10,900	21,800	136,500
Initial passivation solution purchase[8]	500	1,000	6,500
Waste disposal cost of hexavalent chromium solution[30]	3,700	7,400	41,000
Subtotal	15,100	30,200	184,000
Purchased equipment cost			
Ampere-hour meter[8]	1,600	3,200	8,000
Tank liner[5]	2,200	4,400	18,000
Replacement anodes and hangers[5]	3,300	6,600	43,500
Anode boxes[8]	7,800	15,600	39,000
Chiller[b,8]	9,300	18,600	71,000
Filter[b,5]	7,600	15,200	54,500
Subtotal	31,800	63,600	234,000
Taxes and freight[c,25]	2,500	5,100	18,700
TOTAL	34,300	68,700	252,700
Installation/modification[d,24]	6,900	13,700	50,500
Indirect[e,25]	10,600	21,300	78,300
Total cost[f]	66,900	133,900	565,500

[a]Startup costs include the initial makeup of the trivalent chromium solution and the disposal cost of the hexavalent chromium plating solution.
[b]Optional equipment.
[c]Taxes and freight are estimated to be 3 and 5 percent, respectively, of the base equipment cost.
[d]Installation/modification costs are based on 20 percent of purchased equipment costs.
[e]Indirect costs include costs associated with engineering and supervision (10 percent), process startup (1 percent), and contingencies (20 percent) and are estimated to be 31 percent of the purchased equipment cost.
[f]The total capital cost is not solely attributable to air pollution control but also to process improvement.

TABLE 7-18. SCENARIO 1: PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE ACTUAL HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE 7-18. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	1.000	3.000	15.000
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	5.15E+06	3.92E+05	2.30E+06
c. No. of once-through parts, parts/yr	5.10E+06	3.80E+05	1.89E+06
d. No. of rework parts (parts processed twice), parts/yr	5.20E+04	1.21E+04	4.05E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d. No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0.6725

TABLE 7-18. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1 UNIT PLATING COSTS			
a Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$508,581	$160,085	$18,884,502
2)plating costs—rework, $/yr	$10,379	$10,218	$8,093,358
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE 7-18. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1010	0.4467	11.7653
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	-0.0020	-0.0070	1.0410
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	-0.0156	-0.0130	0.0813
ANNUAL COST DIFFERENTIAL, $/YR (c)	($10,300)	($2,700)	$2,389,100

(a) Obtained from G.1.e minus G.2.d. Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE 7-19. SCENARIO 2: PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE AVERAGE HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A. END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B. MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE 7-19. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	7.000	7.000	7.000
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	4.84E+06	3.76E+05	2.51E+06
c. No. of once-through parts, parts/yr	4.47E+06	3.48E+05	2.32E+06
d. No. of rework parts (parts processed twice), parts/yr	3.64E+05	2.83E+04	1.89E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0.6725

TABLE 7-19. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1. UNIT PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b. Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$446,306	$146,461	$23,200,960
2)plating costs—rework, $/yr	$72,654	$23,842	$3,776,900
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE 7-19. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1076	0.4660	10.7532
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390.656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	0.0050	0.0120	0.0290
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	0.0391	0.0222	0.0023
ANNUAL COST DIFFERENTIAL, $/YR (c)	$24,200	$4,500	$72,800

(a) Obtained from G.1.e minus G.2.d. Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE 7-20. SCENARIO 3: PLATING LINE COSTS FOR EACH MODEL PLANT BASED ON THE BREAK-EVEN HEXAVALENT CHROMIUM REWORK RATES

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
A END-PRODUCT PARAMETERS			
PART PLATED	Ratchets	Faucets	Bumpers
PLATING TIME, MIN	3.00	3.55	2.25
CURRENT DENSITY, A/FT2	50.00	125.00	200.00
SURFACE AREA OF PART, FT2	0.128	0.540	12.810
PLATING THICKNESS, MILS	0.011	0.00031	0.014
AMPERE-HOURS/FT2	2.50	7.40	7.50
AMPERE-HOURS/PART	0.32	3.99	96.08
B MODEL PLANT PARAMETERS			
NO. OF PLATING LINES	1	2	5
OPERATING TIME, H/YR	2000	4000	6000
% TIME ELECTRODES ARE ENERGIZED, %	60	60	60
FAN HORSEPOWER REQUIREMENT, HP	10	20	35
CHROMIUM WASTEWATER FLOW RATE, GPM/PLATING LINE	6	6	12
C. COST PARAMETERS			
CR+6 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.75	0.75	0.75
CR+3 WASTEWATER TREATMENT COSTS, $/1000 GAL	0.34	0.34	0.34
CR+6 CHEMICAL COSTS, $/AH	0.00052	0.00052	0.00052
CR+3 CHEMICAL COSTS, $/AH	0.007	0.007	0.007
FAN ELECTRICAL COSTS, $/KWH	0.0461	0.0461	0.0461

TABLE 7-20. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
D. PRODUCTION PARAMETERS			
1. REWORK RATES			
a) Hexavalent Chromium Process, %	2.850	4.500	6.750
b) Trivalent Chromium Process, %	1.0	1.0	1.0
2. TRIVALENT CHROMIUM PRODUCTIVITY INCREASE, %	20	20	20
3. HEXAVALENT CHROMIUM MAXIMUM PRODUCTION RATE, PARTS/YR	5.20E+06	4.04E+05	2.70E+06
E. PRODUCTION RATES			
1. HEXAVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	6.66E+05	2.18E+05	3.46E+07
b. Total # of parts produced, parts/yr	5.05E+06	3.86E+05	2.52E+06
c. No. of once-through parts, parts/yr	4.90E+06	3.68E+05	2.34E+06
d. No. of rework parts (parts processed twice), parts/yr	1.48E+05	1.82E+04	1.82E+05
2. TRIVALENT CHROMIUM PROCESS			
a. Maximum surface area per year, ft2/yr	7.99E+05	2.62E+05	4.15E+07
b. Maximum # of parts plated per year, parts/yr	6.24E+06	4.85E+05	3.24E+06
c. Total # of parts produced, parts/yr	6.18E+06	4.80E+05	3.21E+06
d. No. of once-through parts, parts/yr	6.12E+06	4.75E+05	3.18E+06
e. No. of rework parts (parts processed twice), parts/yr	6.24E+04	4.85E+03	3.24E+04
F. CHEMICAL COST			
HEXAVALENT CHROMIUM SOLUTION, $/FT2	0.0013	0.0038	0.0039
HEXAVALENT CHROMIUM SOLUTION, $/PART	0.0002	0.0021	0.0500
TRIVALENT CHROMIUM PROCESS, $/FT2	0.0175	0.0518	0.0525
TRIVALENT CHROMIUM PROCESS, $/PART	0.0022	0.0280	0 6725

TABLE 7-20. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
G. ANNUAL PLATING COST			
1. UNIT PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating cost, $/part	$0.100	$0.421	$9.992
2)plating cost, $/ft2	$0.780	$0.780	$0.780
3)rework plating cost, $/part	0.200	0.842	19.984
b. Trivalent Chromium Process			
1)plating cost, $/part	$0.102	$0.447	$10.614
2)plating cost, $/ft2	0.796	0.828	0.829
3)rework plating cost, $/part	0.204	0.894	21.229
2. ANNUAL PLATING COSTS			
a. Hexavalent Chromium Process			
1)plating costs—once-through parts, $/yr	$489,379	$154,976	$23,335,849
2)plating costs—rework, $/yr	$29,581	$15,327	$3,642,011
3)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b. Trivalent Chromium Process			
1)plating costs—once-through parts, $/yr	$623,139	$212,592	$33,702,843
2)plating costs—rework, $/yr	$12,717	$4,339	$687,813
3)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
H. WASTEWATER TREATMENT COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$540	$2,160	$16,200
2. TRIVALENT CHROMIUM PROCESS			
a) Wastewater volumes, gal/yr	720,000	2,880,000	21,600,000
b) Treatment costs, $/yr	$240	$970	$7,290

TABLE 7-20. (Continued)

PRODUCTION FACTORS	MODEL PLANT SIZE		
	SMALL	MEDIUM	LARGE
I. FAN ELECTRICAL COSTS			
HEXAVALENT CHROMIUM PROCESS			
a) Fan electrical usage, kWh/yr	14,920	59,680	156,660
b) Fan electrical costs, $/yr	$688	$2,751	$7,222
J. PLATING LINE COSTS			
1. HEXAVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$518,960	$170,303	$26,977,860
b)wastewater treatment costs, $/yr	$540	$2,160	$16,200
c)fan electrical costs, $/yr	$688	$2,751	$7,222
d)total plating line costs, $/yr	$520,188	$175,214	$27,001,282
e)total plating line costs, $/part	0.1030	0.4538	10.7244
2. TRIVALENT CHROMIUM PROCESS			
a)annual plating costs, $/yr	$635,856	$216,931	$34,390,656
b)wastewater treatment costs, $/yr	$240	$970	$7,290
c)total plating line cost, $/yr	$636,096	$217,901	$34,397,946
d)total plating line costs, $/part	0.1030	0.4536	10.7239
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/PART (a)	0.0000	0.0000	0.0000
COST DIFFERENTIAL BETWEEN THE PROCESSES, $/FT2 (b)	0.0000	0.0000	0.0000
ANNUAL COST DIFFERENTIAL, $/YR (c)	$0	$0	$0

(a) Obtained from G.1.e minus G.2.d. Numbers were independently rounded.

(b) Obtained by dividing the $/part value by the surface area of the part.

(c) Based on hexavalent chromium production rates.

TABLE 7-21. CAPITAL RECOVERY COSTS FOR EACH MODEL PLANT REPRESENTATIVE OF BOTH NEW AND EXISTING FACILITIES

	Model plant size		
Capital recovery costs, $/yr	Small	Medium	Large
Existing facility	13,200	26,300	108,900
New facility	6,000	3,400	54,000

TABLE 7-22. MODEL PLANT INCREMENTAL ANNUALIZED COSTS ASSOCIATED WITH THE USE OF THE TRIVALENT CHROMIUM PROCESS

	Model plant size: end-product[a]		
	Small: ratchets	Medium: faucets	Large: bumpers
Annualized cost components			
Capital recovery values, $/yr			
1. Existing facility	13,200	26,300	108,900
2. New facility	6,000	13,400	54,000
Process cost differential, $/yr			
1. Scenario 1[b]	10,300	2,700	(2,389,100)
2. Scenario 2[c]	(24,200)	(4,500)	(72,800)
3. Scenario 3[d]	0	0	0
Incremental annualized costs, $/yr			
1. Scenario 1			
a. Existing facility	23,500	29,000	(2,280,200)
b. New facility	16,300	16,100	(2,335,100)
2. Scenario 2			
a. Existing facility	(11,000)	21,800	36,100
b. New facility	(18,200)	8,900	(18,800)
3. Scenario 3			
a. Existing facility	13,200	26,300	108,900
b. New facility	6,000	13,400	54,000

[a]Parentheses indicate a cost savings.
[b]Hexavalent chromium reject rate was set at the value given by the plants that produce the end product selected.
[c]Hexavalent chromium reject rate was set at the average of the values given by the plants.
[d]Hexavalent chromium reject rate was set so that a process cost differential of zero was obtained.

TABLE 7-23. CHROMIC ACID ANODIZING MODEL PLANT PARAMETERS AND BASELINE CONDITIONS

	Model plant size	
	Small	Large
Model plant parameters		
Operating time, hr/yr	2,000	6,000
Percent of operating time electrodes are energized	70	40
Time electrodes are energized, hr/yr	1,400	2,400
Uncontrolled emission factor, kg/hr/m^2 (lb/hr/ft^2)[a]	6×10^{-4} (1.23×10^{-4})	6×10^{-4} (1.23×10^{-4})
Uncontrolled emission rate per plant, kg/yr (lb/yr)[b]	3.3 (7.2)	40 (88)
No. of tanks	1	2
Tank dimensions (l, w, d), m (ft)	3.6, 1.1, 1.8 (12.0, 3.5, 6.0)	9.1, 1.5, 2.7 (30.0, 5.0, 9.0)
Total surface area of tanks, m^2 (ft^2)	3.9 (42)	28 (300)
Total tank capacity, L (gal)[c]	6,500 (1,730)	72,190 (19,070)
Ventilation rate per tank, m^3/min (ft^3/min)	297 (10,500)	2 @ 531 (18,750)
Packed-bed scrubbers		
No. of control devices	1	1
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	1,130 (40,000)
Mesh-pad mist eliminator		
No. of control devices	1	4
Inlet gas flow rate per control device, m^3/min (ft^3/min)	340 (12,000)	4 @ 283 (10,000)
Baseline conditions[d]		
No. of operations nationwide:		
Level of control, percent:	515	165
Uncontrolled		
Mist eliminator[e]	40	40
Chemical fume suppressant[f]	10	10
Packed-bed scrubber[g]	30	30
Total	20	20
	100	100
No. of operations nationwide:		
Uncontrolled		
Mist eliminator[e]	206	66
Chemical fume suppressant[f]	51	16
Packed-bed scrubber[g]	103	33
Total	155	50
	515	165

[a]Kg/hr/m^2 (lb/hr/ft^2) of tank surface area.
[b]Uncontrolled emission rate = (total tank surface area) (emission factor) (time electrodes are energized).
[c]Assumed 15.2 cm (6.0 in.) of freeboard space between surface of tank and surface of plating solution.
[d]See Appendix F for derivation of number of operations nationwide and baseline level of control.
[e]Chevron-blade mist eliminator with a single set of blades with control efficiency of 90 percent.
[f]Fume suppressant with control efficiency of 97 percent.
[g]Packed-bed scrubber with control efficiency of 95 percent.

TABLE 7-24. CAPITAL COSTS OF CHEVRON-BLADE MIST ELIMINATORS AND SINGLE PACKED-BED SCRUBBERS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

Model plant size	Chevron-blade mist eliminators with a single set of blades	Single packed-bed scrubber
Small[b]		
Purchased equipment	10,100	19,500
Installation	12,300	17,000
Startup[c]	100	200
Total capital cost[d]	22,500	36,700
Large[e]		
Purchased equipment	27,700	52,100
Installation	20,600	26,100
Startup[c]	300	500
Total capital cost[d]	48,600	78,700

[a]Capital costs for mist eliminators are from Table F-4 in Appendix F, and capital costs for scrubbers are from Table F-6 in Appendix F.
[b]Small model plant costs for each control device type are from Column B in Tables F-4 and F-6 in Appendix F.
[c]Startup costs are 1 percent of the purchased equipment cost.
[d]Total capital cost is the sum of the purchased equipment, installation, and startup costs. Cost data were rounded to nearest $100.
[e]Large model plant costs for each control device type are from Column E in Tables F-4 and F-6 in Appendix F.

TABLE 7-25. ANNUALIZED COSTS OF CHEVRON-BLADE MIST ELIMINATORS AND SINGLE PACKED-BED SCRUBBERS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

Model plant size	Chevron-blade mist eliminator with a single set of blades	Single packed-bed scrubber
Small[b]		
Utilities	0	600
Operator and maintenance labor[c]	800	1,700
Maintenance materials	200	500
Packing replacement[d]	---	200
Indirect costs[e]	1,500	2,800
Capital recovery	2,600	4,300
Annualized cost, $	5,100	10,100
Chromic acid recovery[f]	0	0
Net annualized cost, $[g]	5,100	10,100
Large[h]		
Utilities	0	5,000
Operator and maintenance labor[c]	1,400	3,100
Maintenance materials	800	1,900
Packing replacement[d]	---	400
Indirect costs[e]	3,300	6,200
Capital recovery	5,700	9,200
Annualized cost, $	11,200	25,800
Chromic acid recovery[f]	(200)	(300)
Net annualized cost, $[g]	11,000	25,500

[a]Annualized costs for mist eliminators are from Table F-8 in Appendix F and capital costs for scrubbers are from Table F-10 in Appendix F.
[b]Small model plant costs for each control device type are from Column B_1 presented in Tables F-8 and F-10 in Appendix F.
[c]Includes operator, supervisor, and maintenance labor.
[d]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of old material.
[e]Includes overhead, property tax, insurance, and administration.
[f]Chromic acid recovery credit for chevron-blade mist eliminators is based on a control efficiency of 90 percent. Chromic acid recovery credit for packed-bed scrubbers is based on a control efficiency of 97 percent. Parentheses indicate negative values. Costs were rounded to nearest $100.
[g]Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.
[h]Large model plant costs for each control device type are from Column E in Tables F-8 and F-10 in Appendix F.

TABLE 7-26. CAPITAL COSTS OF MESH-PAD MIST ELIMINATORS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size	
	Small[b]	Large[c]
Total purchased equipment (TPE)	13,900	50,100
Incremental ductwork cost[d]	0	26,100
Installation cost	9,000	15,000
Startup (1 percent of TPE)	100	500
Total capital cost, $	23,000	91,700

[a]Annualized cost data were rounded to the nearest $100.
[b]Small model plant costs are equal to the costs presented in Column D of Table F-20 in Appendix F.
[c]Large model plant costs are equal to four times the costs presented in Column C in Table F-20 in Appendix F.
[d]Estimated cost of additional ductwork required to modify a typical capture system to accommodate installation of a mesh-pad mist eliminator.

TABLE 7-27. ANNUALIZED COSTS OF MESH-PAD MIST ELIMINATORS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size	
	Small	Large
Utilities	500	6,200
Operator and maintenance labor[b]	1,000	3,200
Maintenance materials	400	4,400
Mesh-pad replacement[c]	900	3,000
Indirect costs[d]	1,700	8,300
Capital recovery[e]	3,800	15,000
Annualized cost, $	8,300	40,100
Chromic acid recovery[f]	0	(300)
Net annualized cost, $	8,300	39,800

[a]Cost data were rounded to the nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs are based on a 4-year life for the pad material. Includes costs of mesh pad replacement and transportation and disposal costs of used pads.
[d]Includes overhead, property tax, insurance, and administration.
[e]Capital recovery includes cost of capital for mesh-pad mist eliminator unit(s) plus cost of capital for incremental ductwork.
[f]Chromic acid recovery credits are based on a removal efficiency of 97 percent for mesh-pad mist eliminators used in chromic acid anodizing operations.

TABLE 7-28. ANNUALIZED COSTS OF PERMANENT FUME SUPPRESSANTS FOR CHROMIC ACID ANODIZING MODEL PLANTS[a]
(November 1988 Dollars)

	Model plant size	
	Small	Large
A. Model Tank Data[b]		
1. Surface area of model tanks, ft^2	42	150
2. Average makeup cost, $	110	620
3. Average maintenance cost, $/yr	520	4,050
4. Operating time basis, hr/yr[c]	500	5,760
B. Model Plant Data		
1. No. of model tanks	1	2
2. Surface area of model tanks, ft^2	42	150
3. Operating hours, hr/yr[c]	1,400	2,400
4. Makeup cost, $ (A2 x B1)	110	1,240
5. Maintenance cost, $/yr[d] (A3 x B1)(B3/A4)	1,460	3,380
6. Annual cost, $/yr[e] (B4 + B5)	1,600	4,600
7. Chromic acid recovery, $/yr[e f]	0	(300)
8. Net annual cost, $/yr[e]	1,600	4,300

[a]Cost data were rounded to the nearest $10.
[b]Fume suppressant cost basis (original model tank parameters).
[c]Operating time of tanks = (operating time of plant, hr/yr) multiplied by (percent time electrodes energized).
[d]Maintenance cost is adjusted by applying a ratio that corrects for the difference between the operating time of the model tanks upon which the cost data are based and the revised operating time of the model tanks.
[e]Cost data were rounded to nearest $100.
[f]Chromic acid recovery credits for fume suppressants are based on a control efficiency of 99.5 percent. Parentheses indicate negative values.

TABLE 7-29. NATIONWIDE CAPITAL AND ANNUALIZED COSTS FOR EACH CONTROL OPTION FOR HARD CHROMIUM PLATING OPERATIONS (Millions of Dollars)[a] [b]

Control option	Small plants	Medium plants	Large plants	Total
Option I[c]				
Capital cost	23.14	13.42	13.00	49.57
Annualized cost	6.02	3.65	4.03	13.70
Chromic acid recovery credit[d]	(0.23)	(0.55)	(1.00)	(1.78)
Net annualized cost	5.79	3.11	3.03	11.93
Option II[e]				
Capital cost	33.22	19.64	19.01	71.86
Annualized cost	8.41	5.19	5.79	19.39
Chromic acid recovery credit[d]	(0.32)	(0.79)	(1.45)	(2.56)
Net annualized cost	8.09	4.40	4.34	16.83
Option IIIa[f]				
Capital cost	42.62	24.73	23.93	91.28
Annualized cost	11.36	6.87	7.61	25.85
Chromic acid recovery credit[d]	(0.32)	(0.81)	(1.50)	(2.63)
Net annualized cost	11.04	6.07	6.11	23.22
Option IIIb[g]				
Capital cost	32.67	23.01	21.56	77.24
Annualized cost	10.13	7.91	8.86	26.90
Chromic acid recovery credit[d]	(0.32)	(0.81)	(1.50)	(2.63)
Net annualized cost	9.81	7.10	7.36	24.27

[a]November 1988 dollars.
[b]Numbers may not add exactly due to independent rounding.
[c]Option I is the baseline, or no-action, alternative that is based on the existing level of control.
[d]Parentheses indicate negative values.
[e]Option II represents 95 percent level of control and is based on the use of chevron-blade mist eliminators with double sets of blades.
[f]Option IIIa represents 99 percent level of control and is based on the use of single packed-bed scrubbers.
[g]Option IIIb represents 99 percent level of control and is based on the use of mesh-pad mist eliminators.

TABLE 7-30. COST EFFECTIVENESS OF THE CONTROL OPTIONS FOR HARD CHROMIUM ELECTROPLATING

Control options	Nationwide net annualized control costs, $\$10^6$/yr				Nationwide emissions, Mg/yr				Cost effectiveness, $/Mg			
	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total
Option II vs. Option I[a b]												
Option I (baseline)	5.79	3.11	3.03	11.93	18.47	44.53	82.08	145.08				
Option II	8.09	4.40	4.34	16.83	2.27	5.47	10.08	17.82				
Difference[c]	2.30	1.29	1.31	4.90	16.20	39.06	72.00	127.26	140,000	30,000	20,000	40,000
Option IIIa vs. Option I[a d]												
Option I (baseline)	5.79	3.11	3.03	11.93	18.47	44.53	82.08	145.08				
Option IIIa	11.04	6.07	6.11	23.22	0.54	1.30	2.40	4.24				
Difference[c]	5.25	2.96	3.08	11 29	17.93	43.23	79.68	140.84	290,000	70,000	40,000	80,000
Option IIIb vs. Option I[a e]												
Option I (baseline)	5.79	3.11	3 03	11.93	18.47	44.53	82.08	145.08				
Option IIIb	9.81	7.10	7.36	24.27	0.54	1.30	2.40	4.24				
Difference[c]	4.02	3.99	4.33	12.34	17.93	43.23	79.68	140.84	220,000	90,000	50,000	90,000
Option IIIa vs. Option II[b d]												
Option II	8.09	4.40	4.34	16 83	2.27	5 47	10.08	17 82				
Option IIIa	11.04	6.07	6.11	23 22	0.54	1.30	2.40	4.24				
Difference[c]	2.95	1.67	1.77	6.39	1.73	4.17	7.68	13.58	1,710,000	400,000	230,000	470,000
Option IIIb vs. Option II[b e]												
Option II	8.09	4.40	4.34	16.83	2.27	5.47	10.08	17.82				
Option IIIb	9.81	7.10	7.36	24.27	0.54	1.30	2.40	4.24				
Difference[c]	1.72	2.70	3.02	7.44	1.73	4.17	7.68	13.58	990,000	650,000	390,000	550,000

[a]Option I is the no-action, or baseline, option that is based on the existing level of control.
[b]Option II represents 95 percent level of control and is based on the use of chevron-blade mist eliminators with double sets of blades.
[c]Nationwide annualized cost differences are calculated by subtracting the annualized costs for the less stringent option from those for the more stringent option (e.g., Option II - Option I). Nationwide emission reductions (differences) are calculated by subtracting the emissions under the more stringent option from those for the emissions under the less stringent option (e.g., Option I - Option II). Parentheses indicate negative values.
[d]Option IIIa represents 99 percent level of control and is based on the use of single packed-bed scrubbers.
[e]Option IIIb represents 99 percent level of control and is based on the use of mesh-pad mist eliminators.

TABLE 7-31. NATIONWIDE CAPITAL AND ANNUALIZED COSTS FOR EACH CONTROL OPTION FOR DECORATIVE CHROMIUM ELECTROPLATING OPERATIONS [a] [b]
(Millions of Dollars)

Control option	Small plants	Medium plants	Large plants	Total
Option I[c]				
Capital cost	36.99	13.89	7.85	58.73
Annualized cost	11.97	5.30	4.73	22.00
Chromic acid recovery credit[d]	0.00	(0.07)	(0.18)	(0.25)
Net annualized cost[b]	11.97	5.23	4.56	21.76
Option IIa[e]				
Capital cost	49.32	18.52	10.47	78.31
Annualized cost	15.37	6.67	5.61	27.65
Chromic acid recovery credit[d]	0.00	(0.08)	(0.21)	(0.29)
Net annualized cost[b]	15.37	6.59	5.40	27.36
Option IIb[f]				
Capital cost	44.72	16.36	9.68	70.76
Annualized cost	14.76	6.37	5.66	26.80
Chromic acid recovery credit[d]	0.00	(0.08)	(0.21)	(0.29)
Net annualized cost[b]	14.76	6.29	5.45	26.51
Option III[g]				
Capital cost	34.94	13.08	7.35	55.37
Annualized cost	11.86	5.35	5.08	22.28
Chromic acid recovery credit[d]	0.00	(0.08)	(0.21)	(0.29)
Net annualized cost[b]	11.86	5.26	4.87	21.99
Option IV[h]				
Capital cost	149.86	56.24	79.17	285.26
Annualized cost[i]	52.64	12.18	(319.23)	(254.41)
Annualized cost[j]	(24.64)	9.16	5.05	(10.43)
Annualized cost[k]	29.57	11.05	15.25	55.86

[a]November 1988 dollars.
[b]Numbers may not add exactly due to independent rounding.
[c]Option I is the baseline, or no-action, option that is based on the existing level of control.
[d]Parentheses indicate negative values.
[e]Option IIa represents 97 percent level of control and is based on the use of single packed-bed scrubbers.
[f]Option IIb represents 97 percent level of control and is based on the use of mesh-pad mist eliminators.
[g]Option III represents 99.5 percent level of control and is based on the use of chemical fume suppressants.
[h]Option IV represents 100 percent level of control and is based on the use of trivalent chromium plating process.
[i]Annualized costs are based on Scenario 1 for the trivalent chromium process. This scenario assumes reject rates of 1, 3, and 15 percent, respectively, for each model plant.
[j]Annualized costs are based on Scenario 2 for the trivalent chromium process. This scenario assumes a reject rate of 7 percent for each model plant.
[k]Annualized costs are based on Scenario 3 for the trivalent chromium process. This scenario assumes reject rates of 2.85, 4.5, and 6.75, respectively, for each model plant.

TABLE 7-32. COST EFFECTIVENESS OF THE CONTROL OPTIONS FOR DECORATIVE CHROMIUM ELECTROPLATING

Control options	Nationwide net annualized control cost, $\$10^6$/yr				Nationwide emissions, Mg/yr				Cost effectiveness, $/Mg			
	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total
Option IIa vs. Option I[a b]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1 01	1.71				
Difference[c]	3.40	1.36	0.84	5.60	1.97	1.48	4.92	8.37	1,730,000	920,000	170,000	670,000
Option IIb vs. Option I[a d]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Difference[c]	2.79	1.06	0.89	4.75	1.97	1.48	4.92	8.37	1,420,000	720,000	180,000	570,000
Option III vs. Option I[a e]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0 29				
Difference[c]	(0.11)	0.03	0.31	0.23	2.30	1.73	5.76	9.79	(50,000)	20,000	50,000	20,000
Option IVa vs. Option I[a f]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVa	52.64	12.18	(319.23)	(254.41)	0.00	0.00	0.00	0.00				
Difference[c]	40.67	6.95	(323.79)	(276.17)	2.37	1.78	5.93	10.08	17,160,000	3,900,000	(54,600,000)	(27,400,000)
Option IVb vs Option I[a g]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVb	(24.64)	9.16	5.05	(10.43)	0.00	0 00	0.00	0.00				
Difference[c]	(36.61)	3.93	0.49	(32.19)	2.37	1.78	5.93	10.08	(15,450,000)	2,210,000	80,000	(3,190,000)
Option IVc vs Option I[a h]												
Option I (baseline)	11.97	5.23	4.56	21.76	2.37	1.78	5.93	10.08				
Option IVc	29.57	11.05	15.25	55.86	0.00	0.00	0.00	0.00				
Difference[c]	17.60	5.82	10.69	34.10	2.37	1.78	5.93	10.08	7,430,000	3,270,000	1,800,000	3,380,000
Option III vs. Option IIa[b e]												
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Difference[c]	(3.51)	(1.33)	(0.53)	(5.37)	0.33	0.25	0.84	1.42	(10,640,000)	(5,320,000)	(630,000)	(3,780,000)
Option III vs. Option IIb[d e]												
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Difference[c]	(2.9)	(1.03)	(0.58)	(4.52)	0.33	0.25	0.84	1.42	(8,790,000)	(4,120,000)	(690,000)	(3,180,000)

TABLE 7-32. (Continued)

Control options	Nationwide net annualized control cost, 10^6/yr				Nationwide emissions, Mg/yr				Cost effectiveness, $/Mg			
	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total
Option IVa vs. Option IIa[b f]												
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Option IVa	52.64	12.18	(319.23)	(254.41)	0.00	0.00	0.00	0.00				
Difference[c]	37.27	5.59	(324.63)	(281.77)	0.40	0.30	1.01	1.71	93,180,000	18,630,000	(321,420,000)	(164,780,000)
Option IVa vs Option IIb[d f]												
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Option IVa	52.64	12.18	(319.23)	(254.41)	0 00	0 00	0.00	0 00				
Difference[c]	37.88	5.89	(324.68)	(280.92)	0.40	0.30	1.01	1.71	94,700,000	19,630,000	(321,470,000)	(164,280,000)
Option IVb vs Option IIa[b g]												
Option IIa	15.37	6.59	5.40	27.36	0 40	0.30	1.01	1.71				
Option IVb	(24.64)	9.16	5.05	(10.43)	0.00	0.00	0.00	0.00				
Difference[c]	(40.01)	2.57	(0.35)	(37.79)	0.40	0.30	1.01	1.71	(100,020,000)	8,570,000	(350,000)	(22,100,000)
Option IVb vs Option IIb[d g]												
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Option IVb	(24.64)	9.16	5.05	(10.43)	0.00	0.00	0.00	1.71				
Difference[c]	(39.40)	2.87	(0.40)	(36.94)	0.40	0.30	1.01	1.71	(98,500,000)	(9,570,000)	(400,000)	(21,600,000)
Option IVc vs Option IIa[b h]												
Option IIa	15.37	6.59	5.40	27.36	0.40	0.30	1.01	1.71				
Option IVc	29.57	11.05	15.25	55.86	0.00	0.00	0.00	0.00				
Difference[c]	14.20	4.46	9.85	28.50	0.40	0.30	1.01	1.71	35,500,000	14,870,000	9,750,000	16,670,000
Option IVc vs Option IIb[d h]												
Option IIb	14.76	6.29	5.45	26.51	0.40	0.30	1.01	1.71				
Option IVc	29.57	11.05	15.25	55.86	0.00	0.00	0.00	0.00				
Difference[c]	14.81	4.76	9.80	29.35	0.40	0.30	1.01	1.71	37,030,000	15,870,000	9,700,000	17,160,000
Option IVa vs. Option III[e f]												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVa	52.64	12.18	(319.23)	(254.41)	0.00	0 00	0.00	0.00				
Difference[c]	40.78	6.92	(324.10)	(276.40)	0.07	0.05	0.17	0.29	582,570,000	138,400,000	(1,906,470,000)	(953,100,000)

TABLE 7-32. (Continued)

Control options	Nationwide net annualized control cost, 10^6/yr				Nationwide emissions, Mg/yr				Cost effectiveness, $/Mg			
	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total	Small plants	Medium plants	Large plants	Total
Option IVb vs Option III[e] [g]												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVb	(24.64)	9.16	5.05	(10.43)	0.00	0.00	0.00	0.00				
Difference[c]	(36.50)	3.90	0.18	(32.42)	0.07	0.05	0.17	0.29	(521,430,000)	78,000,000	1,060,000	(111,790,000)
Option IVc vs Option III[e] [h]												
Option III	11.86	5.26	4.87	21.99	0.07	0.05	0.17	0.29				
Option IVc	29.57	11.05	15.25	55.86	0.00	0.00	0.00	0.00				
Difference[c]	17.71	5.79	10.38	33.87	0.07	0.05	0.17	0.29	253,000,000	115,800,000	61,060,000	116,790,000

[a]Option I is the no-action option that is based on the existing level and control.
[b]Option IIa represents 97 percent level of control and is based on the use of packed-bed scrubbers.
[c]Nationwide annualized cost differences are calculated by subtracting the annualized costs for the less stringent option from those for the more stringent option (e g., RA II - RA I). Nationwide emission reductions are calculated by subtracting the emissions under the more stringent option from those for the emissions under the less stringent option (e.g., Option I - Option II). *Parentheses indicate negative values.*
[d]Option IIb represents 97 percent level of control and is based on the use of mesh-pad mist eliminators.
[e]Option III represents 99.5 percent level of control and is based on the use of chemical fume suppressants.
[f]Option IV represents 100 percent level of control and is based on Scenario 1 for the trivalent chromium processes.
[g]Option IV represents 100 percent level of control and is based on Scenario 2 for the trivalent chromium process.
[h]Option IV represents 100 percent level of control and is based on Scenario 3 for the trivalent chromium process.

TABLE 7-33. NATIONWIDE CAPITAL AND ANNUALIZED COSTS FOR EACH CONTROL OPTION FOR CHROMIC ACID ANODIZING OPERATIONS (Millions of Dollars)[a b]

Control options	Small plants	Large plants	Total
Option I[c]			
Capital cost	4.93	3.37	8.30
Annualized cost	1.55	1.26	2.81
Chromic acid recovery credit[d]	0.00	(0.02)	(0.02)
Net annualized cost[b]	1.55	1.24	2.78
Option IIa[e]			
Capital cost	13.68	9.37	23.05
Annualized cost	3.96	3.25	7.20
Chromic acid recovery credit[d]	0.00	(0.05)	(0.05)
Net annualized cost[b]	3.96	3.20	7.15
Option IIb[f]			
Capital cost	9.99	10.49	20.48
Annualized cost	3.48	4.44	7.93
Chromic acid recovery credit[d]	0.00	(0.05)	(0.05)
Net annualized cost[b]	3.48	4.39	7.88
Option III[g]			
Capital cost	0.00	0.00	0.00
Annualized cost	0.82	0.76	1.58
Chromic acid recovery credit[d]	0.00	(0.05)	(0.05)
Net annualized cost[b]	0.82	0.71	1.53

[a]November 1988 dollars.
[b]Numbers may not add exactly due to independent rounding.
[c]Option I is the baseline or no-action option that is based on the existing level of control.
[d]Parentheses indicate negative values.
[e]Option IIa represents 97 percent level of control and is based on the use of single packed-bed scrubbers.
[f]Option IIb represents 97 percent level of control and is based on the use of mesh-pad mist eliminators.
[g]Option III represents 99.5 percent level of control and is based on the use of chemical fume suppressants.

TABLE 7-34. COST EFFECTIVENESS OF THE CONTROL OPTIONS FOR CHROMIC ACID ANODIZING

Control option	Nationwide net annualized control costs, $\$10^6$/yr			Nationwide emissions, Mg/yr			Cost effectiveness, $/Mg		
	Small plants	Large plants	Total	Small plants	Large plants	Total	Small plants	Large plants	Total
Option IIa vs. Option I[a b]									
Option I (baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option IIa	3.96	3.20	7.15	0.05	0.20	0.25			
Difference[c]	2.41	1.96	4.37	0.69	2.64	3.33	3,490,000	740,000	1,310,000
Option IIb vs. Option I[a d]									
Option I (baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option IIb	3.48	4.39	7.88	0.05	0.20	0.25			
Difference[c]	1.93	3.15	5.10	0.69	2.64	3.33	2,800,000	1,190,000	1,530,000
Option III vs. Option I[a e]									
Option I (baseline)	1.55	1.24	2.78	0.74	2.84	3.58			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference[c]	(0.73)	(0.53)	(1.25)	0.73	2.81	3.54	(1,000,000)	(190,000)	(350,000)
Option III vs. Option IIa[b e]									
Option IIa	3.96	3.20	7.15	0.05	0.20	0.25			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference[c]	(3.14)	(2.49)	(5.62)	0.04	0.17	0.21	(78,500,000)	(14,650,000)	(26,760,000)
Option III vs. Option IIb[d e]									
Option IIb	3.48	4.39	7.88	0.05	0.20	0.25			
Option III	0.82	0.71	1.53	0.01	0.03	0.04			
Difference[c]	(2.66)	(3.68)	(6.35)	0.04	0.17	0.21	(66,500,000)	(21,650,000)	(30,240,000)

[a]Option I is the no-action option that is based on the existing level and control.
[b]Option IIa represents 97 percent level of control and is based on the use of single packed-bed scrubbers.
[c]Nationwide annualized cost differences are calculated by subtracting the annualized costs for the less stringent option from those for the more stringent option (e.g., Option II - Option I). Nationwide emission reductions (differences) are calculated by subtracting the emissions under the more stringent option from those for the emissions under the less stringent option (e.g., Option I - Option II). Parentheses indicate negative values.
[d]Option IIb represents 97 percent level of control and is based on the use of mesh-pad mist eliminators.
[e]Option III represents 99.5 percent level of control and is based on the use of chemical fume suppressants.

TABLE 7-35. ANNUALIZED HAZARDOUS WASTE TRANSPORTATION AND DISPOSAL COSTS ATTRIBUTABLE TO THE CONTROL OPTIONS BASED ON THE USE OF SINGLE PACKED-BED SCRUBBERS OR MESH-PAD MIST ELIMINATORS FOR HARD CHROMIUM PLATING OPERATIONS[a]
(November 1988 Dollars)

Plant size	Packed-bed scrubbers[b]			Mesh-pad eliminators[c]			Total nationwide cost, $[d]
	No. plants using PBS	Cost per plant, $	Total cost, $[d]	No. plants using MPME	Cost per plant, $	Total cost, $[d]	
Option I							
Small	432	80	34,600	0	0	0	34,600
Medium	124	170	21,100	0	0	0	21,100
Large	60	340	20,400	0	0	0	20,400
Total	616		76,000	0		0	76,000
Option II							
Small	432	80	34,600	0	0	0	34,600
Medium	124	170	21,100	0	0	0	21,100
Large	60	340	20,400	0	0	0	20,400
Total	616		76,000	0		0	76,000
Option IIIa							
Small	1,080	80	86,400	0	0	0	86,400
Medium	310	170	52,700	0	0	0	52,700
Large	150	340	51,000	0	0	0	51,000
Total	1,540		190,100	0		0	190,100
Option IIIb							
Small	432	80	34,600	648	60	38,900	73,400
Medium	124	170	21,100	186	180	33,500	54,600
Large	60	340	20,400	90	360	32,400	52,800
Total	616		76,000	924		104,800	180,800

[a]Costs are based on estimates of $40 per 55-gal drum for transportation, $55 per 55-gal drum (including 10 percent tax) for disposal and capital recovery factors of 0.1628 for packed-bed scrubbers and 0.3154 for mesh-pad mist eliminators.

[b]Frequency of packing material replacement is estimated to be 10 years. Volumes of packing material for each plant size are given in Table 6-13 in Chapter 6.

[c]Frequency of mesh pad replacement is estimated to be 4 years. Volumes of mesh pads for each plant size are given in Table 6-13 in Chapter 6.

[d]Numbers may not add exactly due to independent rounding.

TABLE 7-36. ANNUALIZED HAZARDOUS WASTE TRANSPORTATION AND DISPOSAL COSTS ATTRIBUTABLE TO THE CONTROL OPTIONS BASED ON THE USE OF SINGLE PACKED-BED SCRUBBERS OR MESH-PAD MIST ELIMINATORS FOR DECORATIVE CHROMIUM PLATING OPERATIONS[a]
(November 1988 Dollars)

	Packed-bed scrubbers[b]			Mesh-pad mist eliminators[c]			Total nationwide cost, $[d]
Plant size	No. plants using PBS	Cost per plant $	Total cost, $[d]	No. plants using MPME	Cost per plant, $[d]	Total cost, $[d]	
Option I							
Small	1,008	80	80,600	0	0	0	80,600
Medium	189	160	30,200	0	0	0	30,200
Large	63	240	15,100	0	0	0	15,100
Total	1,260		126,000	0		0	126,000
Option IIa							
Small	1,344	80	107,500	0	0	0	107,500
Medium	252	160	40,300	0	0	0	40,300
Large	84	240	20,200	0	0	0	20,200
Total	1,680		168,000	0		0	168,000
Option IIb							
Small	1,008	80	80,600	336	60	20,200	100,800
Medium	189	160	30,200	63	120	7,600	37,800
Large	63	240	15,100	21	300	6,300	21,400
Total	1,260		126,000	420		34,000	160,000
Option III							
Small	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0
Large	0	0	0	0	0	0	0
Total	0		0	0		0	0
Option IV							
Small	0	0	0	0	0	0	0
Medium	0	0	0	0	0	0	0
Large	0	0	0	0	0	0	0
Total	0		0	0		0	0

[a]Costs are based on estimates of $40 per 55-gal drum for transportation, $55 per 55-gal drum (including 10 percent tax) for disposal and capital recovery factors of 0.1628 for packed-bed scrubbers and 0.3154 for mesh-pad mist eliminators.

[b]Frequency of packing material replacement is estimated to be 10 years. Volumes of packing material for each plant size are given in Table 6-14 in Chapter 6.

[c]Frequency of mesh pad replacement is estimated to be 4 years. Volumes of mesh pads for each plant size are given in Table 6-14 in Chapter 6.

[d]Numbers may not add exactly due to independent rounding.

TABLE 7-37. ANNUALIZED HAZARDOUS WASTE TRANSPORTATION AND DISPOSAL COSTS ATTRIBUTABLE TO THE CONTROL OPTIONS BASED ON THE USE OF SINGLE PACKED-BED SCRUBBERS OR MESH-PAD MIST ELIMINATORS FOR CHROMIC ACID ANODIZING OPERATIONS[a]
(November 1988 Dollars)

	Packed-bed scrubbers[b]			Mesh-pad mist eliminators[c]			Total nationwide cost, $[d]
Plant size	No. plants using PBS	Cost per plant, $	Total cost, $[d]	No. plants using MPME	Cost per plant, $	Total cost, $[d]	
Option I							
Small	103	80	8,200	0	0	0	8,200
Large	33	190	6,300	0	0	0	6,300
Total	136		14,500	0		0	14,500
Option IIa							
Small	360	80	28,800	0	0	0	28,800
Large	115	190	21,900	0	0	0	21,900
Total	475		50,700	0		0	50,700
Option IIb							
Small	103	80	8,200	257	60	15,400	23,700
Large	33	190	6,300	82	240	19,700	26,000
Total	136		14,500	339		35,100	49,600
Option III							
Small	0	0	0	0	0	0	0
Large	0	0	0	0	0	0	0
Total	0		0	0		0	0

[a]Costs are based on estimates of $40 per 55-gal drum for transportation, $55 per 55-gal drum (including 10 percent tax) for disposal and capital recovery factors of 0.1628 for packed-bed scrubbers and 0.3154 for mesh-pad mist eliminators.

[b]Frequency of packing material replacement is estimated to be 10 years. Volumes of packing material for each plant size are given in Table 6-15 in Chapter 6.

[c]Frequency of mesh pad replacement is estimated to be 4 years. Volumes of mesh pads for each plant size are given in Table 6-15 in Chapter 6.

[d]Numbers may not add exactly due to independent rounding.

TABLE 7-38. CAPITAL COSTS OF VENTILATION HOODS AND TAKEOFFS

	Model tank dimensions (l, w, d), m (ft)					
	1.2, 1.2, 3.0 (4.0, 4.0, 10.0) A	3.6, 1.1, 1.8 (12.0, 3.5, 6.0) B	3 6, 1.2, 1.8 (12.0, 4.0, 6 0) C	3.6, 1.8, 2.7 (12 0, 6.0, 9.0) D	7.6, 0.9, 1.8 (25.0, 3.0, 6.0) E	9.1, 1.5, 2.7 (30.0, 5.0, 9.0) F
Ventilation hoods						
Type of hood[a]	Push-pull	Double-sided lateral	Push-pull	Push-pull	Double-sided lateral	Push-pull
Ventilation rate, m^3/min (ft^3/min)[b]	Pull--57 (2,000) Push--<2.3 (<80)	297 (10,500)	Pull--170 (6,000) Push--<6.8 (<240)	Pull--255 (9,000) Push--<10 (<360)	531 (18,750)	Pull--531 (18,750) Push--<21 (<750)
Base equipment, $[c]	400	1,460	1,350	1,350	3,040	3,320
Takeoffs						
No. per hood	1	4	2	2	8	5
Base equipment, $[c]	190	930	460	720	1,840	1,510
Ventilation hoods and takeoffs						
Total base equipment cost of hood and takeoffs, $[c]	590	2,390	1,810	2,070	4,880	4,830
Installation cost of hood and takeoffs, $[c d]	530	2,040	1,070	1,070	3,920	2,780
TOTAL CAPITAL COST, $[c]	1,120	4,430	2,880	3,140	8,800	7,610

[a]Hoods are installed along the length of the tank.
[b]Ventilation rates are based on American National Standards Institute guidelines and the following assumptions: (1) all tanks are freestanding, not against a wall or baffle and (2) push-pull hoods are used on tanks wider than 1.1 m (3.5 ft).
[c]November 1988 dollars.
[d]Includes costs of welding materials, erection, contingencies, and fee.

7.8 REFERENCES FOR CHAPTER 7

1. Cost Enclosure for Control Equipment Vendors: Vendor A. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. December 31, 1986. pp. 1-2.

2. Letter and cost enclosure from Vendor I to R. Barker, Midwest Research Institute. November 24, 1988. pp. 3-6.

3. Letter and cost enclosure from Vendor I to R. Barker, Midwest Research Institute. January 24, 1989. pp. 1-4.

4. Telecon. Barker, R., MRI, to Vendor I. February 21, 1989. Information on mesh-pad mist eliminator cost data.

5. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor D. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 18, 1987. p. 4.

6. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor E. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 5, 1987. p. 4.

7. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor F. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 22, 1987. p. 4.

8. Cost Enclosure for Decorative Chromium Electroplating Processes: Vendor H. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. June 22, 1987. p. 4.

9. Monthly Energy Review. Energy Information Administration. Department of Energy. Washington, D.C. October 1988.

10. Telecon. Caldwell, M.J., MRI, with Kraft, G., American Water Works Association. March 13, 1989. Information regarding nationwide residential and commercial water rates for January 1989.

11. Telecon. Barker, R., MRI, to Jones, R., Ashland Chemical Corporation. Raleigh, North Carolina. June 1, 1989. Information concerning industrial-grade chromic acid costs.

12. Supplement to Employment and Earnings, Bureau of Labor Statistics. August 1988. p. 55.

13. Monthly Labor Review, Bureau of Labor Statistics, Volume 112, Number 1. January 1989.

14. EAB Control Cost Manual (Third Edition), U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA 450/5-87-001A, February 1987. pp. 2-1 through 2-33.

15. Cost Enclosure for Fume Suppressant Vendors: Vendor D. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 20, 1987. p. 2-3.

16. Cost Enclosure for Fume Suppressant Vendors: Vendor E. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 26, 1987. p. 2-3.

17. Cost Enclosure for Fume Suppressant Vendors: Vendor F. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. January 20, 1987. p. 2-3.

18. Cost Enclosure for Fume Suppressant Vendors: Vendor G. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. January 20, 1987. p. 2-3.

19. Cost Enclosure for Fume Suppressant Vendors: Vendor H. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 9, 1987. p. 2-3.

20. Cost Enclosure for Control Equipment Vendors: Vendor B. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. February 18, 1987.

21. Cost Enclosure for Control Equipment Vendors: Vendor C. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. August 25, 1987.

22. Telecon. Barker, R., MRI, to Welch, P., Duall Industries, Owosso, Michigan. March 30, 1989. Information regarding scrubber packing lifetime and replacement costs.

23. Telecon. Caldwell, M.J., MRI, with Glovernor, S., Chemical Waste Management. April 11, 1989. Information regarding disposal and transportation costs for solid hexavalent chromium wastes.

24. Memo from Barker, R., MRI, to Smith, Andrew, EPA/ISB. May 20, 1988. Trip report for Universal Gym and Nissan Company, Cedar Rapids, Iowa.

25. Neveril, R. B., Gard, Inc. Capital and Operating Costs of Selected Air Pollution Control Systems. Prepared for U. S. Environmental Protection Agency, Research Triangle Park, North Carolina. Publication No. EPA-450/5-80-002. December 1978. p. 3-3.

26. Telecon. Barker, R., MRI, to Sharples, T., OMI™/Udylite International Corporation, Michigan. December 4, 1989.

27. Telecon. Barker, R., MRI, with Welch, P., Duall Industries. April 28, 1989. Retrofit costs as a percentage of new facility costs.

28. Telecon. Caldwell, M. J., MRI, with Hankinson, K., KCH Services. May 1, 1989. Retrofit costs as a percentage of new facility costs.

29. Telecon. Caldwell, M. J., MRI, with Zitko, L., ChromeTech, Inc. May 1, 1989. Retrofit costs as a percentage of new facility costs.

30. Telecon. Barker, R., MRI, to Glovernor, S., Chemical Waste Management, Anaheim, California. September 16, 1987. Information about hexavalent chromium plating solution disposal costs.

31. Environmental Pollution Control Alternatives: Reducing Water Pollution Control Costs in the Electroplating Industry. U. S. Environmental Protection Agency, Washington, D.C. EPA Publication: 625/5-85-016. September 1985. p. 7.

32. Development Document for Effluent Limitations Guidelines and Standards for the Metal Finishing Industry. U. S. Environmental Protection Agency, Washington, D.C. EPA Publication: 440-1-83-091. June 1983. p. V-12.

33. U.S. Department of Labor. Code of Federal Regulations. 29 CFR 1910.1000. Washington, D.C. July 1, 1986. p. 659.

8. ECONOMIC IMPACTS

This chapter describes the economic profile for chromium electroplating operations and the anticipated economic effects of setting a National Emission Standard for a Hazardous Air Pollutant (NESHAP) for hard and decorative chromium electroplating and anodizing operations. The information provided earlier in Chapter 7 (Cost of Pollution Control) and below in Section 8.1 (Industry Economic Profile) is the basis for a formal analysis of the economic effects of the control options on chromium electroplaters and anodizers. This analysis is presented in Section 8.2. The references for Chapter 8 are provided in Section 8.3.

8.1 INDUSTRY ECONOMIC PROFILE

8.1.1 Background

In general, the process of chromium electroplating involves submerging the object to be plated in a chromic acid solution and then applying an electrical current to make the chromium adhere to the object. Anodizing refers to a similar process for aluminum parts where an oxide is created on the surface of the part. Thousands of different products are chromium plated in the United States. Chromic acid anodizing operations are predominately used in the aircraft industry. Products are chromium plated either by firms specializing in hard and/or decorative electroplating operations (job shops), or byfirms that have electroplating operations as one stage of production within a larger manufacturing operation (captive shops).

Chromium electroplating is better defined as a process than as an industry. Firms specializing in electroplating are primarily job shops and are classified as a distinct industry group (Standard Industrial Classification [SIC] Code 3471). A

larger number of firms in other industry groups also perform electroplating operations. Based upon data from a Bureau of the Census report and other data sources, more than 200 different industry groups (4-digit SIC codes) engage in electroplating operations.[1]

Chromium plated or anodized products are either intermediate products, capital goods used in the production process, or final products. These different stages in the production process in which electroplating services might be performed are illustrated in Figure 8-1. Electroplating services may be provided at any stage of production.

How a product is used determines whether it is an intermediate or final product. Generally, if an item is a component of, or attached to, another unit, it is classified as an intermediate product. By this definition, automobile bumpers and other items that are attached to an automobile are considered intermediate products because they are parts of the final product, i.e., the automobile. Similarly, industrial rolls and hydraulic cylinders are intermediate products because they are component parts of capital goods. On the other hand, a kitchen faucet (or any other plumbing fixture) can be classified as either an intermediate or final product. For example, faucets sold as part of a house are considered intermediate products, while faucets sold separately in home improvement markets are categorized as final products.

Most chromium plated or anodized products are either intermediate products or capital goods. Consequently, any costs associated with the regulation of chromium electroplating and anodizing will have much less of an effect on the price of final products than on the price of intermediate products or capital goods.

8.1.2 Chromite Ore Supply and Demand

The chain of production that eventually leads to chromium electroplating starts with the mining of chromite ore. The major world producers of chromite ore are the Republic of South Africa

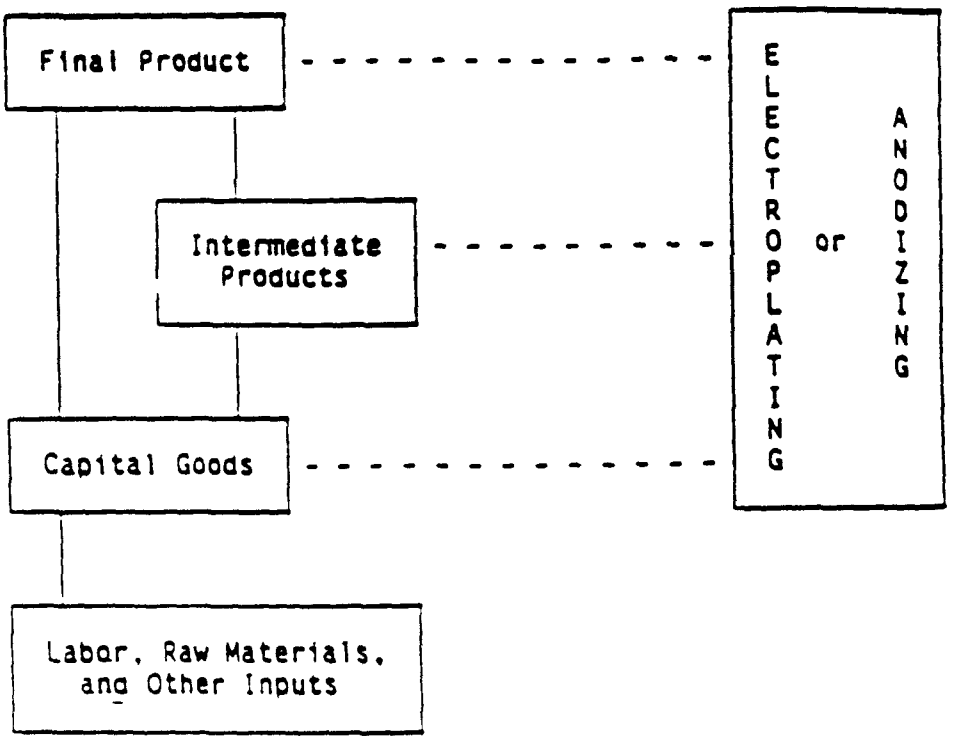


Figure 8-1. Electroplating, Anodizing, and the Production Process.

and the Union of Soviet Socialist Republics. Together, these two countries accounted for about 67 percent of total world production of chromite ore in 1988. Other countries that produce far smaller but still significant amounts of chromite ore include Albania, Finland, India, Turkey, and Zimbabwe.[2] According to the U.S. Bureau of Mines, world chromite reserves, especially those in Africa, are more than adequate to meet forecast world demand through the year 2000 and beyond.[3]

The United States imports all of the chromite ore that it uses. The Republic of South Africa provides about half of the chromite ore used by the U.S., with the other half divided among 6 to 12 other countries.[4] Although the total world supply of chromium is more than adequate, potential interruptions in supplies to the U.S. have been a source of longstanding concern. This concern is an outgrowth of changing world political conditions, as well as the long and vulnerable nature of the supply routes in a time of military emergency. Exporting of chromite ore in various forms from the U.S. does occur, but is not a major factor.

Most chromite ore is used in the steel industry to produce stainless steel. Other industries that use chromite ore include the refractory industry and the chemical industry. Only about 3 to 4 percent of the total chromium consumed in the U.S. is used for plating and anodizing.[5] Table 8-1 presents the amounts of chromite ore consumed by various end-uses.

Table 8-2 shows that the amount of chromite ore used for plating ranged from 13,000 metric tons (14,000 short tons) in 1971 and 1975 to 18,000 metric tons (20,000 short tons) in 1979 and 1980, and averaged about 15,600 metric tons (17,500 short tons) per year.5 After 1981 the U.S. Bureau of Mines stopped keeping aggregate information about the total amount of chromite ore used in plating because plating represents such a small volume and percentage of the total U.S. demand for chromite ore. Total demand figures for 1982 through 1989 were gathered from the U.S. Salient Chromium Statistics.[6 7 8]

TABLE 8-1. CHROMITE ORE END-USES (1981)[a]

	Percent of total amount demanded	Amount demanded[b]
Plating	4	16 (18)
Refractories	5	26 (29)
Chemicals	12	56 (62)
Other	13	59 (65)
Metallurgical	66	306 (336)[c]
Total	100	463 (510)

[a]After 1981, the U.S. Bureau of Mines stopped reporting demand by end-use.
[b]Amount demanded is given in 10^3 metric tons, followed by the English system equivalent (10^3 short tons) in parentheses.
[c]Amount demanded by metallurgical end-uses is broken down as follows:

Transportation	94 (103)
Construction	86 (95)
Machinery	82 (90)
Household Appliances	44 (48)

TABLE 8-2. U.S. DEMAND FOR CHROMIUM PLATING AS A PERCENT OF TOTAL U.S. DEMAND FOR CHROMITE ORE

Year	Total demand[a]	Plating of metals[a]	Plating as % of total
1971	310 (341)	13 (14)	4
1972	462 (508)	16 (18)	4
1973	498 (548)	16 (18)	3
1974	509 (560)	15 (17)	3
1975	338 (372)	13 (14)	4
1976	430 (473)	14 (16)	3
1977	473 (520)	16 (18)	3
1978	495 (544)	17 (19)	3
1979	500 (550)	18 (20)	4
1980	486 (534)	18 (20)	4
1981	413 (455)[b]	16 (18)	4
1982	545 (600)	NA[c]	NA[c]
1983	325 (358)	NA[c]	NA[c]
1984	510 (561)	NA[c]	NA[c]
1985	242 (266)	NA[c]	NA[c]
1986	315 (346)	NA[c]	NA[c]
1987	338 (372)	NA[c]	NA[c]
1988	366 (403)	NA[c]	NA[c]
1989	384 (422)[d]	NA[c]	NA[c]

[a]Figures are given in 10^3 metric tons, followed by the English system equivalent (10^3 short tons) in parentheses.

[b]These figures differ from the total of 463,000 metric tons (510,000 short tons) shown in Table 8-1 because the 50,000 metric ton (55,000 short ton) secondary supply is excluded. Recycled chromium alloys and industrial wastes return small quantities of secondary chromium to the market.

[c]After 1981, the U.S. Bureau of Mines stopped reporting the amount of chromite ore used in plating.

[d]Estimated

8.1.3 Chromic Acid Supply and Demand

The next step in the chain of production leading to chromium electroplating is the production of chromic acid. Currently, two companies, American Chrome and Occidental Chemical Company (formerly owned by Diamond Shamrock Corporation), are the only domestic producers of chromic acid.[9] American Chrome produces chromic acid at its plant in Corpus Christi, Texas. The plant has a capacity of 21,000 metric tons (23,100 short tons) per year. Occidental Chemical produces chromic acid at its plant in Castle Hayne, North Carolina. The Occidental Chemical plant has a capacity of 42,000 metric tons (46,200 short tons) per year. Until 1985, Allied Corporation produced chromic acid at a plant in Baltimore, Maryland, with a capacity of 20,900 metric tons (23,000 short tons) per year. In July 1985, Allied Corporation closed its plant in Baltimore and withdrew from the market. Allied's withdrawal from the market has helped to alleviate domestic overcapacity.

There is no direct relationship between chromic acid demand and economic conditions in the metal finishing industry. This is due in part to increased recycling of chromic acid by this industry in response to water pollution control regulations. Moreover, other industries also use chromic acid. Of the 34,500 metric tons (38,000 short tons) of chromic acid demanded in 1984, the metal finishing industry accounted for about 39 percent of consumption, the wood preservatives industry accounted for about 44 percent, other industries accounted for about 6 percent, and exports accounted for about 11 percent. Growth in demand for chromic acid by the metal finishing industry was expected to range from 0 to 2 percent per year through 1989.[10]

The price of chromic acid remained stable at $2.52 per kg ($1.10 per lb) through 1989.[9] Among the various cost components for electroplating or anodizing (labor, utilities, etc.), the cost of other components is greater than the cost of chromic acid, although any item that affects operating cost is important.

8.1.4 Suppliers of Electroplating and Anodizing Chemicals

After production by chromic acid manufacturers, the acid is sold by suppliers of electroplating chemicals to chromium electroplating and anodizing operations. The suppliers of the acid sell it primarily in flake form and occasionally in combination with other chemicals in their proprietary plating and anodizing solutions. There are over 100 firms in the U.S. that supply chemical solutions for chromium electroplating and chromic acid anodizing. Table 8-3 lists nine of the major suppliers (in alphabetical order) and their headquarters locations.[11] Most of the major suppliers have branch locations throughout the U.S.

8.1.5 Chromium Electroplating and Anodizing Firms and Plants

The following discussion presents estimates of the number of chromium electroplating firms nationwide. Because the number of chromium electroplaters is large, a brief overview is presented below to provide a framework for considering the total number of firms.

8.1.5.1 End-Use Industries for Chromium Electroplating. Chromium plated products are used in a large number of industries. For example, the market for chromium plated products covers 17 two-digit SIC codes. Each two-digit SIC code category includes such a broad group of industries that the code's usefulness is limited for an economic analysis of chromium electroplating, specifically. Therefore, the information that follows is presented at the more detailed four-digit SIC code level.

In September 1985, the Bureau of the Census released a report covering captive metalworking operations, including electroplating establishments, that are present in various industries.1 The Census report defines 184 industries involved in metal work that perform electroplating operations. This report does not include job shops (SIC 3471), i.e., establishments specializing in electroplating operations, in contrast to the regular Census report which does provide statistical data on job shops. Instead, the September 1985

TABLE 8-3. MAJOR SUPPLIERS OF CHROMIUM ELECTROPLATING CHEMICAL SOLUTIONS

Company name	Headquarters location
American Chemical & Refining Co., Inc.[a]	Waterbury, Connecticut
C.P. Chemicals, Inc.	Sewaren, New Jersey
Enthone, Inc.[b]	West Haven, Connecticut
The Lea Manufacturing Co.	Waterbury, Connecticut
Lea-Ronal, Inc.	Freeport, New York
The J.T. MacDermid Group	Plymouth, Connecticut
M&T Chemicals, Inc.	Rahway, New Jersey
McGean-Rohco, Inc.[c]	Cleveland, Ohio
Shipley Co., Inc.	Newtown, Massachusetts

[a]A Handy & Harmon Company.
[b]Subsidiary of ASARCO, Inc.
[c]DuPont sold its business to this company.

Census report defines the number of establishments in other industry categories engaged in electroplating operations as a part of a larger process. The Census report is useful because it covers a large number of SIC groups, identifies the total number of establishments for each SIC group, and identifies the subset of establishments that perform electroplating.

8.1.5.2 Number of Chrome Electroplating Establishments. There are no sources that provide an industry-wide estimate of the number of chromium electroplaters. However, there are three sources that provide information about the percentage of all electroplaters that perform chromium electroplating. The first source is the American Electroplaters and Surface Finishers Shop Guide, which indicates that of 1,103 firms listed, 521 firms or 47 percent perform chromium electroplating. The second source is the EPA report developed for the electroplating pretreatment standards, which indicates that about 40 percent of all electroplaters perform chromium electroplating.[12] The third source is Finishers' Management, which reports that of the 4,022 metal finishing job shops in the U.S., 2,092 or 52 percent are engaged in chromium electroplating.[13] Finishers' Management gathered their data by surveying the yellow pages along with SIC codes. Combining the Finishers' Management data with data from the 1982 Census of Manufactures for electroplating operations shows the estimated nationwide number of chromium plating operations to be 4,340.[a] About 52 percent of the chromium operations are captive and the remaining 48 percent are job shops. About 58 percent of the job shops are engaged in decorative chromium plating, and about 71 percent of the captive shops perform decorative electroplating.

8.1.5.3 Chromium Anodizing Plants. For chromic acid anodizing, the total number of operations nationwide is estimated to be 680, of which 74 percent are classified as job shops and 26

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[a]See Tables in Chapter 7.

percent are classified as captive shops.[b]

8.1.6 Size and Geographical Distribution of Chromium Electroplaters and Anodizers

Chapter 5 presents a breakdown of the estimated number of hard chromium plating, decorative chromium plating, and anodizing operations by plant size. Of the estimated 1,540 hard chromium plating operations, small plants constitute 70 percent, medium plants 20 percent, and large plants 10 percent. Of the estimated 2,800 decorative chromium plating operations, small plants constitute 80 percent, medium plants 15 percent, and large plants 5 percent. Of the estimated 680 chromic acid anodizing operations, small plants constitute 75 percent and large plants 25 percent.

Before discussing specific employment data as the indicator of size, a brief discussion of terminology is necessary. Depending on the source of the information, employment data are typically presented using any one of three definitions: firm employment, establishment employment, and electroplating production worker employment. Firm employment refers to total employment for a company, including all company divisions and all locations if a company has multiple locations. Establishment employment refers to an individual plant, even though a single company might have multiple plants. Electroplating production worker employment refers to only those employees directly involved with electroplating, even though a given plant might have numerous additional employees engaged in other operations, and it excludes all supervisory personnel.

Most electroplating establishments are small. The number of production workers required to operate a single electroplating operation, either a captive operation or a job shop, is typically less than 100 employees. Frequently the electroplating operation involves less than 50 employees, and often less than 20. In the case of job shops, many firms have 10 or fewer employees. The

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[b]See Table in Chapter 7.

use of automated electroplating production lines can obscure the relationship between an operation's size and the number of its employees. Even taking automation into consideration, however, there are many small operations.

Products Finishing[14] provides size distribution information based on employment specific to chromium electroplating. Table 8-4 presents total employment of the firm data. The Products Finishing information shows that in 1985, 52 percent of the chromium firms had less than 100 employees.[14]

The Census report covering SIC 3471 includes employment data on an annual basis from 1972 through 1987. The data for the years 1972 through 1987 show that employment in plants employing 20 or more reached a peak in 1987 with 71,100 total employees and 55,900 production employees.[15]

Electroplaters are geographically dispersed across the U.S. with most electroplaters located near population and manufacturing centers and not near the sources of raw materials. In 1987, the top eight States in terms of number of workers were California, Ohio, Michigan, Illinois, New York, Texas, Pennsylvania, and New Jersey.[16] Collectively, these States represent 62 percent of the total of electroplating production workers in the U.S. The top four States have 42 percent of the total of electroplating production workers. Table 8-5 shows the 1982 distribution by State of electroplating production workers (at all types of electroplating establishments) across the U.S.

8.1.7 Substitutes

In many industrial hard plating applications, there is no satisfactory substitute for chromium. In selected applications, chromium alloys can take the place of hard chromium plating. For plating applications that emphasize corrosion resistance, electroless nickel can be substituted for chromium, based on technical performance. In plating applications that emphasize wear or abrasion resistance, hard chromium typically has superior performance characteristics and, in these cases, the ability to substitute electroless nickel for chromium is not as great.

TABLE 8-4. FIRM SIZE DISTRIBUTION BY EMPLOYMENT

	Products Finishing (1985)								
Employment per firm	1 to 19	20 to 49	50 to 99	100 to 249	250 to 499	500 to 999	1,000 to 2,499	2,500 and More	Total
	462	419	235	284	235	198	193	133	2,159

TABLE 8-5. GEOGRAPHICAL SUMMARY OF ELECTROPLATING

State	Bureau of the census (1982) Electroplating production workers (all types of establishments)
Alabama	500
Alaska	NR[a]
Arizona	400
Arkansas	NR
California	9,300
Colorado	200
Connecticut	2,000
Delaware	NR
District of Columbia	NR
Florida	900
Georgia	300
Hawaii	NR
Idaho	NR
Illinois	4,500
Indiana	1,800
Iowa	NR
Kansas	--[b]
Kentucky	300
Louisiana	200
Maine	NR
Maryland	200
Massachusetts	2,000
Michigan	4,300
Minnesota	1,200
Mississippi	NR
Missouri	1,200
Montana	NR
Nebraska	--[b]
Nevada	NR
New Hampshire	NR
New Jersey	1,800
New Mexico	NR
New York	4,000
North Carolina	700
North Dakota	NR[a]
Ohio	3,900
Oklahoma	400
Oregon	400

TABLE 8-5. (continued)

State	Bureau of the census (1982) Electroplating production workers (all types of establishments)
Pennsylvania	1,500
Rhode Island	1,700
South Carolina	NR
South Dakota	NR
Tennessee	1,200
Texas	1,900
Utah	NR
Vermont	NR
Virginia	200
Washington	500
West Virginia	NR
Wisconsin	--[b]
Wyoming	NR
U.S. Possessions	NR
Total	49,700[c]

[a]NR=not reported.
[b]Withheld by Census.
[c]Individual states do not sum to total due to withheld information.

Also, electroless nickel is significantly more expensive than chromium and, consequently, economics imposes a constraint on substitution.[17]

Examples of applications where electroless nickel is a potential substitute for hard chromium include cylinders and rolls used in the printing and textile industries.[18] Other examples include components used in the petroleum and chemical process industries, where corrosion protection is a major concern.[19] Specific components include blow-out preventers, chokes, heat exchange equipment, pumps, compressors, tubing, vessels, packers, and various valves (ball, gate, plug, and check).[17]

The potential for substitution is much greater in decorative plating applications, where nickel, cadmium, trivalent chromium and zinc can be substituted for hexavalent chromium in some end-uses (see Chapter 5). For selected decorative plating applications, materials that are not metals can be substituted for chromium. In some instances paint or a plastic coating can substitute for chromium plating.

The principle substitute for chromic acid anodizing is sulfuric acid anodizing.

8.1.8 Imports and Exports

Quantitative information about the import or export of manufactured products solely for the purpose of chromium electroplating or anodizing is not available. In general, however, it appears to be uncommon for products manufactured in one country to flow to another country solely for the purpose of chromium electroplating. This is not to say that products manufactured in the U.S. are never sent to foreign countries for chromium electroplating and then returned to the U.S. for sale, but in most cases the possible savings in the cost of electroplating would be more than offset by transportation costs. Shipping of automobile parts to Canada may be an exception to this pattern.

One relatively recent development with potential economic

implications for domestic electroplaters is the introduction of water pollution control regulations with various compliance deadlines that ranged from 1984 through 1986.[21] Because the regulations are a recent development, actual results have not yet been measured. Preliminary indications, however, do not suggest that these water pollution regulations have led to an increase in the use of foreign chromium electroplating.

8.1.9 Profile of Selected Product Markets in Chromium Electroplating

Because so many products are chrome plated, it is not feasible to describe and analyze them all. Therefore, this section provides economic profile information for several specific markets for five chromium plated products.

The five products were selected based on the following criteria:

- Representation of a variety of industries
- Consideration of a relatively broad price range
- Emphasis given to products having a high chromium plating cost relative to the final price of the product (when the information available permitted the identification of such products)
- Representation of both decorative and hard chromium plated products
- Inclusion of at least one capital good, at least one intermediate product, and at least one final end-product
- Representation of a relatively large share of the total number of firms that perform chromium electroplating
- Inclusion of a mixture of job shops and captive operations.

Given these criteria, the five products examined in detail are plumbing materials, hand tools, automobile parts, industrial rolls, and hydraulic cylinders.

The characteristics of the products are discussed in the

following subsections. Plumbing materials and hand tools are decorative chromium plated products. Some automobile parts are decorative chromium plated products, while others are hard chromium plated products. Industrial rolls and hydraulic cylinders are hard chromium plated products.

8.1.9.1 Plumbing Materials. The plumbing material market is an end-use market for decorative chromium plating. This market is classified under SIC 3432, "plumbing fixture fittings and trim (brass goods)." It includes items such as plumbers' drains, metal faucets, nozzles, and lawn sprinklers. Plastic pipe fittings are not included in this SIC group.

Table 8-6 presents data on the value of shipments of plumbing fixtures for the years 1982 through 1987.[1 22] As the table shows, thetotal value of shipments for the industry was $2.2 billion in 1987.

Although the industry includes several types of products, chromium plated metal faucets represent one of the major products. A majority of all metal faucets are plated with chromium. Faucets are available with a polished brass finish or zinc plating as alternatives to chromium plating. Also, plastic faucet handles are available. In 1989, the faucet market is estimated to have increased by about 8 percent, from approximately $404 million in 1988 to $436 million in 1989.[23]

In the past, faucets have usually been sold almost exclusively through plumbing wholesalers, who then sell to plumbers, builders, and remodelers. More recently, an increasing share of faucets has been sold directly to consumers through retail outlets that cater to the do-it-yourself market.

The demand for faucets depends on both new construction and the replacement/remodeling market. Approximately 45 percent of all faucets sold are for new construction, while the remaining 55 percent are sold in the replacement/remodeling market. Of the 45 percent sold for new construction, 30 percent are for residential construction (based on five faucets in each new single-family unit), and the remaining 15 percent are for new commercial,

TABLE 8 6. PLUMBING FITTINGS AND BRASS GOODS (SIC CODE 3432): TRENDS 1982-87
(in millions of dollars except as noted)

Item	1982	1983	1984	1985	1986	1987	Compound annual rate of growth 1982-87
Industry Data							
Value of shipments	1,300.5	1,557.4	1,788.4	1,863.0	1,982.3	2,354.9	12.6
Total employment (000)	14.4	15.4	16.3	16.0	15.9	17.1	3.5
Production workers (000)	11.1	12.0	12.8	12.4	12.2	13.1	3.4
Average hourly earnings of production workers ($)	7.0	7.73	8.12	8.46	8.57	8.55	2.9
Capital expenditures	37.2	28.3	44.8[b]	45.1[b]	24.7	61.9	10.7
Product Data							
Value of shipments[a]	1,325.3	-	-	-	-	2,202.4	10.7

[a]Value of shipments of plumbing fittings and brass goods products produced by all industries.
[b]Limited reliability.

Source: U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-34B(P). Preliminary Report Industry Series: Heating Apparatus (Except Electric and Warm Air Furnaces) and Plumbing Fixtures. Washington, DC. July 1989. p. 3.

institutional, and industrial construction.

8.1.9.2 Hand Tools. Another significant market for chromium plating is the manufacture of hand tools. Hand tools can be chromium plated for decorative or functional purposes. The hand tools category includes products such as pliers and wrenches. The principal SIC group is 3423, "hand and edge tools, except machine tools and hand saws." Hand tools are the principal products of interest, but there are also three other closely related SIC categories that are applicable: SIC 3421, "cutlery"; SIC 3425, "saw blades and hand saws"; and SIC 3429, "hardware, not elsewhere classified."

For the majority of tool manufacturers surveyed, the best selling hand tools (in terms of number of units sold domestically) are ratchets and sockets. Both of these products are decorative chromium plated to prevent tarnish, produce an abrasion resistant surface, and coat the product with an appealing mirror finish. Sockets and ratchets are made of low-carbon steel which is nickel plated for corrosion resistance. Tape measures are also sold in large numbers. A tape measure case is typically ABS plastic which is then chromium plated.

Hand tools might be more sensitive to pollution control costs than the other four products selected for analysis because they are final products and their price is generally lower than that of the other products.

The market for hand tools is segmented into two broad categories: a professional market and a do-it-yourself market. These markets overlap to some extent. The size of the United States' market for all hand tools was estimated to be about $3.6 billion in 1987 (based on value of shipments).[24]

8.1.9.3 Automobile Parts. The automobile industry is commonly considered to be the most important end-use market for decorative chromium electroplating. The automobile industry uses chromium electroplating for a variety of parts, including automobile bumpers (SIC 3465, automotive stampings), grilles, headlamp and tail-light bezels, door handles, side-view mirrors,

stick shifts, wheels, and wheel covers. Also, some engine parts and other parts, such as piston rings, MacPherson Struts, and shock absorber components, are chromium plated. Engine parts, such as air filter covers, are chromium plated for decorative purposes, while other engine parts, such as piston rings, are chromium plated for functional purposes.

The demand for chromium plating in the U.S. automobile industry is influenced by the quantity of automobiles produced in the U.S., as well as by other forces, such as the desire for greater fuel efficiency and changes in the tastes of consumers. As shown in Table 8-7, the total domestic production of automobiles reached its peak in 1973 at 9.7 million cars and declined to as low as 5.1 million cars in 1982.[25]

The volume of domestic truck and bus production is substantially smaller than (i.e., less than one-half) the volume of domestic passenger car production. While the market for trucks and buses has experienced growth, the import share varies from .3 percent for the heavy duty (over 15,000 kg [33,000 lb]) trucks to 12.8 percent for the light-duty (0-6,400 kg [0-14,000 lb]) trucks to 13.7 percent for the medium duty trucks.[26] Therefore, the truck and bus market which is subject to the same import pressure as the passenger car market, results in a fluctuating domestic demand for chromium plating. Exporting of automobiles and trucks produced in the U.S. does occur, but is not a major factor.

Measures to promote fuel efficiency have also influenced the demand for chromium plating. During the past decade, government directives, such as the corporate average fuel economy (CAFE) requirements, have imposed fuel efficiency standards on automobiles produced and sold in the U.S. Consequently, more plastics, less steel, and more aerodynamic designs have been used in automobile production in the U.S. Whereas most automobile bumpers were formerly chromium plated steel, an increasing number of them are now made of plastic. While some of the plastics now being used by the automobile industry are chromium plated

TABLE 8-7. ANNUAL U.S. MOTOR VEHICLE PRODUCTION

Year	Passenger cars (number of units)	Motor trucks and buses (number of units)	Total vehicles
1988	7,110,728	4,079,704	11,190,432
1987	7,098,910	3,825,776	10,924,686
1986	7,828,783	3,505,992	11,334,775
1985	8,184,821	3,465,500	11,650,321
1984	7,773,332	3,151,449	10,924,781
1983	6,781,184	2,443,637	9,224,821
1982	5,073,496	1,912,099	6,985,595
1981	6,253,138	1,689,778	7,942,916
1980	6,375,506	1,634,335	8,009,841
1979	8,433,662	3,046,331	11,479,993
1978	9,176,635	3,722,567	12,899,202
1977	9,213,654	3,489,128	12,702,782
1976	8,497,893	2,999,703	11,497,596
1975	6,716,951	2,269,562	8,986,513
1974	7,324,504	2,746,538	10,071,042
1973	9,667,152	3,014,361	12,681,513
1972	8,828,205	2,482,503	11,310,708
1971	8,583,653	2,088,001	10,671,654
1970	6,550,128	1,733,821	8,283,949

Source: Motor Vehicle Manufacturers Association of the U.S., Inc.

(examples are plastic grilles and knobs), overall there has been a decline in the amount of chromium plating performed by the automobile industry.

Finally, the preference of consumers for more or less chromium plating on automobiles may be another important determinant of the demand for chromium plating in the automobile industry. In general, the taste of consumers over approximately the last 10 years has shifted to a desire for less chrome on automobiles. For example, in 1974, 90 percent of the automobiles produced in the U.S. had chromium plated bumpers, but in 1985 the number had declined to only 50 percent.[27] Despite these trends, the automobile industry is probablystill the largest user of chromium plated products in the U.S.

8.1.9.4 Industrial Rolls. Numerous industries use rolls, including foil, food processing, magnetic tape, metal forming, paper, plastics, printing, textiles, and wallpaper. Rolls can be used for a wide variety of purposes, depending on the particular industry. They can be used for heating, cooling, pressing, coating, and drying. The plating and replating of industrial rolls represents a sizable market for hard chromium plating. Rolls are typically made of steel, stainless steel, or aluminum. The rolls are available in a wide size range, i.e., lengths of from only a few inches to over 12 m (40 ft), diameters of from only a few inches to about 2 m (8 ft), and weights up to 50 tons. There is no "standard size" roll because the size of the roll varies depending on the industry involved and the application.

Defining the size of the market for industrial rolls is difficult because the rolls are used in many different industries, and because the function of the rolls can vary among the industries. Additionally, an industrial roll is only one of many components entering into the production of a finished piece of equipment.

Over 100 firms plate industrial rolls with chromium. The industry includes a mixture of firms, some of which only plate rolls manufactured by others, while others both manufacture and

plate rolls. The firms are dispersed across the United States. Approximately 6 to 10 firms account for a major share of the domestic market, perhaps greater than 50 percent. The larger firms cover a marketing territory that includes the entire U.S. and occasionally other countries. The smaller firms are typically regional.

Rolls are both imported and exported. Sweden, Germany, and Brazil are among the countries that export rolls to the U.S. The U.S. exports rolls to Japan and other countries. The exact quantity and value of imports and exports is not available. However, in general, the import and export activity for rolls does not appear to be significant. Most rolls used in the U.S. are manufactured and chromium plated in the U.S.

With respect to hard chromium plating, industrial rolls are significant for two reasons. First, the number of rolls manufactured is large; therefore, rolls are an important source of demand for hard chromium plating. Second, existing industrial rolls are rechromed periodically, thus providing an additional source of demand for hard chromium plating. The frequency of rechroming varies depending on the application.

8.1.9.5 Hydraulic Cylinders. An important market for hard chromium plating is the manufacture of hydraulic cylinders. Hydraulic cylinders are one of the products manufactured by firms in SIC 3593, "fluid power cylinders and actuators." Because other products, in addition to hydraulic cylinders, are produced by firms in SIC 3593, information about this SIC group that might be available from other sources is frequently not a direct representation of the hydraulic cylinder market.

Information about the hydraulic cylinder market is scarce because a hydraulic cylinder is only one of many components entering into the production of a finished piece of equipment. Hydraulic cylinders are frequently reported within a broader category of items commonly referred to as fluid power products. For example, the principal trade association for the manufacturers of hydraulic cylinders is the National Fluid Power

Association.

Many industries use equipment having hydraulic cylinders. Among users of hydraulic cylinders are the construction, nuclear, mining, oil drilling and marine industries, agriculture, and the military.

Hydraulic cylinders have a variety of functions, including pushing, pulling, lifting, compensating, tensioning, positioning, and absorbing. The sizes of hydraulic cylinders can vary over a wide range, from a length of only a few inches to over 6 m (20 ft) and from a diameter of only a few inches to more than 1 m (3 ft). Cylinder sizes vary from industry to industry depending on the application. Therefore, there is no standard size cylinder, but most cylinders are probably only a few inches in diameter.

There are approximately 80 firms that manufacture hydraulic cylinders.[28] As shown in Table 8-8, in 1987 the total value of shipments of hydraulic and related items was $1.4 billion.[29]

Hydraulic cylinders are widely used in the construction machinery industry. Construction machinery is included in SIC group 3531. The construction machinery industry had an estimated value of shipments in 1988 of $13,090 million and a 1989 forecast of $13,352 million.[30] The expected growth rate is 2.5 percent for the rest of the decade. The low expected growth is mainly due to the unfavorable trade balance for this industry that began in the late 1970s.

Imports and exports of cylinders do exist. In general, however, the import and export market for cylinders is not a major factor in the market. Most cylinders used in the U.S. are manufactured and chrome plated in the U.S. Cylinders usually are not rechromed.

8.1.10 Chromic Acid Anodizing

As much as 10 percent of chromium use is for chromic acid anodizing. Unlike chromic acid electroplating, chromic acid anodizing is a process wherein an oxide is created on the surface of an aluminum part in an electrolytic bath of chromic acid.

Military aircraft manufacturers are the largest user of the

TABLE 8 8. MANUFACTURERS' SHIPMENTS OF FLUID POWER CYLINDERS AND ACTUATORS (SIC CODE 3593): TRENDS 1982-1987
(in millions of dollars except as noted)

	1982	1983	1984	1985	1986	1987
Industry Data						
Value of shipments[a]	12,272.2	12,483.2	13,560.2	14,765.1	15,167.0	1,896.6
Total employment (000)	250.9	247.2	249.9	252.6	244.2	14.8
Production workers (000)	196.8	194.7	195.1	197.4	185.1	9.0
Average hourly earnings of production workers ($)	8.20	8.23	8.86	9.28	9.74	12.71
Capital expenditures	660.7	543.3	559.5	701.9	572.7	81.1
Product Data						
Value of shipments[b]	15,580.5	-	-	-	-	1,404.4

[a]Prior to 1987, Industry SIC 3593 was included in the statistics for Industry SIC 3599.
[b]Value of all products and services sold by Industry SIC 3599, except for year 1987 where the value is for Industry SIC 3593.

Source: U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-35H. Industry Series: Miscellaneous Machinery, Except Electrical. Washington, DC. April 1990, p. 35H-7.

chromic acid anodizing process. Depending on the type of aircraft, major portions of the airplane's "skin" may be anodized using chromic acid. Other parts of the aircraft may also be anodized, e.g., the inside diameter of the hydraulic cylinders. Because the Department of Defense (DOD) specifically requires chromic acid anodizing, private contractors to DOD should be able to pass on all cost increases due to the proposed control options in the form of higher costs. Thus the impact on the individual chromic acid anodizers of military products is expected to be negligible.

The impact of the proposed control options on several nonmilitary anodized parts will be assessed in Section 8.2.4.6.

8.2 ECONOMIC IMPACT ANALYSIS

8.2.1 Introduction

The principal objective of the economic impact analysis is to estimate the effects of various control options on the prices and output of chromium plated or anodized products and substitutes, as well as on prices, output, and employment in electroplating and anodizing establishments (either captive or job shops). Another set of objectives is to estimate total control costs for each control option and to estimate any distributive impacts, such as on small businesses. As explained in Section 8.1, chromium electroplaters and anodizers are not a cohesive industry, but a group of firms engaged in a similar process spread across a variety of industries. Because chromium electroplating or anodizing is viewed as a process rather than as a well-defined industry, a methodology which focuses on industry behavior will not render a useful economic analysis. Therefore, this section provides ranges of probable values of the price and output effects for specific products for which the chromium electroplating or anodizing process is an integral and separable stage of production.

Five product groups for which chromium electroplating is an important component were analyzed to illustrate a range of

probable impacts. The five product groups chosen for analysis are plumbing materials, hand tools, automobile parts, industrial rolls, and hydraulic cylinders. This combination of products covers both hard and decorative plated products. For each of the product markets, estimates of the impact of the control options on both the cost of electroplating and the final price were calculated. The increase in the cost of chromium electroplating illustrates the potential for substitution away from chromium electroplating at the input stage. The increase in the final price of the product allows estimation of output reduction and the concomitant effects on revenue.

Aggregate economic impacts for all chromium electroplating processes were expressed as total control costs based on the estimated number of plants. The methodology does not permit direct extrapolation of process-wide price effects or output reductions because the five product markets are only illustrative of chromium electroplating activities and not representative of all chromium electroplating operations.

Chromic acid anodizing was analyzed by examining several nonmilitary aircraft parts to determine the increase in anodizing costs for the small and large plants.

8.2.2 Overview

Five product groups were selected to illustrate the economic impacts associated with the control options for the chromium electroplating operations. The product groups selected include plumbing materials (represented by faucets); hand tools (represented by sockets, ratchets, and tape measures); automobile parts; industrial rolls; and hydraulic cylinders (represented by backhoes). The product groups were selected to illustrate the effect of each control option on both hard and decorative plated products and on both capital and consumer goods. The impact results are summarized in Table 8-9.

The impacts are greater for products that are hard chromium plated. Table 8-9 displays worst-case quantitative results from the most costly control option for the model plant sizes

TABLE 8-9. OVERVIEW OF THE PRODUCTS SELECTED FOR ANALYSIS

Product analyzed	Type of good	Demand growth	Potential substitutes	Foreign competition	Type of plating	Type of plating shop	Maximum estim. % increase in cost of chromium electroplating[a]	Maximum estim. % increase in the final price[a]
Plumbing materials: faucets	Final Good, Intermediate Good	Demand is highly correlated with residential construction	Brass and zinc, plastic substitutes tend to be higher priced	Modest, mostly in the DIY market and the lower price ranges	Decorative	Mostly captive	3.64	0.024
Hand Tools: ratchets, sockets, tape measures	Final Good	Unknown	Experimentation with trivalent chrome has met with some success. Painted surfaces for tape measure cases.	Substantial, particularly from Pacific rim exporters; also copycat exporters to U.S.	Decorative	Mostly captive	2.51 4.92 0.78	0.068 0.015 0.026
Automobile Parts	Intermediate Good	Substantial decline in chrome plated auto parts	Plastic, paint, elastomeric substitution has been dramatic	Substantial	Decorative and hard	Mixture of job and captive	1.84 decor. 9.43 hard	0.007 decor. 0.111 hard
Industrial Rolls	Intermediate Good, Capital Good	Minimal growth, less than 2%	Electroless nickel is closest but has not proven to be a viable substitute for most applications	No perceived threat from imports	Hard	Mostly captive	13.79	N.A.
Hydraulic Cylinders, Backhoes	Intermediate Good, Capital Good	Correlated with GNP, est. growth rate approx. 2%	No close substitutes	Imports modest threat, however exports have fallen off	Hard	More job shops than captive	27.25	0.054
Aviation Parts	Intermediate Good, Final Good	Moderate growth	Sulfuric Acid	Modest	Anodizing	Captive and job shops	5.8	Negligible

[a]The maximum estimated percent increase in the cost of chromium electroplating and the maximum estimated percent increase in the final price are based on the most costly control option for the small model plant.
N.A. - Not Available
DIY - Do It Yourself

incurring the greatest control costs per unit of output, i.e., Control Option II or Scenario 1 for trivalent chromium for the small decorative model plants and Control Option III for the small hard model plants. (The percentage increases in price for each control option and each model size plant are presented in Section 8.2.4.) The estimated increase in the final price of the selected electroplated or anodized products was always 0.1 percent or less for even the most costly control option.

Substitution away from hard chromium electroplating appears very unlikely, even though control costs are higher than for decorative plating, because comparably priced hard chromium substitutes are not available. Therefore, it is likely that the costs of the control options for hard chromium electroplating will in large part be passed on to consumers which as indicated above results in minimal price increases of 0.1 percent or less.

For the decorative plated products studied, substitution away from hexavalent chrome to, for example, trivalent chrome or paint, is likely to accelerate for a product like tape measures. This is based on the 0.8 percent electroplating cost increase of the most costly control option and the recent extent to which tape measures are being successfully decorated by substitute processes. For the other decorative coated products, the control costs will in large part be passed on to consumers and will not lead to substitutes for electroplating or to diminished purchases of those consumer products.

For purposes of illustration, faucets can be used to describe the two different effects, summarized above, resulting from implementation of a control option. The first effect is the increase in electroplating costs and the second effect is the increase in the final price of the product for which electroplating is generally an intermediate process. Assume a faucet sells for $62.65 and costs $0.42 to electroplate. The most costly Control Option II results in an approximate $0.015 (3.6 percent) increase in chromium electroplating cost, which raises the cost of chromium electroplating to $0.435. At this

cost increase level, faucet manufacturers would have little incentive to substitute other products for chromium plating because the closest substitutes cost more than the increase due to the control options.

Assuming that the $0.015 increase in chromium electroplating cost is therefore passed on to consumers, the price of the faucet would increase from $62.65 to $62.67, or by approximately 0.03 percent under Control Option II. In this case, the small increase in price for the final product (the faucet) is not likely to result in a significant reduction in the number of faucets purchased, nor will it have a significant impact on the revenues earned by faucet manufacturers.

Cost and price increases for each product studied are calculated in Section 8.2.4. Section 8.2.5 examines potential quantity and revenue effects for each of the five products. For the final products studied, changes in revenues and output are always well below one percent. Section 8.2.6 reports that the nationwide costs are a maximum of $88.0 million under the most costly combination of control options. Section 8.2.7 investigates the possibility of differential impacts on small businesses. Some small chromium electroplating operations, particularly hard chromium operations, will face capital availability difficulties for some regulatory alternatives. Also, up to 15 of the uncontrolled hard chromium operations are expected to close if the most stringent control option (i.e., III) is implemented under worst case conditions.

8.2.3 General Methodology of the Analysis

This section presents the methodology used in estimating the price and output impacts for chromium electroplating operations and chromium plated products. The methodology for estimating small business impacts is presented in Section 8.2.7.

The analysis first isolates and quantifies the cost of the control options. Second, it compares the control costs for a particular control option per unit of model plant output to the direct costs of chromium electroplating a unit of output to

determine if electroplating could be replaced by competitive coatings, materials, or processes. Third, this analysis compares the same control costs per unit of output to the final (i.e., manufacturer's) list price of the product to determine, along with a demand elasticity coefficient, any likely changes in the quantity demanded of that product. This step permits estimation of product-wide output and revenue effects, while the first two steps provide an assessment of employment and small business impacts for chromium operators, particularly job shops.

This particular approach implicitly assumes that chromium electroplating applied to an individual product can be performed by any size model plant. The primary advantage of adopting this method is that cost increases associated with a control option and its subsequent effects on output and revenue can then be analyzed in the same manner regardless of the product, the firm, or the market in which the electroplating occurs.[a]

For each of the five product markets studied, the following detailed description of the analysis supplements the above summary. In order to calculate the potential increase in final price, the increase in the marginal control cost due to each control option must be estimated for each model plant.[b] This calculation consisted of dividing the annualized control costs for a particular size plant by the number of units of output for that size of plant.

Chapter 5 identifies seven control options for chromium electroplating, four for decorative chromium electroplating, and three for hard chromium electroplating. Table 8-10 gives the capital costs and the annualized control costs for each

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[a]An implicit assumption is that the electroplating is performed by the least cost technique consistent with profit maximization.

[b]Throughout this analysis, the average total cost curve is assumed to be horizontal for a particular size plant; hence the marginal cost is equal to the average cost (i.e., the cost per unit was assumed to be constant).

TABLE 8-10. DECORATIVE CHROMIUM PLATING MODEL PLANT COST[a] DATA
(1988 $)

Control Options	Small Model Plant Capital cost, $	Small Model Plant Annualized[b] cost, $	Medium Model Plant Capital cost, $	Medium Model Plant Annualized[b] cost, $	Large Model Plant Capital cost, $	Large Model Plant Annualized[b] cost, $
I Baseline or no action	0	0	0	0	0	0
II[c] Single packed-bed scrubber	45,900	11,500	91,800	24,600	155,900	46,700
or mesh-pad mist eliminators	28,900	9,500	49,000	19,100	109,100	48,800
III Chemical fume suppressant, permanent	0	1,000	0	3,500	0	18,700
IV[d] Trivalent Chromium		Ratchets		Faucets		Bumpers
	66,900	23,500	133,900	29,000	565,500	(2,280,000)
		(11,000)		21,800		36,100
		13,200		26,300		108,900

[a]Retrofit costs.
[b]These costs were not adjusted for chromic acid recovery costs.
[c]Underlined values represent the least-cost controls for Control Option II.
[d]Three scenarios of annualized costs are presented as a function of product reject rates when using the trivalent chromium process. Scenario 1 is for a reject rate given by the plants that produce the specified product. Scenario 2 reflects a reject rate set at the average of the values given by the plants. Scenario 3 reflects a reject rate set so that the process cost differential is zero.

decorative chromium electroplating alternative. The control options for hard chromium electroplating are shown in Table 8-11. Each model plant has a unique set of capital and annualized control costs based on its production capacity. The annualized control costs were computed using a 10 percent discount rate and an equipment life of 20 years except for mesh-pad mist eliminators which have a 10-year life.

The costs shown in Tables 8-10 and 8-11 are those for retrofitting an existing plant. Chapter 7 contains two sets of costs; retrofit and incremental costs for compliance if building a new electroplating facility. Retrofit costs are always higher and were chosen for calculations in all subsequent tables because retrofits to existing plants is expected to be the most common form of compliance.

The calculation of the potential increase in final price was done by first converting the model plant parameter of Ah/yr to number of units of output for each of the model plants and each of the five product markets. Tables in Chapter 5 list the production capacity of each of the model plants in terms of Ah/yr. The parameters of the products selected to illustrate the impact of the control options were obtained from manufacturers of the products. These parameters included surface area plated, current density applied during the plating process, and plating time. These parametric values allowed an estimation of the Ah per part needed to plate the surface area efficiently. Because the model plants' capacities were measured in Ah/yr, and the products analyzed were measured in Ah per part, an estimate of the potential output per plant could then be calculated. In order to allow for the loading of parts in the tanks and general maintenance of the electroplating facilities, the model plants were assumed to operate at less than 100 percent of their capacity. The capacity utilization rates for each plant size are displayed in Chapter 5.

Next an estimate of the cost per unit output of the selected product due to chromium electroplating was obtained.

TABLE 8-11. HARD CHROMIUM PLATING MODEL PLANT COST[a] DATA
(1988 $)

Control Options	Small Model Plant		Medium Model Plant		Large Model Plant	
	Capital cost, $	Annualized[b] cost, $	Capital cost, $	Annualized[b] cost, $	Capital cost, $	Annualized[b] cost, $
I Baseline or no action	0	0	0	0	0	0
II Chevron-blade mist eliminator (double)	29,800	6,700	62,400	14,700	124,800	33,600
III[c] Single packed-bed scrubber	45,900	11,500	92,800	<u>24,200</u>	185,500	<u>54,800</u>
or mesh-pads mist eliminators	28,900	<u>9,500</u>	82,500	29,900	156,300	69,000

[a]Retrofit costs.
[b]These costs were not adjusted for chromic acid recovery costs.
[c]Underlined values represent the least-cost controls for Control Option III.

The cost was defined as the direct cost of chromium electroplating the product or part exclusive of all other costs.

Finally, by dividing the annualized control cost by the firm's potential output, an estimate of the control cost increase per unit was derived. This increase in the final price was then used, along with an assumed or estimated price elasticity, to obtain an estimate of the reduction in output and the accompanying effect on the firm's revenue.

Overall, the economics of plating operations is a poorly understood subject.[31] The actual cost of the deposited metal is generally considered to be a minor factor in the total cost of plating, and power cost is even less important. Overhead and labor are the major costs. Hence, it is more important, in a cost minimizing sense, to deposit the required plating thickness in the shortest time with the fewest rejections than it is to economize on chromic acid, plating solution supplies, or power.

Since the proposed pollution control devices are intended to reduce the emissions from the electroplating operation, the entire burden of the control costs must first be placed on the additional cost of electroplating, and not spread over the entire manufacturing operation. Hence, the analysis first had to determine if the manufacturers would continue to use chromium plated parts or switch to a substitute process. If manufacturers do substitute, the potential impact of the regulation would then be felt on chromic acid manufacturers and suppliers and electroplating operators. Substitution away from chromium electroplating can only occur if a technically and economically suitable substitute is available. Furthermore, the degree of substitution possible is significantly less for hard chromium applications than for decorative chromium.

Control Option II for decorative chromium plating has two alternatives; each with the same control effectiveness - single packed-bed scrubbers or mesh-pad mist eliminators. Control Option III for hard chromium plating also contains the same two alternatives. Regarding Control Option IV for decorative

chromium electroplating (substitution of trivalent chromium), preliminary estimates indicate that the use of trivalent chromium may confer cost savings or cost increases, depending upon the reject rate. Three different scenarios are depicted in Table 8-10. Scenario 1 contains costs commensurate with a reject rate given by the plants that produce the end product shown. The costs for Scenario 2 reflect a reject rate of the average values given by the plants and the costs for Scenario 3 reflect a reject rate that produces a process cost differential of zero over the costs of the hexavalent chromium process.

8.2.4 Economic Analysis of the Selected Products

This section discusses the economic impact associated with applying each of the control options to each of five products: plumbing materials (represented by faucets); hand tools (represented by sockets, ratchets, and tape measures); automobile parts; industrial rolls; and hydraulic cylinders (represented by backhoes). The analysis focuses on the effects on the final price of the product being studied and on the electroplating cost associated with the control costs of each of the control options. The two decorative chromium electroplated products -- faucets and hand tools -- are presented first. The impact of the control options on automobile parts, which include both decorative and hard chromium plated parts, follows. Then, two capital goods that are hard chromium plated -- industrial rolls and hydraulic cylinders (hydraulic cylinders in backhoes) -- are analyzed. Finally, aviation parts are analyzed for chromic acid anodizing impacts.

8.2.4.1 Plumbing Materials. The particular product chosen to represent the plumbing fittings industry was a kitchen faucet. The particular faucet is single-handled, sells for approximately $62.67, and is one of the best selling faucets in this market. At retail outlets, the price range for faucets is $30 to $75 per unit.

As stated in the general methodology section, two values had to be calculated to assess the economic impact of the control

options: first, the cost of electroplating the product and second, the compliance cost per unit produced due to the pollution control device used.

A computer program was used to assist in calculating the unit cost of chromium electroplating per faucet based on surface area, current density, production rate, and plating time.[32] The faucet used for the analysis is assembled from four separate chromium plated parts with a total surface area of 500 cm^2 (77.5 $in.^2$). The component parts are plated to a thickness of 0.25 to 0.51 µm (0.01 to 0.02 mil). The plating time is 3.55 minutes with a current density of 1,350 A/m^2 (125 A/ft^2). Using the above parameters and assuming reasonable production rates, wage rates, and overhead, an estimated cost of 42 cents per faucet was established. This value represents 0.67 percent of the $62.67 list price for the faucet.

Using the above parameters, a reasonable estimate of the Ah per part is 3.98. Given the model decorative plant parameters from Chapter 5, the model plants are estimated to have the following yearly potential outputs per plant: 753,258 faucets for a small sized plant; 3,013,031 faucets for a medium sized plant; and 30,130,314 faucets for a large sized plant. These figures assume a current density of 1,350 A/m^2 (125 A/ft^2).

Table 8-12 displays the estimated percent increase in electroplating cost for the candidate control options, assuming a baseline electroplating cost of $8.40/$m^2$ ($0.78/$ft^2$) (see Appendix G, Section G.5). As displayed in Table 8-12, the additional cost of chromium electroplating a single faucet could be as much as 3.64 percent for a small model plant using a single packed-bed scrubber. With such an increase in cost, substitution away from chromium plating is unlikely to occur for two reasons. First, most of the large plumbing fitting companies are full-line suppliers with their own captive electroplating departments. As a result, a firm would be more inclined to look at the effect on the final price of faucets rather than on an intermediate electroplating cost. Second, there is presently no low cost

TABLE 8-12. ESTIMATED PERCENT CHANGE IN ELECTROPLATING COST, ESTIMATED PERCENT CHANGE IN THE FINAL PRICE, AND ESTIMATED DOLLAR AMOUNT (1988 $) CHANGE IN THE FINAL PRICE DUE TO VARIOUS CONTROL OPTION:, KITCHEN FAUCETS

Control Option	Percent increase in electroplating costs, model plant size			Final product percent price increase, model plant size			Dollar amount of final product price increase, model plant size		
	small	medium	large	small	medium	large	small	medium	large
I	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
II[a,e]	3.635	1.944	0.369	0.024	0.013	0.003	0.015	0.008	0.002
II[b,e]	3.003	1.509	0.386	0.020	0.010	0.003	0.013	0.006	0.002
III[c]	0.316	0.277	0.148	0.002	0.002	0.001	0.001	0.001	0.001
IV[d]									
IV-1	NA	2.291	NA	NA	0.017	NA	NA	0.010	NA
IV-2	NA	1.723	NA	NA	0.013	NA	NA	0.008	NA
IV-3	NA	2.078	NA	NA	0.015	NA	NA	0.009	NA

[a]Based on single packed-bed scrubber.
[b]Based on mesh-pad mist eliminators.
[c]Based on permanent chemical fume suppressant costs.
[d]Control costs only available for medium-sized plant.
[e]Underlined values represent the least-cost controls for Control Option II.

process with the corrosion resistant properties of hexavalent or trivalent chromium plating. Further, without a significant change in consumers' tastes for chromium plated faucets, substitution away from chromium plating at the input stage is unlikely to occur.

Even though the worst-case cost increase for chromium electroplating a faucet could be 3.64 percent for the small model plant under Control Option II, the impact on the final price would be extremely small. Table 8-12 presents both the estimated dollar amount and percent change in the final price. Control Option II would increase the price of a kitchen faucet about 1 cents over the present cost of $62.65 or a 0.03 percent increase (rounded up).

On the other hand, Control Option III, the use of permanent chemical fume suppressants, would result in electroplating cost increases of only 0.3 percent for a small plant and a product price increase of 1/10th of one cent. The impact of trivalent chromium conversion is close to that of Control Option II.

8.2.4.2 Hand Tools. The hand tool market was selected primarily to illustrate the economic impact of the control options on a commonly used but relatively low priced product. Most hand tools are sold in either the professional or the do-it-yourself markets, and are sold at retail stores for less than $25. (The final price is much lower than the other products under investigation.) Also, unlike most other products selected for analysis, hand tools are sold directly to consumers. The hand tools analyzed are sockets, ratchets (socket wrenches), and tape measures.

The surface area of one socket is about 72.3 cm^2 (11.2 $in.^2$). The socket is chromium plated to a thickness of 0.15 μm (0.006 mil). The plating time is 3 min at 2,150 A/m^2 (200 A/ft^2). The cost of chromium electroplating a socket is estimated at six cents per socket. Given this estimate, the electroplating cost is 0.3 percent of the final price of $19.95.

The second hand tool selected for study was a 0.95 cm (3/8

in.) ratchet. As sockets and ratchets are used together, adverse effects on either one would clearly impact the other. Because ratchets and sockets are often sold separately, however, they can be analyzed as distinct products. The surface area of one ratchet is 118.9 cm^2 (18.43 $in.^2$). The ratchet is chromium plated to a thickness of 0.15 µm (0.006 mil). The plating time is 3 minutes at 540 A/m^2 (50 A/ft^2).

The estimated cost per ratchet of chromium electroplating is ten cents. The electroplating cost is estimated as 2.7 percent assuming a final price of $3.69. The third hand tool investigated is a tape measure. The product is the common steel tape enclosed in a chromium plated ABS plastic case. The case undergoes a two-stage chromium plating process in which it is first etched and then decorative plated to a thickness of 0.26 µm (0.01 mil). The surface area of the plastic case is 90 cm^2 (14 $in.^2$). The plating time is 4 min. at 810 A/m^2 (75 A/ft^2). The manufacturers' estimated cost of chromium plating is 25 cents per tape measure. Thus, the chromium plating of this product is approximately 3.5 percent of the final price of $7.15, which is higher than the plating costs for either the ratchet or the socket.

Table 8-13 presents the parameters used to calculate annual production rates for the three selected hand tools for the model plants. The right-hand column of Table 8-13 displays the calculated Ah per part for each of the selected products.

The potential output for each model plant was calculated by dividing the production capacity (Ah/yr) by the Ah per part. The production capacities of the model plants are displayed in Chapter 5.

Table 8-14 summarizes the percent increases in electroplating cost per unit of output for each of the selected products under the control options. The numbers suggest that there are some economies of scale for the larger model plants. The lower percent increase in the electroplating cost for larger model plants reflects the ability of these plants to process the

TABLE 8-13. PARAMETRIC VALUES OF THREE HAND TOOLS

Hand tool	Surface area cm^2 (in^2)	Current density A/m^2 (A/ft^2)	Plating time, min.	Ah per part
Socket	8 (3)	540 (50)	4	0.0694
Ratchet	64 (25)	650 (60)	3	0.5208
Tape Measure	36 (14)	810 (75)	4	0.4861

TABLE 8-14. ESTIMATED PERCENT CHANGE IN CHROMIUM ELECTROPLATING COST, ESTIMATED PERCENT CHANGE IN THE FINAL PRICE, AND ESTIMATED DOLLAR AMOUNT (1988 $) CHANGE IN THE FINAL PRICE DUE TO VARIOUS CONTROL OPTION: THREE HAND TOOLS

Control Option	Product	Percent change in electroplating cost, model plant size: small	medium	large	Percent product price change, model plant size: small	medium	large	Dollar amount of price change, model plant size: small	medium	large
I	Socket	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Ratchet	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
	Tape Measure	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000	0.000
II[a,f]	Socket	4.919	2.631	0.499	0.015	0.008	0.001	0.003	0.001	0.000
	Ratchet	1.227	0.656	0.124	0.033	0.018	0.003	0.001	0.001	0.000
	Tape Measure	0.776	0.415	0.079	0.026	0.014	0.003	0.006	0.001	0.000
II[b,f]	Socket	4.064	2.043	0.522	0.012	0.006	0.002	0.002	0.001	0.000
	Ratchet	1.013	0.509	0.130	0.027	0.014	0.004	0.001	0.001	0.000
	Tape Measure	0.641	0.322	0.083	0.022	0.110	0.003	0.002	0.001	0.000
III[c]	Socket	0.428	0.374	0.200	0.001	0.001	0.001	0.000	0.000	0.000
	Ratchet	0.107	0.093	0.050	0.003	0.002	0.001	0.000	0.000	0.000
	Tape Measure	0.067	0.059	0.031	0.002	0.002	0.001	0.000	0.000	0.000
IV[d]										
IV-1	Ratchet	2.507	NA	NA	0.068	NA	NA	0.003	NA	NA
IV-2[e]	Ratchets	(1.173)	NA	NA	(0.032)	NA	NA	(0.001)	NA	NA
IV-3	Ratchets	1.408	NA	NA	0.038	NA	NA	0.001	NA	NA

[a]Based on retrofit costs for single packed-bed scrubber.
[b]Based on retrofit costs for mesh pad mist eliminator.
[c]Based on permanent chemical fume suppressant.
[d]Trivalent chromium costs only available for small ratchets plant.
[e]( ) denotes savings in costs.
[f]Underlined values represent the least-cost controls for Control Option II.

chromium emissions from two tanks through a single pollution control device, thereby reducing a company's cost per tank.

In the case of the tape measure, the probability of substituting away from hexavalent chromium plating appears likely for two reasons. The increase in cost for Control Option II and Control Option III ranges from 0.07 percent to 0.78 percent for the small model plant. While this increase is not dramatic when compared to the other hand tools analyzed, tape measure cases may have a viable substitute in trivalent chromium (Control Option IV). Under Scenario 2, for example, the use of trivalent chromium would yield lower control costs. Also, there are suitable substitutes for chromium plating ABS plastic, for example, painting and pigmentation.

The likelihood of eliminating chromium electroplating for sockets and ratchets would appear to be very small for Control Option III and moderate for Control Option II. Chromium plating provides a much valued tarnish- and abrasive-resistant surface, however, the estimated additional electroplating cost for sockets would be more than four percent for the most costly Control Option II for the small plant. As indicated by the small plant data, trivalent control costs for ratchets vary from creating a savings to being costlier than Control Option II and Control Option III.

Table 8-14 also shows the estimated price changes for each of the selected products (both percent change and dollar amount of change). For sockets, ratchets, and tape measures, the economic impacts associated with the control options range from a slight savings to a maximum price increase of less than 3/10 of a cent.

8.2.4.3 Automobile Parts. Domestically produced automobiles are equipped with a wide variety of chromium plated parts. Table 8-15 provides a list of most of the automobile parts that typically are either decorative or hard chromium plated. To assess the economic impacts associated with the control options, an estimate of the total additional cost from

TABLE 8-15. LIST OF AUTOMOBILE PARTS TYPICALLY CHROMIUM ELECROPLATED

Decorative		Hard
Bumper	Name Plate	Power Steering Shafts
Bumper Guards	Window Surrounds	MacPherson Struts and/or Shock Absorber Components
Grilles	Windshield Surrounds	
Grille Surrounds	Cruise Control Knob	Valves
Head Lamp Bezels	Wheel Covers	Valve Lifters
Door Handles	Window Handles	Piston Rings
Side View Mirror	Tail Light Bezel	Seals
Trunk Lock Assembly	Hood Medallion	
Interior Door Trim	Strip Molding	
Radio Knobs	Miscellaneous Trim	
Drip Rail Molding	Door Locks	

all the chromium plated parts of a typical automobile must be established.

The first portion of this section presents a discussion of the decorative plated parts, and the latter part focuses on the hard chromium plated parts. The trend in recent years has been to reduce or eliminate certain decorative chromium plated automobile parts. There are several major factors simultaneously influencing the substitution away from chromium plated parts. The primary cause is the production of lighter cars in order to comply with Federal fuel economy regulations and to satisfy consumer demands for more fuel efficient automobiles. The weight of steel used in the average new domestic car decreased from 966 kg (2,129 lb) in 1978 to 793 kg (1,748 lb) in 1988, an 18 percent decline.[33] Second, higher chromium electroplating pollution control costs due to water pollution regulations have induced producers to seek lower cost substitutes for chromium electroplated parts where possible (e.g., urethane, rubber, and paint). Also, the advent of superior substitutes for steel, such as the heat, weather, and impact resistant arylon46, have obviated the need for chromium electroplating.[34] An additional impetus for substitution is the damageability of steel and aluminum parts, e.g., bumpers, during low impact accidents. Finally, another explanation for the trend away from brightwork may be a change in consumers' tastes toward the European or Japanese style of black trim in place of chromium trim.

Six of the major chromium plated parts have been examined in detail in an effort to document further this dramatic trend away from chromium plated automotive parts. These parts include bumpers, bumper guards, grilles, grille surrounds, head light bezels, and door handles. The major source of data concerning these parts is an extensive survey of external automotive trim conducted by International Nickel, Inc.[35] The survey is conducted each year at the Annual Auto Show in Detroit, Michigan. The information used in this section covers model years from 1980 to 1986.

In 1980, 66 percent of all domestically produced automobiles were equipped with chromium plated bumpers. By 1986, the number of new models with chromium plated bumpers had been reduced by 32 percent. The use of elastomeric bumpers (elastomers are polymers possessing rubbery properties) has increased by 141 percent during the seven years from 1980 to 1986. The movement away from chromium appears to be slowing down with respect to passenger cars, while for recreational vehicles the trend may have actually begun to reverse itself.

The trend away from chromium plated bumper guards is more dramatic. In the last seven years, there has been a 65 percent reduction in the number of new models sporting chromium plated bumper guards. The elastomeric bumpers have done away with the necessity of bumper guards. Over the last seven years, 68 percent of new passenger cars have eliminated bumper guards altogether.

For grilles, chromium plated plastic remains the primary choice of manufacturers. There has been a gradual movement toward plastic coating. In 1986 a substantial number of new models, perhaps as many as 10 percent, had no grilles at all.

While there is no clear trend, most grille surrounds are either chromium plated or have been eliminated. The popularity of brightwork reemerged as an important choice in 1986, when 44 percent of the new models had chromium plated surrounds as opposed to 37 percent without any surrounds.

Two areas where chromium plated parts have maintained some popularity are head lamp bezels and door handles. From 1980 to 1986, the survey shows that chromium plating has remained dominant over either plastic or zinc as the metal coating of choice. However, over the last seven years there has been a slight trend away from chromium plating the bezels. Further, approximately 23 percent of the 1986 models have removed the bezel trim altogether.

Door handles have also experienced a movement away from chromium plating. The alternatives to chromium are plastic and

painted zinc. In 1980, 95 percent of the domestic models were equipped with chromium plated door handles, and by 1986 the number had dropped to about 70 percent.

To investigate the economic impacts associated with the control options on domestic automobiles, one model was chosen for an in-depth analysis. The largest selling domestically-produced automobile for six consecutive years in the 1980s was the Oldsmobile Cutlass/Ciera. In 1985, the Cutlass/Ciera accounted for 51.7 percent of Oldsmobile's unit sales, 12 percent of General Motors' unit sales, and 6.7 percent of total retail sales of domestically produced automobiles. In each of the six years, an average of 489,875 units of the Cutlass/Ciera was sold.36 The Cutlass/Ciera usually is equipped with a wide variety of chromium plated parts, including bumpers, bumper guards, grilles, grille and rear window surrounds, head lamp and tail light bezels, hood medallions, wheel covers, and door handles.

The total amount of decorative chromium plating is assumed to be about 4.9 m^2 (53 ft^2), with approximately 2.4 m^2 (26 ft^2) of the decorative chromium plated parts provided by the front and rear bumpers. Information provided by Section 114 letters indicate an average electroplating cost of \$8.40/m^2 (\$0.78/ft^2) for all plated parts. Assuming this cost the automotive decorative chromium plating may be as high as \$42, or 0.46 percent of the total value of the car. The bumpers are plated by large plants, while the other decorative parts are plated by small and medium plants.

Table 8-16 presents the estimated percent change in decorative electroplating cost for each of the control options, assuming a baseline electroplating cost of \$42 per automobile. The changes range from a cost savings for Control Option IV, Scenario 1 to a 1.84 percent increase for Control Option II single packed-bed scrubber for the small model plant.

Table 8-16 also shows the estimated price changes for the representative automobile (both percent change and dollar amount of change). Control Option II, single packed-bed scrubber, would

TABLE 8-16. ESTIMATED PERCENT CHANGE IN CHROMIUM ELECTROPLATING COST, ESTIMATED PERCENT CHANGE IN THE FINAL PRICE, AND ESTIMATED DOLLAR AMOUNT (1988 $) CHANGE IN THE FINAL PRICE DUE TO VARIOUS CONTROL OPTIONS DECORATIVE CHROMIUM PARTS IN REPRESENTATIVE AUTOMOBILE[a]

Control Option	Percent increase in electroplating cost, model plant size			Final product percent price increase, model plant size			Dollar amount of product price increase, model plant size		
	small	medium	large	small	medium	large	small	medium	large
I	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00
II[b,f]	1.840	0.984	0.246	0.007	0.003	0.000	0.52	0.28	0.04
II[c,f]	1.520	0.764	0.257	0.006	0.002	0.000	0.43	0.22	0.04
III[d]	0.161	0.139	0.098	0.003	0.000	0.000	0.04	0.03	0.03
IV									
IV-1[e]	NA	NA	(18.268)	NA	NA	(0.040)	NA	NA	(3.65)
IV-2	NA	NA	0.289	NA	NA	0.001	NA	NA	0.06
IV-3	NA	NA	0.872	NA	NA	0.002	NA	NA	0.17

[a]Estimates for the small and medium model plants are for all decorative plated parts except bumpers. Estimates for the large model plants pertain exclusively to bumpers.
[b]Based on single packed-bed scrubber.
[c]Based on mesh-pad mist eliminator.
[d]Based on permanent chemical fume and suppressant costs.
[e]( ) represents savings.
[f]Underlined values represent least cost controls for Control Option II.

increase the final price by 52 cents (0.007 percent of the final price). These price changes will be combined in Table 8-18 with the price changes associated with the control options for hard chromium parts to assess the total effect on the retail price of the automobile.

The parts of an automobile that typically are hard chromium plated are listed on the right hand side of Table 8-15. As much as 0.69 m^2 (7.4 ft^2) of total surface area is hard chromium plated. The electroplating cost may be as high as $106 (1.6 cents/$cm^2$ [10 cents/$in.^2$]), or 1.2 percent, of the total retail price of the automobile.

Applying the same methodology used for decorative chromium automobile parts, Table 8-17 displays the percent increase in the cost for the hard chromium plated parts under each control option. The ability of firms to substitute for hard chromium plated parts is severely limited, even though electroplating cost increases for Control Option II and Control Option III range from 5.55 percent to 9.43 percent for the small plant.

Table 8-17 also presents the estimated price increase for hard chromium parts used in automobiles (both percent increase and dollar amount of increase). Because chromium plated parts constitute a small portion of the total cost of manufacturing an automobile (i.e., less than two percent), the impact associated with any of the control options on the final price is quite small, i.e., generally less than 1/10th of one percent.

Since automobiles contain both decorative and hard chromium plated parts, the impact on final price must include the control costs from both sources. Because both impacts were measured by estimating the additional cost from separate processes, the total additional cost attributable to chromium plating can be calculated by combining the individual effects. Table 8-18 shows the total estimated change in the final price of the automobile for each of the control options. Various combinations of the control options were paired to determine the total effect of the control options for both hard and decorative automobile parts.

TABLE 8-17. ESTIMATED PERCENT CHANGE IN CHROMIUM ELECTROPLATING COST, ESTIMATED PERCENT CHANGE IN THE FINAL PRICE, AND ESTIMATED DOLLAR AMOUNT (1988 $) CHANGE IN THE FINAL PRICE DUE TO VARIOUS CONTROL OPTIONS HARD CHROMIUM PARTS FOR REPRESENTATIVE AUTOMOBILE

Control Option	Percent increase in electroplating cost, model plant size			Percent price increase, model plant size			Dollar amount of price increase, model plant size		
	small	medium	large	small	medium	large	small	medium	large
I	0.000	0.000	0.000	0.000	0.000	0.000	0.00	0.00	0.00
II	5.549	1.467	0.888	0.065	0.017	0.011	5.87	1.55	0.95
III[a,c]	9.431	2.398	1.973	0.111	0.029	0.018	10.00	2.54	1.52
III[b,c]	7.791	2.963	2.484	0.092	0.036	0.023	8.26	3.14	1.91

[a]Based on single packed-bed scrubber.
[b]Based on mesh-pad mist eliminator.
[c]Underlined values represent the least-cost control options for Control Option III.

TABLE 8-18. ESTIMATED CHANGE IN THE FINAL PRICE PER AUTOMOBILE DUE TO THE VARIOUS CONTROL OPTIONS: SUM OF BOTH HARD AND DECORATIVE CHROMIUM PARTS FOR REPRESENTATIVE AUTOMOBILE

Control Option		Percent price change model plant size			Dollar amount of price change model plant size		
decorative	hard	small	medium	large	small	medium	large
I	I	0.00	0.00	0.00	0.00	0.00	0.00
II	II	0.07	0.02	0.01	6.30	1.77	0.99
III	II	0.07	0.02	0.01	5.91	1.58	0.98
II	III	0.10	0.03	0.02	8.69	2.76	1.56
III	III	0.10	0.03	0.02	8.30	2.57	1.55
IV-1	II	NA	NA	(0.04)	NA	NA	(3.65)
IV-1	III	NA	NA	(0.02)	NA	NA	(1.74)
IV-2	II	NA	NA	0.01	NA	NA	1.01
IV-2	III	NA	NA	0.02	NA	NA	1.58
IV-3	II	NA	NA	0.01	NA	NA	1.12
IV-3	III	NA	NA	0.02	NA	NA	1.69

The combined impact on the final price resulting from the most stringent control options is estimated to be $8.69, or approximately 0.10 percent of the final price. This estimate applies to the small model plant size for decorative and hard chromium plated parts under Control Option II and Control Option III, respectively, both with single packed-bed scrubbers.

8.2.4.4 Industrial Rolls. The price of industrial rolls can vary from a low of several hundred dollars to as much as $20,000, with most rolls in the price range of about $5,000 to $9,000. The cost of chromium electroplating industrial rolls is largely a function of surface area (diameter x π x length) and the thickness of the chromium to be deposited. Most industrial rolls are chromium plated to a thickness of between 25 and 130 μm (1 and 5 mil), using a current density of approximately 0.31 A/cm^2 (2 $A/in.^2$). Based on data obtained during emission testing, the average surface area of an industrial roll is approximately 6,500 cm^2 (1,000 $in.^2$). Table 8-19 shows this information applied to an industrial roll with a surface area of 6,500 cm2 (1,000 $in.^2$).[a]

The electroplating cost as a percentage of the price of the final product, in this case a capital good, may differ for rolls with the same plating costs because of variations in roll thickness (not plating thickness) prior to plating or in the quality of the steel substrate. For most industrial rolls, the cost of chromium electroplating is generally less than 10 percent of the final price.

A more specific approach to estimating the electroplating cost is to assume a cost factor per cm^2 ($in.^2$). This cost factor is the cost of chromium plating excluding any increase associated with the control options. The cost factors used for the analysis

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[a]Any reasonably sized roll (e.g., a roll from 3,200 to 51,6000 cm^2 [500 to 8,000 $in.^2$]) would serve equally well for purposes of illustration because the plating time and, therefore, the Ah per part can be approximated as a linear function of the surface area.

TABLE 8-19. PARAMETRIC VALUES: INDUSTRIAL ROLLS

Plating thickness µm (mil)	Surface area cm^2 ($in.^2$)	Current density A/m^2 (A/ft^2)	Plating time, min.	Ah per part
25 (1)	6,500 (1,000)	3,100 (288)	108	3,600
130 (5)	6,500 (1,000)	3,100 (288)	540	18,000

were 1 and 2 cents/cm^2 (6 and 10 cents/in.^{2}) for industrial rolls plated to 25 µm (1 mil) thickness, and 5 and 6 cents/cm^2 (30 and 40 cents/in.^{2}) for industrial rolls plated to 130 µm (5 mil) thickness. These cost factors were obtained from telephone interviews with domestic manufacturers of industrial rolls and by reviewing data obtained from information requested in Section 114 letters.

Table 8-20 presents the potential output of 6,500 cm^2 (1,000 in.^{2}) rolls plated to a thickness of 25 and 130 µm (1 and 5 mil) for the model plants based on the production capacity (Ah/yr) of these plants. The small plant can produce 1,390 rolls and the large plant can produce 44,440 rolls at a plating thickness of 25 µm (1 mil). At a plating thickness of 130 µm (5 mil), small model plants can produce 280 rolls and the large plants can produce 8,890 rolls. Table 8-21 presents the potential electroplating cost for hard chromium plated rolls for each size model plant under four distinct cost assumptions: 1, 2, 5, and 6 cents/cm^2 (6, 10, 30, and 40 cents/in.^{2}).

Table 8-22 contains the estimated percentage increase in the electroplating cost associated with the control options. The percentage increase in the cost is inversely related to the assumed hard chromium finish cost factor (i.e., higher cost factors would have smaller percentage increases in cost due to the compliance costs).

Even though the increase in the electroplating cost could be as high as 13.79 percent for the small plant for the most stringent control option, it is unlikely that substitution away from hard chromium plating will occur for the majority of industrial rolls. The newest potential substitute for hard chromium plating is electroless nickel, but this process is not satisfactory for most applications and is more expensive than hard chromium plating.[17] Moreover, the demand for industrial rolls is a derived demand, that is, a firm purchases the roll as an intermediate good to produce its own product. The demand for rolls is derived from the profitability of selling the final

TABLE 8-20. ANNUAL PLANT OUTPUT: INDUSTRIAL ROLLS[a]

Surface area cm^2 ($in.^2$)	Plating thickness µm (mil)	Plating time, min.	Ah per part	Model plant size: small (output of 6,500 cm^2 [1,000 $in.^2$] rolls)	medium	large
6,500 (1,000)	25 (1)	108	3,600	1,390	11,670	44,440
6,500 (1,000)	130 (5)	540	18,000	280	2,330	8,890

[a]Production capacity is 5,000,000; 42,000,000; and 160,000,000 Ah/yr for the small, medium, and large model plants, respectively.

TABLE 8-21. ESTIMATED ELECTROPLATING COST PER PLANT PER YEAR: INDUSTRIAL ROLLS

Price per cm^2 ($in.^2$) ($)	Surface area cm^2 ($in.^2$)	Estimated cost per roll ($)	Plating thickness µm (mil)	Estimated Annual Cost ($) model plant size		
				small	medium	large
0.01 (0.06)	6,500 (1,000)	60	25 (1)	83,000	700,000	2,667,000
0.02 (0.10)	6,500 (1,000)	100	25 (1)	139,000	1,167,000	4,444,000
0.05 (0.30)	6,500 (1,000)	300	130 (5)	84,000	699,000	2,667,000
0.06 (0.40)	6,500 (1,000)	400	130 (5)	112,000	932,000	3,556,000

TABLE 8-22. ESTIMATED PERCENT CHANGE IN THE HARD CHROMIUM ELECTROPLATING COST DUE TO THE VARIOUS CONTROL OPTIONS: INDUSTRIAL ROLLS WITH DIFFERING COST FACTORS

Control Option	Plating thickness µm (mil)	Percent increase in electroplating cost at 1 cent/cm² (6 cents/in.²) model plant size		
		small	medium	large
I	25 (1)	0.000	0.000	0.000
II	25 (1)	8.040	2.124	1.261
III[a,c]	25 (1)	13.790	3.457	2.055
III[b,c]	25 (1)	11.397	4.273	2.587
		Percent increase in electroplating cost at 2 cents/cm² (10 cents/in.²) model plant size		
		small	medium	large
I	25 (1)	0.000	0.000	0.000
II	25 (1)	4.824	1.260	0.757
III[a,c]	25 (1)	8.274	2.076	1.233
III[b,c]	25 (1)	6.838	2.566	1.533
		Percent increase in electroplating cost at 5 cents/cm² (30 cents/in.²) model plant size		
		small	medium	large
I	130 (5)	0.000	0.000	0.000
II	130 (5)	8.040	2.124	1.261
III[a,c]	130 (5)	13.790	3.457	2.055
III[b,c]	130 (5)	11.397	4.273	2.587
		Percent increase in electroplating cost at 6 cents/cm² (40 cents/in.²) model plant size		
		small	medium	large
I	130 (5)	0.000	0.000	0.000
II	130 (5)	6.030	1.574	0.946
III[a,c]	130 (5)	10.343	2.594	1.541
III[b,c]	130 (5)	8.548	3.206	1.940

[a]Based on single packed-bed scrubber.
[b]Based on mesh-pad mist eliminator.
[c]Underlined values represent least-cost control option for Control Option III.

good, for example, newspapers. In other words, the willingness of a firm to pay for an additional unit of an intermediate good can be thought of as the marginal revenue expected to result from its use.[37] Because the impact on the final goods associated with the control options is very small, the incentive to search for more economical substitutes is small.

8.2.4.5 Hydraulic Cylinders -- Backhoes. Hydraulic cylinders used in backhoes were selected for the economic impact analysis because backhoes are widely used in the construction industry and backhoe hydraulic cylinders are typical of hard chromium plated cylinders classified in SIC Code 3531.

Table 8-23 presents a list of the hard chromium plated cylinders found in a typical backhoe and the diameter, length, and surface area of each cylinder that is chromium plated. Unit prices for hydraulic cylinders range from $55 to hundreds of dollars. A very common backhoe has a list price of a little more than $37,000.[38]

As with industrial rolls, the manufacturing cost of chromium plating hydraulic cylinders is largely a function of the surface area of the parts. The 11 hydraulic cylinders in a typical backhoe are chromium plated to a thickness of 25 µm (1 mil). Approximately 8,160 Ah (at a current density of 3,100 A/m^2 [288 A/ft^2]) are needed to plate all 11 cylinders.

Table 8-24 shows the potential output for the model plants producing chromium plated cylinders for an individual backhoe. The large model plant could produce approximately 32 times the output of the small model plant.

Through interviews with industry representatives, a reasonable estimate of the cost of chromium plating the hydraulic cylinders ranges from to 1 cent/cm^2 (3 to 6 cents/$in.^2$). Table 8-25 provides the potential electroplating costs per each size plant per year based on these cost factors.

Table 8-26 contains the estimated percent increase in electroplating cost for the two different cost factors. The most stringent Control Option (III, single packed bed scrubber) could

TABLE 8-23. LIST OF TYPICAL HARD CHROMIUM ELECTROPLATED BACKHOE CYLINDERS

Function	Number of cylinders	Diameter (cm)	Length (cm)	Diameter (inches)	Length (inches)	Surface area[a] (cm^2)	Surface area (in^2)
boom	1	11.43	97.9	4.50	38.54	3,516.9	545
crowd	1	10.15	83.8	4.00	32.99	2,673.2	414
sling	2	10.15	24.1	4.00	9.49	768.8	119
stabilize	2	10.15	51.5	4.00	20.28	1,642.9	255
motor bucket	1	8.9	69.5	3.60	27.36	1,944.0	301
boom lift	2	8.25	75.8	3.25	29.84	1,965.4	305
loader bucket	1	8.89	62.0	3.50	24.41	1,731.3	268
steering	1	5.08	24.1	2.00	9.49	384.4	60
Totals	11					14,626.9	2,266
Averages		9.12	61.1	3.59	24.05	1,751.7	271

[a]Surface area is calculated by the following formula: (diameter x π x length).

TABLE 8-24. OUTPUT PER PLANT PER YEAR
AT 80 PERCENT CAPACITY: BACKHOE CYLINDERS

Surface area cm^2 ($in.^2$)	Plating thickness µm (mil)	Ah per part	Output of cylinders model plant size		
			small	medium	large
14,600 (2,300)	25 (1)	8,160	620	5,150	19,610

TABLE 8-25. ESTIMATED ANNUAL CHROMIUM ELECTROPLATING COST: BACKHOE CYLINDERS

Price per cm^2 ($in.^2$)	Surface area cm^2 ($in.^2$)	Cost per set of backhoe cylinders ($)	Cost per plant ($) model plant size		
			small	medium	large
0.005 (0.03)	14,600 (2,300)	68	$42,200	$350,000	$1,333,000
0.01 (0.06)	14,600 (2,300)	136	$84,300	$700,000	$2,667,000

TABLE 8-26. ESTIMATED PERCENT CHANGE IN THE COST OF HARD CHROMIUM ELECTROPLATING DUE TO THE VARIOUS CONTROL OPTIONS: HYDRAULIC CYLINDERS FOR BACKHOES WITH DIFFERING COST FACTORS

Control Option	Cost factor $/cm^2 ($/in.^{2})	Percent increase in electroplating cost model plant size		
		small	medium	large
I	0.005 (0.03)	0.000	0.000	0.000
II	0.005 (0.03)	15.877	4.200	2.521
III[a,c]	0.005 (0.03)	27.251	6.914	4.111
III[b,c]	0.005 (0.03)	22.512	8.543	5.176
I	0.01 (0.06)	0.000	0.000	0.000
II	0.01 (0.06)	7.948	2.124	1.260
III[a,c]	0.01 (0.06)	13.642	3.457	2.055
III[b,c]	0.01 (0.06)	11.269	4.271	2.587

[a]Based on single packed-bed scrubber.
[b]Based on mesh-pad mist eliminator.
[c]Underlined values represent least-cost control options for Control Option III.

increase the cost by about 28 percent.

Manufacturers have been attempting to discover a suitable substitute for hexavalent chrome. Given the sizable potential increases in the cost of manufacturing hard chromium plated cylinders, the quest for a substitute for hexavalent chrome will certainly continue, but, at this time, there is no close substitute.

Table 8-27 provides estimates of the potential dollar and percentage increases in the final price of the backhoe. Because the only parts of a backhoe that are chromium plated are the hydraulic cylinders, and the total dollar value of chromium plated parts is small relative to the final price of the backhoe, the impact of the control options on the final price would also be quite small, i.e., less than 1/10 of one percent.

8.2.4.6 Analysis of Anodized Products

In order to assess the economic impact of Control Option II[a] and Control Option III[b] on anodizing operations, several products from the aviation industry (e.g., wing skins, jet engine parts, housings, flanges, and miscellaneous aircraft parts) were examined. These were the only chromium anodized products for which Section 114 letters had complete process and cost information. Anodizing operations fall into one of two categories, small or large, depending on the chromic acid consumed annually by the plant.

For large model plants, Table 8-28 shows that the anodizing cost was estimated to increase by up to 0.72 percent for Control Option II mesh-pad mist eliminator to 0.08 percent for Control Option III. For small model plants, the estimated increase in

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[a]Single packed-bed scrubbers with annualized costs of $10,000 for small model plants and $25,800 for large model plants or mesh-pad mist eliminators with annualized costs of $8,300 for small model plants and $40,100 for large model plants.

[b]Permanent chemical fume suppressants with annualized costs of $1,600 for small model plants and $4,600 for large model plants.

TABLE 8-27. ESTIMATED DOLLAR (1988 $) AND PERCENT CHANGE IN THE FINAL PRICE DUE TO THE VARIOUS CONTROL OPTIONS: BACKHOES

Control Option	Dollar price increase model plant size			Percent price increase model plant size		
	small	medium	large	small	medium	large
I	0.00	0.00	0.00	0.000	0.000	0.000
II	10.93	2.85	1.71	0.031	0.009	0.006
III[a,c]	18.76	4.71	2.80	0.054	0.013	0.008
III[b,c]	15.50	5.82	3.53	0.045	0.016	0.010

[a]Based on single packed-bed scrubber.
[b]Based on mesh-pad mist eliminator.
[c]Underlined values represent least cost control options for Control Option III.

TABLE 8-28. ESTIMATED PERCENT CHANGE IN THE COST OF CHROMIC ACID ANODIZING DUE TO THE VARIOUS CONTROL OPTIONS

Anodizing cost		Control Cost			Percent increase in anodizing cost model plant size	
Small	Large	Small ($)	Large ($)	Control Option	Small	Large
144,000	5,550,000	10,100	25,800	II Single packed-bed scrubber	7.0	0.46
144,000	5,550,000	8,300	40,100	Mesh-pad mist eliminator	5.8	0.7
144,000	5,550,000	1,600	4,600	III Permanent chemical fume suppressant	1.1	0.08

anodizing cost for a mesh-pad mist eliminator was approximately 5.8 percent for Control Option II and 1.1 percent for Control Option III. Although the large model plants are approximately 10 times larger in capacity than the small model plants, the small plants have higher percent increases in anodizing costs. This is because the annualized cost of the control option is only approximately three times greater for the large model plants than for the small model plants.

The impacts on the price of final products containing anodized products are expected to be negligible because the anodized products constitute such a small percentage of the price of the final airplane product and an even smaller percentage of the price of a trip.

On the other hand, the price increase at the intermediate stage of anodizing could be large enough to cause small plant owners to explore the substitution of chromic acid anodizing with sulfuric acid anodizing.

8.2.5 Quantity and Revenue Effects

To estimate the impacts associated with the control options on quantity and revenue, the concept of price elasticity of demand was applied to the five electroplated products. Price elasticity is defined as the percentage change in the quantity demanded divided by the percentage change in price. Goods with a price elasticity of demand that is greater than -1.0 are insensitive to price change and have increases in revenue as a result of a given price increase. Goods with price elasticities less than -1.0 are sensitive to price change and have decreases in revenue as a result of increases in price.

The estimated effect on revenue was derived from the following equation:

$$\%\Delta R = \%\Delta P \ (1 + E)$$

where,

$\%\Delta R$ = percentage change in revenue
$\%\Delta P$ = percentage change in price.
E = price elasticity

Table 8-28 displays the estimates of the percentage changes in price, quantity, and revenue for the selected products. The percentage change in price used in this section was drawn from the largest price change of each of the selected products in Section 8.2.4. The largest price change was typically associated with the most costly control option for the small model plant. Because the analysis in Section 8.2.4 did not present estimates of price elasticity for each of the selected products, price elasticities ranging from -0.01 to -1.2 were assumed.

The first four products listed in Table 8-29 (i.e., faucets, sockets, ratchets, and tape measures) are usually final products that are not capital goods. These products are all composed of decorative chromium. The remaining four products (i.e., decorative chromium automobile parts, hard chromium automobile parts, industrial rolls, and hydraulic cylinders used in backhoes) are considered either intermediate products or capital goods.

As the costs of the capital goods and intermediate products surveyed for this study represent only a fraction of the cost of the final products to which they contribute, the derived demand for these goods and products should be highly inelastic, i.e., greater than -0.25.[39] Consequently, in such cases, electroplating firms are likely to be able to pass on a cost increase without affecting the quantity of electroplating demanded.

The data presented in Table 8-29 supports this assumption. As shown in this table, the price elasticities for the first four products generally range from -0.25 to -1.2, whereas the price elasticities for the remaining four products generally range from

TABLE 8-29. ESTIMATED PERCENT CHANGES IN QUANTITY AND REVENUE FOR EACH OF THE PRODUCTS SELECTED FOR ANALYSIS [a,b,c]

Type of Plate/ Product/change	Assumed size of elasticity						
	-0.01	-0.10	-0.25	-0.50	-0.75	-1.00	-1.20
DECORATIVE CHROMIUM							
FAUCETS							
Price Change (%)			0.024	0.024	0.024	0.024	0.024
Quantity Change (%)			-0.006	-0.012	-0.018	-0.024	-0.029
Revenue Change (%)			0.018	0.012	0.006	0.000	-0.005
SOCKETS							
Price Change (%)			0.015	0.015	0.015	0.015	0.015
Quantity Change (%)			-0.004	-0.008	-0.011	-0.015	-0.018
Revenue Change (%)			0.011	0.008	0.004	0.000	-0.003
RATCHETS							
Price Change (%)			0.033	0.033	0.033	0.033	0.033
Quantity Change (%)			-0.008	-0.017	-0.025	-0.033	-0.040
Revenue Change (%)			0.025	0.017	0.008	0.000	-0.007
TAPE MEASURES							
Price Change (%)			0.026	0.026	0.026	0.026	0.026
Quantity Change (%)			-0.007	-0.013	-0.020	-0.026	-0.031
Revenue Change (%)			0.020	0.013	0.007	0.000	-0.005
AUTO DECORATIVE							
Price Change (%)	0.065	0.065	0.065				
Quantity Change (%)	-0.001	-0.007	-0.016				
Revenue Change (%)	0.064	0.059	0.049				
HARD CHROMIUM							
AUTO HARD							
Price Change (%)	0.111	0.111	0.111				
Quantity Change (%)	-0.001	-0.011	-0.028				
Revenue Change (%)	0.110	0.100	0.083				
INDUSTRIAL ROLLS							
Price Change (%)	0.820	0.820	0.820				
Quantity Change (%)	-0.008	-0.082	-0.205				
Revenue Change (%)	0.812	0.738	0.615				
BACKHOES							
Price Change (%)	0.054	0.054	0.054				
Quantity Change (%)	-0.001	-0.005	-0.014				
Revenue Change (%)	0.053	0.049	0.041				

[a] To determine the percent change in price industrial rolls, an initial price of $5,000 per industrial roll is used.
[b] Price changes used in this table are for highest cost control option for model plant size with highest costs.
[c] Only the most applicable elasticity coefficients were used to calculate the percentage changes in the table.

-0.01 to -0.25. This indicates that the latter four products' demands are relatively inelastic compared to those of the first four products. However, as the percentage price changes for the first five products are much less than those for the remaining three products, the revenue effects with respect to all eight products studied are very small. The revenue changes range from 0.110 percent to -0.005 percent for final goods, including those final goods associated with the intermediate products and capital goods studied.

8.2.6 Total Industry Impacts

See Chapter 7 "Cost Analysis of Control Options" for details of the derivation of total costs.

Nationwide annualized costs for chromium emissions control are separated into three categories: decorative plating sources, hard plating and anodizing.

For decorative plating the annualized costs are as follows:

	Millions
Control Option II, single packed bed scrubber	$12.30
Control Option II, mesh pad mist eliminator	11.45
Control Option III, chemical fume suppressants	6.04
Control Option IV, trivalent chromium	
Scenario 1	(254.41)
Scenario 2	(10.43)
Scenario 3	55.87

For hard chromium plating, the annualized costs are as follows:

Control Option II, Chevron blade mist eliminator	$16.83
Control Option III, single packed bed scrubbers	23.22
Control Option III, mesh-pad mist eliminators	24.27

For anodizing the annualized costs are as follows:

Control Option II, single packed-bed scrubbers	$7.16
Control Option II, mesh-pad mist eliminators	7.87

Control Option III, chemical fume suppressants	1.53

The most costly combination of controls would total $88.0 million: decorative, Control Option IV-3 ($55.86); hard, Control Option III, mesh-pad mist eliminator ($24.27); and anodizing, Control Option II, mesh-pad mist eliminator ($7.87).

It should be noted that the above annualized expenditures data for Control Option I (the baseline) shows costs greater than zero whereas the model plant analysis tables for each product presented earlier in the chapter shows zero costs. The explanation is that the above greater than zero aggregate costs for Control Option I represent incremental costs for the small portion of operations that are presently uncontrolled (25 percent of the hard chromium electroplating operations and 15 percent of the decorative operations). The earlier model plant analysis designates Control Option I as the most prevalent baseline control situation in the industry which is that the majority of operations have scrubbers, mist eliminators or fume suppressants. Therefore the incremental cost for achieving Control Option I is zero.

8.2.7 Small Business Impacts

Section 8.2.4 demonstrates that the control costs associated with the various control options would be several times larger for hard chromium electroplaters than for decorative platers. Thus, if small businesses are going to be differentially impacted, the effects would more readily be found in hard plating operations. In addition, the average electroplating job shop is a small business with annual sales in 1986 of $1,134,900. Estimates indicate there are presently 885 hard chromium job shops in the U.S.[13]

The Small Business Administration (SBA) defines SIC 3471, job shops, by an employee size of 500 or less. Number of employees is not always a good criterion for designating small business for this analysis, because electroplating and anodizing are processes and most reported data on number of employees

includes people from other manufacturing processes. In addition, many large capacity operations are automated and only require a small number of employees. As shown in Table 8-4, 1635 of the 2159 firms, or 75.7 percent, in the Products Finishing list had 500 employees or less. The level of 500 employees is used herein as the definition of a small business.

The small size model plant in this report has a 5,000,000 Ah capacity. For hard chromium electroplating operations, which will be the focus of the small business impacts analysis, 1,170 (or 76 percent) of the 1,540 chromium electroplating operations fit the small model plant category. This means there is a high likelihood that a small hard chrome electroplating plant will also be a small business.

The Regulatory Flexibility Act (RFA) requires that special consideration be given to the impacts of all proposed regulations affecting small businesses. As just shown, there is a substantial number of small businesses performing hard chromium electroplating, many of which are job shops. The EPA has issued RFA guidelines containing the following criteria for use in determining what is a "significant adverse economic impact" and what would therefore require the performance of a Regulatory Flexibility Analysis.

- Annualized compliance cost increases total cost of production by more than 5 percent.
- Compliance costs as a percentage of sales for small plants are at least 10 percentage points higher than for large plants.
- Capital costs of compliance represent a significant portion of capital available to small entities, where available capital is measured by pretax cash flow minus annual capital expenditures.
- The requirements of the regulation are likely to result in closures of small entities.

The impacts associated with the control options will have a negligible effect on the price of any final good, as shown in Section 8.2.6. Clearly, the cost of the hard chromium components of a final good (e.g., industrial rolls) is insignificant relative to the cost of other materials involved in the manufacture and distribution of the final good. Thus, the first criterion listed above for significant impacts is not satisfied.

Table 8-30 presents control costs as a percent of net sales for the three sizes of model plants. The control costs used to calculate these figures are from Table 8-11. Net sales figures are derived form the RMA Annual Statement Studies 1991. Table 8-30 indicates that control costs as a percentage of net sales for a small model plant are not ten percentage points higher than for large model plants for any control option. The greatest differential that could occur would be 1.7 percentage points if the single packed bed scrubber control option is implemented.

There are two ways in which capital availability arises as an issue (third criterion). The first concern is the ability of small decorative plants to raise capital to make a conversion to trivalent electroplating that in some instances will save annual costs. Decorative chromium platers have the option of converting to trivalent electroplating (Control Option IV), whereas hard chromium platers do not have this ability. However, the conversion requires more capital for decorative platers than the installation of add-on controls such as for Control Option II. The second question arises as to whether capital can be obtained to finance the other add-on controls at hard or decorative plated shops.

Table 8-31 was constructed from financial data reported by Robert Morris Associates for the electroplating industry.[40] A small firm with annual sales of $500,000 was selected. This size firm is at the lower end of the range of small firms. The table shows how profits before taxes would be impacted by the various costs of controls and also shows how several financial ratios for the firm would be affected by the RAs. These ratios are used by lenders to determine whether to loan money. (Outside financing

TABLE 8-30. HARD CHROMIUM ELECTROPLATING CONTROL COST AS PERCENT OF SALES FOR SMALL, MEDIUM AND LARGE MODEL PLANTS

Control option	Model plant size		
	small	medium	large
II			
Chevron blade mist eliminator (double)			
Control Costs	$ 6,700	$ 14,700	$ 33,600
Sales	$600,476	$3,650,496	$28,118,286
Control Costs Divided by Sales (%)	1.1	0.4	0.1
III			
Single packed-bed scrubber			
Control Costs	$ 11,500	$ 24,200	$ 54,800
Sales	$600,476	$3,650,496	$28,118,286
Control Costs Divided by Sales (%)	1.9	0.7	0.2
Mesh-pad mist eliminator			
Control Costs	$ 9,500	$ 29,900	$ 69,000
Sales	$600,476	$3,650,496	$28,118,286
Control Costs Divided by Sales (%)	1.6	0.8	0.2

TABLE 8-31. CAPITAL AVAILABILITY ANALYSIS FOR SMALL CHROMIUM ELECTROPLATING FIRM

Sales		$500,000
Profit Before Taxes without controls (@3.6% of sales)		18,000
Profits After Taxes (3.0% of Sales)		15,000
Profit Before Taxes with Controls		
	Annualized Cost	
Chevron blade mist eliminator	$ 6,700	11,300
Single packed-bed scrubber	11,500	6,500
Mesh-pad mist eliminator	9,500	8,500
Fume Suppresant	1,000	17,000
Trivalent Chromium		
Scenario 1	23,500	Negative
Scenario 2	(11,000)	29,000
Scenario 3	13,200	4,800
Depreciation (4.2% of sales)		21,000
Cash Flow (Profits & Depr.)		36,000
Current Maturities Long-Term Debt (CMLTD)		17,143
Total Assets (Sales/Assets = 2.57)		194,500
Total Debt (56.9% of Assets		110,865
Net Worth (43.1% of Assets)		83,635
Current Assets (60.8% of assets)		118,256
Current Liabilities (CA:CL=1.8)		65,698
Interest		13,304

	Capital Outlays	Debt: Net Worth	CA:CL	EBIT	CF:CMLTD
Baseline Ratio	-	1.32	1.80	2.35	2.10
New Ratios					
Single packed-bed scrubber	$ 45,900	1.87	1.57	1.45	1.15
Mesh-pad mist eliminator	28,900	1.67	1.65	1.60	1.32
Chevron blade mist eliminator	29,800	1.68	1.65	1.76	1.43
Trivalent Scenarios 1	66,900	2.13	1.50	0.83	0.71
2		2.13	1.50	2.55	1.76
3		2.13	1.50	1.33	1.01

would be needed by many small chromium electroplating firms because the profits before taxes plus the depreciation cash flow would generally be insufficient to pay for most sets of controls.) As Table 8-31 shows, the debt-to-net-worth ratio increases substantially for a firm of this size under all add-on and trivalent control alternatives. The ratio is 1.32 before controls and anywhere from 1.67 to 2.13 with controls. Ratios above 1.0 are considered high to begin with and ratios above 1.5 are very high. The ratio is highest for trivalent chromium.

The current ratio (i.e. current assets divided by current liabilities) is 1.8 before controls and reduces to between 1.5 and 1.65 after controls. This ratio is less affected because the assumption was made herein that the controls are financed by long-term debt. The reduction in the ratio is due to the current portion of the long-term debt being carried as a current liability. The performance of this ratio would not deter firms from obtaining financing for control systems.

Cash flow over current maturities of long-term debt (CF: CMLTD) is a ratio that lenders examine to determine the assurance that cash flow will be sufficient to repay debt principal. The small size firm's baseline ratio is 2.1. A similar ratio is earnings before interest and taxes (EBIT) over interest (baseline 2.35). Lenders look to this ratio to evaluate the adequacy of a company's earnings to cover interest payments.

The baseline CF: CMLTD ratio drops from 2.1 to between 0.7 and 1.76. A ratio below 1.2 is considered insufficient. Two of the three trivalent chromium scenarios produce insufficient ratios. The SPBS also produces an insufficient ratio. The EBIT ratio changes from 2.35 to 0.8 to 2.6. For the same insufficiency level for this ratio the same control systems produce insufficient ratios as for CF:CMLTD.

In conclusion, some of these very small firms aren't likely to be granted capital for add-on controls particularly for SPBSs. For conversions to trivalent chromium the ability for these very small firms to obtain capital will depend upon their reject rate

and its effect on annualized control costs.

It should be remembered that the above static analysis is performed with statistics that have a great deal of variability within them. The performance of firms varies from year-to-year and a certain number of firms enter or leave the business each year causing the data to change along with effects from business cycles. The analysis above used median data for the financial ratios. As an example of the variation, although the median for the debt worth ratio was 1.3 the values for the 25th and 75th percentiles were 2.8 and 0.5. Still using 1.5 as the ratio of acceptability for lenders, the variation in data for this ratio shows that over 25 percent of all firms start off with a ratio unacceptable to lenders. Some of these firms may be already headed for business closure or some may be in temporary difficulty where an infusion of equity capital may be planned. Likewise for the ratio cash flow to current maturities of long-term debt the median is 2.1 while the other two quartiles are 1.7 and 5.6

For firms with sales above $500,000 the capital availability ratios quickly begin to improve. Only a few firms with sales above $500,000 are likely to face capital availability problems.

Closure potential (the fourth criterion) ties in directly with the availability of capital (the third criterion) and the impact of differential control costs. As Table 8-30 showed, a differential control cost exists between the small and medium hard chromium plating model plants, and between the small and large hard chromium plating model plants. Furthermore, many small hard chromium job shops would experience even larger differential cost impacts because they operate their tanks at lower capacity utilization rates than medium and large size model plants. Plants operating at low utilization rates would incur the same annualized capital costs as plants operating at high percentages of production capacity, causing higher per unit output control costs.

Because the large and medium plants have more discretion over price than the small plants, small plants that do not have their own market niche will bear a portion of the control cost differential in the form of reduced profitability. Table 8-30 showed that the small plants may only be able to pass on 10 to 20 percent of the control costs in the form of higher prices, because the industry price will be established by the more efficient firms.

The concern is whether the control cost that cannot be passed on to consumers by small hard chromium plants would be significant enough to cause closures. A limited survey of job shops revealed that the majority of small job shops compete vigorously with large job shops for hard chromium plating.[41] Thus, it cannot be claimed that all small plants have their own market niche and can pass these differential costs on to their customers. On the other hand, it was revealed that competition is based more on quality of service and delivery time than it is on price. For small plants that have their own market niche, some or all of the differential is likely to be passed on as price increases due to the competitive advantage of the plants. On balance, however, it is likely that many small plants will have to absorb some compliance costs, causing profits to decrease. Whether or not the profit decrease would cause small plant closure requires an analysis of existing profit rates, cash flows, and net present values of small firms before and after effects associated with the control options.

Two approaches were used to estimate this closure potential for small plants. In the first approach, a formula was used whereby the net present value (NPV) of the plant could be estimated with and without the control costs of the control option. Allowing for chromium electroplating operations to earn their cost of capital, the decision to close occurs when the control cost causes a plant's NPV to go from positive to negative.

The formula is:

$$NPV = \sum_{t=1}^{20} \frac{[(1-.4)\ (EBTt-CCt)]}{(1+r)t} + \frac{.8(WC)}{(1+r)^{20}} + \frac{.2(FA)}{(1+r)^{20}}$$

where,

CC = Annual control costs absorbed by the hard chromium plating operations
EBT = Earnings before taxes chromium plating operations
WC = Working capital
FA = Fixed assets
r = Cost of capital
.4 = Combined federal, state, and local corporate income tax rate.

The assumptions inherent in the above formula are:

- Depreciation cash flows of the operation will be used for sustaining capital expenditures
- 80 percent of the operation's working capital value will be recovered at the end of 20 years
- 20 percent of the operation's fixed asset value will be recovered at the end of 20 years
- The cost of capital is 10 percent. This assumption is consistent with the discount rate used in Chapter 7.

This formula is particularly sensitive to the level of control costs absorbed. As shown earlier in this section, the small plants should be able to recover approximately 10 to 20 percent of the control costs through the price increases of the larger job shop price leaders.

Because there are so many operations with controls already in place, thus threatening potential price increases, the NPV

calculations were made with and without some control costs being passed on.

Ninety-one companies with $1 million or less in assets in SIC codes 3471 and 3479 reported median earnings before tax profit rates (EBT) on sales of 3.6 percent for these companies' fiscal year 1989. For the same companies, the median sales to working capital (WC) ratio was 13.6 and the median sales to net fixed asset (FA) ratio was 7.1.[40]

The NPV calculations revealed that firms of $245,000 sales or less which could not pass on any control costs under Control Option III would close. For plants which could pass on one-tenth of their control costs, the closure point was about $220,000 in sales.

There are about 116 hard chromium job operations with sales less than $500,000.[13] The number of operations with sales of $220,000 or less is 51 assuming proportional representation. Because 70 percent of the small hard chromium operations already have packed-bed scrubbers (Control Option III) or Chevron blade mist eliminators (Control Option II), the number of plants likely to close is 0.3 x 51 or about 15 plants.

The 70 percent of already-controlled plants includes plants with Chevron blade mist eliminators. In reality if Control Option III is selected these plants will also incur incremental control expenditures. For example for the small hard chromium plant the incremental annualized cost is $2800 (see Table 8-11) which is enough to cause closure for plants of $70,000 or less assuming a pass forward of one-tenth of the control costs. The number of plants affected would be 5 (0.3 x 16 plants). These 20 plants constitute approximately 1.7 percent of the total of 1,170 small hard chromium job operations.

The estimate of 20 total closures under Control Option III is likely a worst-case estimate for three reasons. First, the above calculations assume that all plant sales are attributable to direct electroplating only, and exclude sales revenue of ancillary operations such as polishing, grinding, etc. Because

revenue and earnings before taxes would, in reality, be higher than revenues exclusively from the electroplating process, the above estimate represents an upper limit. The second reason is that some small firms have their own market niche and will be able to pass on the differential control costs. The third reason is that even though the number of electroplating plants is depicted herein as being stable over the next five years, there is a trend toward large operations as opposed to smaller operations. An unknown percentage of small operations would be expected to cease operations for economic reasons over the impact time frame, some of them possibly overlapping with the above estimated closures. Fourth, this estimate only applies for the most costly Control Option III, for hard chrome electroplating.

An alternative method to determine the number of potential plant closures can be performed based on the data presented in Table 8-32. This data shows that the bulk of the industry capacity is provided by large operations. As a result, large operations will most influence the price for hard chromium products and so will be able to pass on their increased costs to the consumer. However, the smaller operations will be less able to pass on their full cost increases. It is, therefore, assumed that closures will occur only in the smaller, less efficient operations. The number of closures would equate to the reduction in industry output expressed in Ah, divided by the average Ah capacity of the small model plant.

Table 8-33 presents a range of percent price increases compared against two elasticity values (i.e., -0.05 and -0.15) that represent the derived demand for hard chromium plated products. The numbers in the center of the matrix indicate the number of plant closures for each percent price increase and elasticity value combination for Control Option III. The most likely percent price increase would be a weighted average percent price increase based on a plating cost of 40 cents per square inch, plated to a thickness of 0.005 inches and calculated as

TABLE 8-32. NUMBER OF PLANTS, PLANT SIZE, INDUSTRY CAPACITY, AND PERCENT OF INDUSTRY CAPACITY -- HARD CHROMIUM ELECTROPLATERS

Model plant size	Number of plants	Ah	Industry capacity (Ah)	Percent of industry capacity
Small	1,080	5,000,000	5,400,000,000	12.73
Medium	310	42,000,000	13,020,000,000	30.69
Large	150	160,000,000	24,000,000,000	56.58

TABLE 8-33. NUMBER OF SMALL PLANT CLOSURES BASED ON PERCENT PRICE INCREASE AND ELASTICITY VALUE COMPARISONS

Percent price increase	Elasticities	
	-0.05	-0.15
0.25	1	3
0.50	2	6
0.75	3	10
1.00	4	13
1.15	5	15
1.50	6	19

follows:

$$W = \sum_{i=1}^{3} (Mi\ Pi)\ .\ NC$$

where:

W = Weighted average percent price increase
M = Market share for each model plant size
P = Percent price increase for each model plant size
i = Small, medium and large size plants
NC = Percent noncompliance in industry (.30 percent)

The value of such a weighted average percent price increase is 1.12 percent and is comprised of 0.83 percent for those without controls and .29 for those with Control Option II.

Next the number of closures was estimated using the following formula:

$$N = (W * E * O)/S$$

where

N = Number of closures
W = Weighted average percent price increase/100
E = Price elasticity
O = Industry wide capacity for hard chromium electroplaters
S = Ampere hours of capacity for a small model plant

Thus a percentage price increase of 1.12 and a price elasticity of -.15, coupled with an industry wide capacity of 42,420,000,000 Ah and an Ah capacity of 5,000,000 for a small model plant would produce an estimated fourteen closures.

Based on the two closure analyses presented above, this report assumes that 14 to 20 plant closures will potentially

occur as a result of the most stringent Control Option III. The capital availability analysis performed earlier suggests that those who close are likely to be those who have difficulty raising capital.

In summary, none of the four economic impact criteria examined for small business impacts are triggered by the control options. The price increases and control costs as a percent of sales do not produce significant impacts on small firms. Capital availability difficulties discussed earlier will be felt by the smallest of the small firms but not a substantial number of all small entities. The 14 to 20 plant closures estimated are also not a substantial portion of the total number of small hard chromium electroplating plants.

8.3 REFERENCES FOR CHAPTER 8

1. U.S. Department of Commerce. Bureau of the Census. 1982 Census of Manufactures. MC82-S-8 Subject Series: Selected Metalworking Operations. Washington, DC. September 1985. pp. 8-3 through 8-4.

2. U.S. Department of the Interior. Bureau of Mines. Chromium. Minerals Yearbook. Washington, DC. 1988, p.11.

3. U.S. Department of the Interior. Bureau of Mines. Chromium. In: Mineral Commodity Summaries. Washington, DC. 1990, p. 44.

4. Reference 2, p. 8.

5. U.S. Department of the Interior. Bureau of Mines. Chromium. Mineral Commodity Profiles. Washington, DC. 1983, p. 13.

6. U.S. Department of the Interior. Bureau of Mines. Chromium in December 1983. Mineral Industry Surveys. Washington, DC. March 5, 1984, p. 1.

7. U.S. Department of the Interior. Bureau of Mines. Chromium in December 1984. Mineral Industry Surveys. Washington, DC. March 20, 1985, p. 1.

8. Reference 3, p. 45.

9. Chrome Chemicals. Chemical Marketing Reporter. Schnell Publishing Co., Inc. New York, NY. August 21, 1989, p. 24.

10. Chemical Profile: Chromic Acid. Chemical Marketing Reporter. Schnell Publishing Co., Inc. New York, NY. October 21, 1985, p. 54.

11. Thomas Register of American Manufacturers. Chemicals: Electroplating. New York. 1989, pp. 4047-4048.

12. U.S. Environmental Protection Agency. Office of Analysis and Evaluation. Economic Analysis of Pretreatment Standards for Existing Sources of the Electroplating Point Source Category. Washington, DC. Publication No. EPA-440/2-79-031. February 1979. Appendix C, p. 25.

13. Metal Finishing Job Shop Industry Profile 1985/86, Finishers' Management, Media/Market Bulletin. Glenview, IL, Finishers' Management. 1986, p. 35H-7.

14. Chromium Plating: Operations crosshatch by SIC and plant size. Products Finishing. December 11, 1985.

15. U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-34D Industry Series: Screw Machine Products, Fasteners and Washers; Metal Forgings and Stampings; and Metal Services. Washington, DC. April 1990. p. 34D-9.

16. Reference 15. p. 34D-14.

17. Duncan, R.N. Electroless Nickel: Alternative to Chromium Coatings. Metal Progress. June 1985, p. 35.

18. Reference 17, p. 32.

19. Colaruotolo, J.F. Trends in Electroless Nickel Plating. Plating and Surface Finishing. December 1985.

20. Reference 17, p. 36.

21. 40 CFR 413. Effluent Guidelines and Standards for Electroplating. Published by The Bureau of National Affairs, Inc. Washington, DC. November 28, 1986, p. 275.

22. U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-34B(P). Preliminary Report Industry Series: Heating Apparatus (Except Electric and Warm Air Furnaces) and Plumbing Fixtures. Washington, DC. July 1989. p. 3.

23. Masco Corporation. 1989 10-K Report. Securities and Exchange Commission. Washington, DC. 1990, p. 4.

24. U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-34A(P). Preliminary Report Industry Series: Metal Cans, Cutlery, Hand Tools, and General Hardware. Washington, DC. April 1989. p. 3.

25. Motor Vehicle Manufacturers Association of the United States, Inc. MVMA Motor Vehicle Facts & Figures 1989. Detroit, MI 1989. p. 6.

26. Reference 25, p. 19.

27. DiBari, G.A. Nickel Electroplating: Prospects for Growth. Plating and Surface Finishing. December 1985. p. 53.

28. Iron Age Data Bank Market Guide. Radnor, PA, Chilton Co. 1984. p. 33.

29. U.S. Department of Commerce. Bureau of Census. 1987 Census of Manufactures. MC87-I-35H. Industry Series: Miscellaneous Machinery, Except Electrical. Washington, DC. April 1990, p. 35H-7.

30. U.S. Department of Commerce. Bureau of Census. U.S. Industrial Outlook. Washington, DC. January 1990, pp. 22-1 through 22-2.

31. Kirk-Othmer. Encyclopedia of Chemical Technology, 3rd ed., Volume 8. New York, John Wiley & Sons. 1979. p. 835.

32. Durney, L. Calculating Plating Costs. Products Finishing. January 1985. pp. 79-82.

33. Reference 25, p. 73.

34. DuPont Grooms Resin for Big Role in Detroit; Breakthrough Claimed. Chemical Marketing Reporter. November 10, 1986, pp. 7 and 15.

35. DiBari, G.A. Automotive External Trim Survey and Trends. Suffern, NY, International Nickel, Inc. 1984 (with 1985 update). p. 1.

36. Motor Vehicle Manufacturers Association of the United States, Inc. MVMA Motor Vehicle, Facts and Figures 1986. Detroit, MI. 1986. pp. 14-15.

37. Friedman, L.S. Microeconomic Policy Analysis. New York, McGraw-Hill Book Company. 1984. p. 303.

38. Telecon. Donato, S.A., JACA Corp., with Gary Tindel of John Deere, Moline, IL. March 17, 1987. Information on the average cost of the most commonly used backhoe and size of the hydraulic cylinders in the backhoe.

39. Intermediate Microeconomics, 2nd Ed. New York, McGraw-Hill Book Company. 1982. p. 349.

40. Robert Morris Associates. 1989 Annual Statement of Studies. Philadelphia, PA. 1989. p. 135.

41. Telephone survey conducted by Donato, S.A., JACA Corp., to contacts at the following companies: Accurate Electroplating (Philadelphia, Pennsylvania), Armolog Company (Croydon, Pennsylvania), Easton Plating and Metal Finishing (Easton, Pennsylvania), Frankford Plating (Philadelphia, Pennsylvania), and Garnet Chemical (Allentown, Pennsylvania). April 30 - May 1, 1987. Information about small job shop operations.