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Technical Assessment of New Emission Control Technologies Used in the Hard Chromium Electroplating Industry

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TECHNICAL ASSESSMENT OF NEW EMISSION CONTROL TECHNOLOGIES USED IN THE HARD CHROMIUM ELECTROPLATING INDUSTRY

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NOTICE

This report was prepared by Midwest Research Institute, Cary, North Carolina. It has been reviewed for technical accuracy by the Emission Standards Division of the Office of Air Quality Planning and Standards and approved for publication. Mention of trade names or commercial products is not intended to constitute endorsement or recommendation of use.

PREFACE

The Office of Air Quality Planning and Standards is responsible for establishing national emission standards for hazardous air pollutants. This document serves as a supplement to Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations--Background Information for Proposed Standards (BID), which provides technical support for the development of national emission standards for chromium electroplating operations. The information contained herein provides a detailed technical assessment of control technologies that have been demonstrated for use in the hard chromium electroplating industry since the BID was written. The assessment includes performance evaluations of each new control technology as well as the environmental and economic impacts associated with the use of the technologies.

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ABBREVIATIONS USED IN THIS DOCUMENT

A	=	ampere
Ah	=	ampere-hour
^oC	=	degrees Celsius
cm	=	centimeter
CrO_3	=	chromium anhydride, commonly known as chromic acid
dscf	=	dry standard cubic foot
dscm	=	dry standard cubic meter
^oF	=	degrees Fahrenheit
ft	=	foot
ft^2	=	square foot
ft^3	=	cubic foot
g	=	gram
gal	=	gallon
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
kWh	=	kilowatt-hour
L	=	liter
lb	=	pound
lb_f/ft	=	pound force per foot
m	=	meter
m^2	=	square meter
m^3	=	cubic meters
mg	=	milligram
mil	=	thousandth of an inch
min	=	minute
MW	=	megawatt

oz	= ounce
μm	= micrometer (micron)
V	= volt
yr	= year

TECHNICAL ASSESSMENT OF NEW EMISSION CONTROL TECHNOLOGIES USED IN THE HARD CHROMIUM ELECTROPLATING INDUSTRY

1.0 INTRODUCTION

In 1989, the California Air Resources Board (CARB) approved an Airborne Toxic Control Measure (ATCM) for hexavalent chromium emissions from chromium plating and anodizing operations. Under the ACTM for hard chromium electroplating tanks, emission reductions are related to the facility-wide emission level considering any preexisting control. Facilities with emissions less than or equal to 0.91 kg/yr (2 lb/yr) must reduce emissions from each tank by 95 percent or achieve an emission limit of 0.15 mg/Ah (0.002 gr/Ah). Facilities with emissions of at least 0.91 kg/yr (2 lb/yr) but less than 4.5 kg/yr (10 lb/yr) must reduce emissions from each tank by 99 percent or achieve an emission limit of 0.03 mg/Ah (0.005 gr/Ah). Facilities with emissions of 4.5 kg/yr (10 lb/yr) or greater must reduce emissions from each tank by 99.8 percent or achieve an emission limit of 0.006 mg/Ah (9.3×10^{-4} gr/Ah).

The effect of this ATCM was to force development of innovative approaches to control that might achieve higher reductions than those presently achieved with more conventional technologies typically applied in chromium electroplating and anodizing operations. Vendors of conventional equipment incorporated the use of composite mesh pads into traditional control systems in an effort to increase control device performance. In addition, based on the high performance levels of fiber-bed mist eliminators in controlling sulfuric acid mists, these systems were examined to determine their applicability and effectiveness in controlling chromic acid emissions.

Section 2.0 provides background information for the new control technologies. Section 3.0 presents brief descriptions of each new control technology. Performance data for each technology are presented in Section 4.0. Section 5.0 contains assessments of cost and environmental impacts associated with each technology. Finally, conclusions regarding the applicability and effectiveness of the new control technologies are presented in Section 6.0.

2.0 BACKGROUND

2.1 Mesh-Pad Mist Eliminators

Mesh-pad mist eliminators designed prior to 1986 had a single mesh pad consisting of layers of woven material with fiber diameters of 0.09 cm (36 mils). The units were designed for vertical gas flow and did not incorporate an internal spray system for cleaning of the pad. Because of the tendency of these units to plug, they generally were not recommended for controlling chromic acid mist. Subsequent generations of mesh-pad mist eliminators (designed in 1988 - 1989) incorporated two or three mesh pads that consisted of material woven from strands of fiber with the same fiber diameter, which varied between 0.05 and 0.09 cm (20 and 36 mils). These newer units were equipped with internal spray systems to clean the pads and were designed to accommodate the removal of the pads for additional cleaning. Thus, the plugging potential was minimized. In addition, these units were designed to accommodate horizontal gas flow, permitting better drainage of the system. The second generation mesh-pad mist eliminator systems had performance levels that approximated those obtained through the use of traditional packed-bed scrubbers.

In the early 1990's, the performance level of mesh-pad mist eliminator systems was further enhanced by changing the pad configuration to facilitate the capture of particles less than 5 μm (0.20 mil). The most recent design change involves the use of a composite mesh pad. These pads differ from traditional mesh pads in that the composite pads are woven with layers of material with varying fiber diameters instead of layers of material with the same fiber diameter. The layers in the center of the composite mesh pad consist of extremely small diameter fibers (0.01 to 0.02 cm [4 to 8 mils]). The layers on either side of the center are made up of progressively larger diameter fibers (0.04 to 0.09 cm [16 to 37 mils]). The primary purpose of this configuration is to produce a coalescing effect. Small mist droplets that impinge on the pad coalesce into larger droplets as they travel through the finer mesh layers. The enlarged particles can then be easily removed in the back layers of the pad or in a subsequent stage in the control system. These pads may be used in series with other standard types of pads in mist eliminators, or in conjunction with packed-bed scrubbers, to capture chromic acid mists.

When composite mesh pads are used in mist eliminators, multiple pads (typically two to four) are used in series. The design of each pad is determined by the size of the mist droplets to be collected. The composite pad is typically the second or third stage in this type of control system. Irrigation systems and provisions for pad removal to facilitate cleaning have been incorporated to achieve better chromium emission control efficiencies.

Traditionally, packed-bed scrubbers used to control chromic acid mist were horizontal or vertical countercurrent-flow units equipped with one or two packed beds followed by a chevron-blade mist eliminator section. The designs of these conventional scrubber systems have been upgraded in an effort to increase the performance level. Overhead spray systems have been added to ensure sufficient wetting of the packed bed and to prevent chromium buildup. Finally, the addition of a composite mesh pad section behind the packed bed(s) has made it possible to improve the overall performance of the scrubber unit and eliminate the need for a chevron-blade mist eliminator.

2.2 Fiber-Bed Mist Eliminators

Fiber-bed mist eliminators have been used predominantly to control acid mists from sulfuric, phosphoric, and nitric acid plants. Fiber beds have also been used to capture solid particulates and mixtures of liquid mists and soluble solids (e.g., sodium chloride, ammonium nitrate).[1] The transfer of this technology to the control of emissions of chromic acid mist from chromium electroplating and chromic acid anodizing operations has occurred only recently.

Fiber-bed mist eliminators typically consist of one or more fiber beds. Each bed consists of a hollow cylinder formed from two concentric screens with the fiber packed into the annular space between the two screens. These control systems use inertial impaction and Brownian diffusion to remove contaminants from a gas stream. Fiber-bed units are designed for horizontal, concurrent gas-liquid flow through the bed. As the gas stream flows toward the downstream face of the bed, the acid mist in the gas stream impacts on the surface of the fibers and drains down the outer face of the bed to the sump while the cleaned gas flows up and out the top of the unit. These systems are equipped with spray nozzles to reduce the potential for plugging. In a further effort to prevent plugging, most vendors recommend a pre-filtering system.

3.0 DESCRIPTIONS OF EMISSIONS CONTROL TECHNOLOGIES

This section presents basic descriptions and operating principles for each of the technologies examined.

The mist eliminator and packed-bed scrubber systems operate with inertial impaction and direct interception as the primary control mechanisms. Inertial impaction involves the collision of large particles with a stationary surface to which they adhere. When the mechanism is direct interception, particles attempt to follow the streamline around the collection surface, but because of 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.

Another control mechanism used in fiber-bed mist eliminators is Brownian diffusion. Brownian diffusion is the random movement of particles due to collisions on a molecular level. This random motion places the particles on a collision path with the collection media. Brownian diffusion is not a major factor for particles larger than 3 μm (0.12 mil).

3.1 <u>Composite Mesh-Pad Mist Eliminator Systems</u>

The principal control mechanisms for mesh-pad mist eliminators are droplet impaction and interception. Inertial impaction occurs when larger particles, traveling with sufficient velocity, collide with the pad 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.

In the composite mesh-pad system, the material layers in the center of the pad are composed of extremely small-diameter (0.01 to 0.02 cm [4 to 8 mil]) fibers. The material layers on either side of the center are composed of progressively larger (0.04 to 0.09 cm [16 to 37 mil]) diameter fibers. As the gas stream flows through the composite mesh pad, the small particles that escape the collection device upstream of the mesh pad (e.g., packed-bed scrubber or other mesh pads) impinge on the composite pad and coalesce into larger droplets. This process is accomplished by using a pad comprised of layers of material with various fiber diameters and operating the pad at its flood point.[2] The flood point is the condition in which the liquid flow in the pad is hampered causing liquid to build up in the pad. The enlarged particles are then removed in the back side of the composite mesh pad or in the backup mesh pad downstream of the composite pad. When composite mesh pads are used in series, the pressure drop across the system typically ranges from 1.2 to 1.7 kPa (5 to 7 in. w.c.).

The performance of mesh-pad mist eliminators is dependent upon the fiber diameter, void fraction (amount of free volume), and the air velocity passing through the pad. One of the major factors that affects mesh-pad mist eliminator performance is the tendency of the unit to plug, with the tendency being inversely proportional to the size of the fiber. Regular cleaning of the pads is critical to optimizing performance. The void fraction influences performance because the higher the void fraction, the greater the resistance to plugging. Mesh pads with higher void fractions can handle heavier contaminant loadings.

Gas stream velocity affects performance because the entrained particles must have adequate velocity to collide with the fibers. However, gas velocities that are too high can cause collected particles to be reentrained in the gas stream. Therefore, gas velocities should be maintained high enough to optimize collection through inertial impaction yet not cause reentrainment.

Composite mesh pads are used in various configurations and are available through many chromium electroplating equipment suppliers.

3.1.1 Composite Mesh Pads Used in Series.

When mesh pads are used in series, the first stages of the unit generally serve to reduce the loading on the pads. The first stage is sometimes a single or double set of chevron blades. These parallel, chevron-shaped baffles are used to remove the large particles, which constitute the majority of chromium emissions. The use of chevron blades reduces the tendency for the pads to plug. The chevron-blade section may be followed by a coarse mesh pad that is used to further reduce the loading on the composite pad. This first mesh pad is sometimes irrigated with water to promote the coalescing (enlargement) of the mist droplets, which makes the droplets easier to remove.[2] The primary purpose of the second pad (composite pad) is to increase the size of the particles that penetrated the first pad. The larger particles are then collected or reentrained in the back side of the second pad.[2] The last pad is used to capture the reentrained material that was not collected by the previous pads. In some mesh-pad systems, all the pads are operated dry with periodic washing to clean the pads.

3.1.2 Composite Mesh Pads Used in Conjunction with Packed-Bed Scrubbers.

Removal of chromic acid mist is accomplished by impingement of the droplets on the packing material in the upgraded scrubber systems. The velocity of the gas stream is reduced at the scrubber inlet to maximize impingement efficiency. Water is sprayed countercurrent to the flow of the gas stream, thereby enlarging the mist droplets contained in the gas stream and causing some droplets to drop to the bottom of the scrubber. The gas stream then passes through the packed bed where chromic acid droplets impinge on the packing material and are washed to the bottom of the scrubber. The packing material used in the newer scrubbers has a high surface area-to-volume ratio (presenting more impaction opportunities) and the capacity to distribute, collect, and redisperse the scrubbing liquid quickly. Composite mesh pads, which are located behind the packed bed, are used to remove any reentrained droplets that are carried over from the packed-bed section, as well as particles that are too small to be captured by the packed bed. One or two coarse mesh pads follow the composite pad and are used to remove any enlarged droplets that are reentrained from the composite pad.

3.2 Fiber-Bed Mist Eliminators

Fiber-bed mist eliminators remove contaminants from a gas stream using the mechanisms of inertial impaction and Brownian diffusion. When inertial impaction is the principal control mechanism, fiber-bed mist eliminators are more efficient than other control devices using this mechanism (e.g., typical mesh-pad mist eliminators and packed-bed scrubbers) because of the higher surface area-to-volume ratios. These higher ratios result in greater obstruction of the gas flow, permitting additional opportunities for impaction of the mist droplets onto the bed fibers. Fiber beds designed for contaminant removal by Brownian diffusion as well as inertial impaction are the most efficient mist eliminators currently available.

Fiber-bed units are designed for horizontal, concurrent gas-liquid flow through the bed. The contaminated gas stream flows toward the downstream face of the bed. The acid mist in the gas stream impacts on the surface of the fibers and drains down the outer face of the bed to the sump while the cleaned gas flows up and out the top of the unit. Fiber-bed units are equipped with a water spray system to wash down any large particulates that may clog the unit. The spray is activated in response to an increase in pressure drop over that specified in the design of the unit. Pressure drops for impaction units range from 0.15 to 2.0 kPa (0.5 to 8 in. w.c.), and pressure drops for Brownian diffusion units range from 1.2 to 3.7 kPa (5 to 15 in. w.c.).

The major factors affecting the performance of fiber-bed mist eliminators are the velocity of the inlet gas stream, pressure drop across the fiber bed, and the water recirculation rate. With impaction-type units, the velocity of the gas flowing to the unit must be maintained above a certain lower limit because of the decrease in efficiency of inertial impaction at low flow rates.[3] This lower limit varies, depending on the specific design of the impaction bed, but typically ranges from 30 m/min (100 ft/min) for some fiber beds to 110 m/min (350 ft/min) for other beds.[4] The Brownian-diffusion type units have no lower limit on gas flow rate because mist collection increases as the gas flow rate approaches zero.[3] The maximum gas flow rate in fiber-bed mist eliminators is defined by the point at which: (1) collection efficiency begins to drop below acceptable levels, or (2) the gas-phase pressure drop becomes excessive.[3] Performance may be affected as a result of plugging of the bed if the water spray system is not activated in response to an increase in the pressure drop.

Most vendors do not recommend fiber-bed mist eliminators as the first stage of the control system because of their tendency to plug. It is recommended that coarse pre-filtering be provided upstream of the fiber beds to prevent plugging. The pre-filtering devices range from a series of mesh pads to a complete packed-bed scrubber unit.

4.0 EMISSIONS TEST DATA

This section presents the results of full-scale emission testing conducted on commercial units used to control chromium emissions from hard chromium electroplating and chromic acid anodizing operations. Samples to be analyzed for hexavalent and total chromium were obtained through isokinetic sampling using a modified EPA Method 5 sampling train (40 CFR Part 60 - Appendix A). The train was modified by eliminating the filter, using glass-lined probes and glass nozzles, and using 0.1 normal sodium hydroxide instead of water in the impingers. Method 5, which also requires the use of EPA Methods 1 through 4, provides detailed procedures, equipment criteria, and other considerations necessary to obtain accurate and representative emissions samples. The collected samples were analyzed using ion chromatography with a post-column reactor for hexavalent chromium and atomic absorption for total chromium.

In two of the emissions tests described in this section, both hexavalent and total chromium were measured. In the remaining two, only total chromium was measured. Results of the emissions tests performed by EPA to evaluate performances of control techniques for chromium emissions indicate that hexavalent chromium constitutes the majority of total chromium emissions from chromium electroplating and anodizing operations.[5] Thus, for those tests in which only total chromium was measured, the results are assumed to be representative of hexavalent chromium levels.

More detailed information about each test is presented in tabular form in Appendix A.

4.1 Composite Mesh-Pad Tests

4.1.1 Mesh-Pad Mist Eliminator--Precision Engineering, Seattle, Washington[6]

Emission source tests were conducted by EPA at Precision Engineering on December 17-19, 1991, to evaluate the performance of a state-of-the-art mesh-pad mist eliminator. Precision Engineering is a medium size job shop that performs hard chromium plating of industrial rolls, hydraulic cylinders, and miscellaneous small parts.

4.1.1.1 Process Description.[6] The plating shop typically operates 24 hours per day, 5 days per week. There are six hard chromium plating tanks at this facility. During the source tests, Tanks 1, 2, and 7 were tested. Table 1 presents the dimensions and operating parameters for each process tank. All three plating tanks are divided into two cells and each cell is equipped with a rectifier to control the current flow. Current ratings (per cell) of the rectifiers are 5,000 A, 3,000 A, and 10,000 A for Tanks 1, 2, and 7, respectively. The plating solution in each tank consists of chromic acid at a concentration of 250 g/L (33 oz/gal). The temperature of the plating solution is maintained at approximately 60°C (140°F).

TABLE 1. DIMENSIONS AND OPERATING PARAMETERS FOR THE HARD CHROMIUM PLATING TANKS AT PRECISION ENGINEERING, SEATTLE, WASHINGTON

Tank No.	Dimensions (l, w, d), m (ft)	Capacity, L (gal)	Maximum rated current per cell, A
1	2.0, 1.3, 3.7 (6.5, 4.2, 12.0)	9,280 (2,450)	5,000
2	2.0, 1.3, 3.7 (6.5, 4.2, 12.0)	9,280 (2,450)	3,000
7	1.2, 1.8, 5.5 (4.0, 5.9, 18.0)	11,830 (3,120)	10,000

All of the plating tanks are serviced by overhead hoists that are used to transfer parts in and out of the tanks. Heating and cooling systems are located in each tank to maintain uniform solution temperature. In addition, each of the tanks is equipped with an air agitation system to aid in maintaining uniform bath concentration and temperature.

4.1.1.2 Air Pollution Control.[2,6]

A schematic of the ventilation system and control device servicing the plating tanks is shown in Figure 1. The system was installed in 1991. Each tank is equipped with a double-sided hood for ventilation. Moisture extractors are located in the

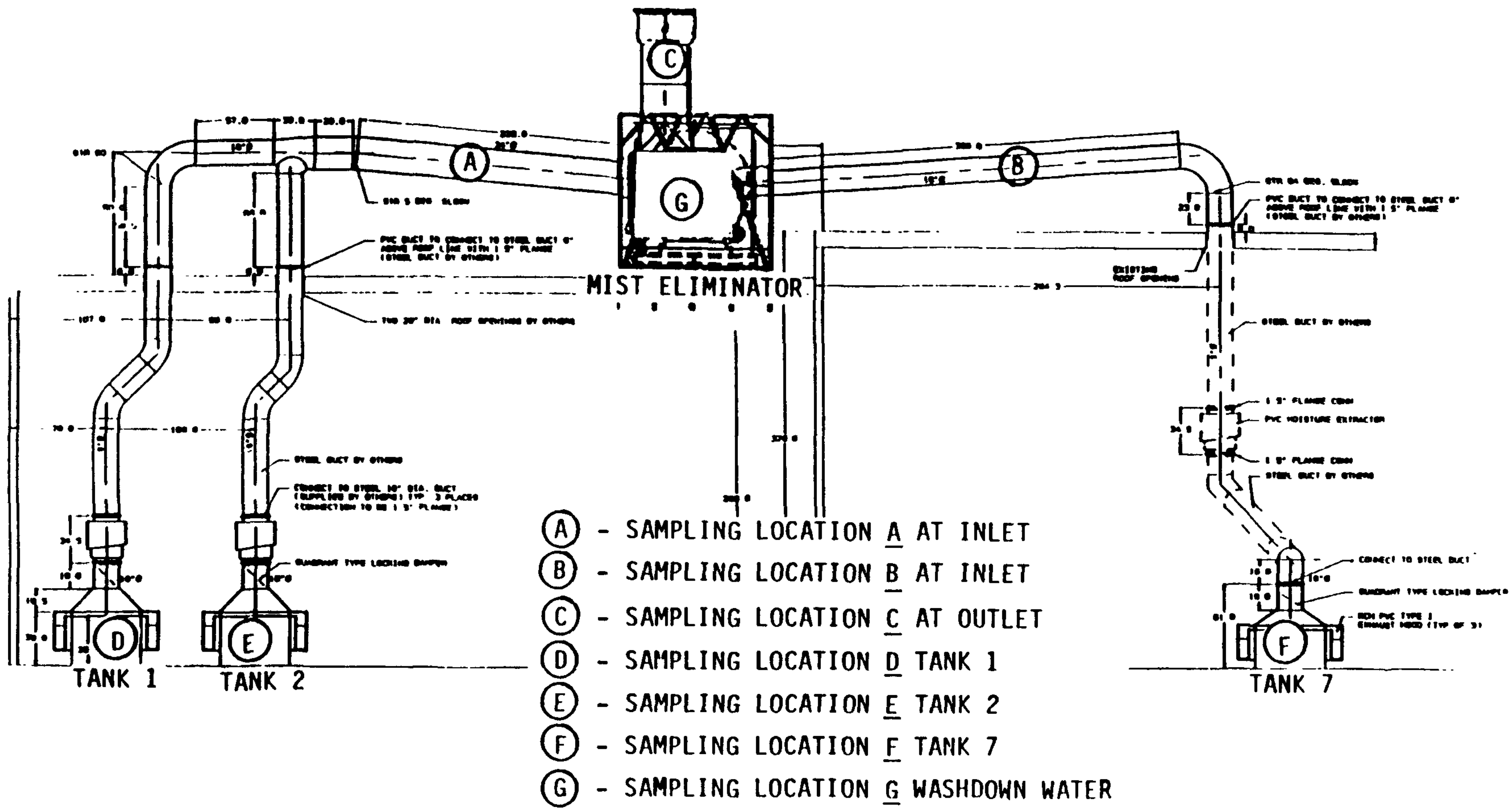

Figure 1. Schematic of the ventilation and control system at Precision Engineering, Seattle, Washington.

hood uptakes to remove the coarser mist droplets from the exhaust stream, thereby reducing the inlet loading to the mist eliminator. Tanks 1 and 2 are ducted together to form one inlet leg to the mist eliminator, while Tank 7 is ducted separately to form another inlet leg to the mist eliminator. The two inlet legs join just prior to the inlet plenum of the mist eliminator.

The mesh-pad mist eliminator is located on the roof of the plating shop and is a first generation Spectra V manufactured by KCH Services, Inc.* The unit consists of a set of chevron-blade baffles followed by a series of three mesh pads. The mesh pads were manufactured by Kimre, Inc.* The first pad in the series is a coarse mesh that consists of material woven from strands of fiber with the same fiber diameter, which ranges from 0.04 to 0.09 cm (16 to 37 mils). This pad removes the majority of the chromic acid mist particles. The second pad (the composite mesh pad) serves to enlarge the size of the particles that penetrate the first pad, and these particles then impinge on the back side of the second pad and coalesce into larger droplets. This pad is comprised of layers of material with fiber diameters typically ranging from 0.005 to 0.04 cm (2 to 16 mils). The material layers in the center of this second pad contain the smallest diameter fibers, with the layers on either side of the center containing progressively larger diameter fibers. The purpose of the third pad, which is identical to the first pad, is to remove any reentrained droplets carried over from the second pad.

The design pressure drop across the mist eliminator is 1.7 kPa (7 in. w.c.). An increase in pressure drop above the normal operating range for a given pad indicates that the pad

*Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

needs to be washed down to remove chromium that has built up on the pad. This is accomplished with a series of spray nozzles located in front of each mesh pad.

4.1.1.3 Process Conditions During Testing.[6] Three sample runs were conducted at each of the two inlet locations (A and B) and at the outlet (stack, C) of the mist eliminator. Testing at the three locations was performed simultaneously. Each test run was 4 to 6 hours in duration. Process operating parameters monitored during each sample run included the voltage, current, ampere-hours, and plating solution temperature for each plating tank in operation. Average values for each sample run are presented in Table 2. Hydraulic cylinders were plated during each test run. The surface areas of the parts plated during the test program are included in Table 2. Pressure drops across each mesh pad and across the overall unit were monitored during each test run and no increase in pressure drop was noted.

4.1.1.4 Results of Emissions Testing.[6] Results of the emissions testing are presented in Tables 3a and 3b. Total chromium emissions from Tanks 1 and 2 measured at Inlet A averaged 0.35 mg/dscm (0.15×10^{-3} gr/dscf), or 5.6×10^{-3} kg/hr (12×10^{-3} lb/hr). At Inlet B, total chromium emissions from Tank 7 averaged 0.15 mg/dscm (0.06×10^{-3} gr/dscf), or 1.3×10^{-3} kg/hr (2.9×10^{-3} lb/hr). Total chromium emissions measured at the outlet of the mesh-pad mist eliminator averaged 0.011 mg/dscm (5×10^{-6} gr/dscf), or 0.27×10^{-3} kg/hr (0.58×10^{-3} lb/hr).

Hexavalent chromium emissions from Tanks 1 and 2 measured at Inlet A averaged 0.34 mg/dscm (0.15×10^{-3} gr/dscf), or 5.3×10^{-3} kg/hr (12×10^{-3} lb/hr). Hexavalent chromium emissions from Tank 7 at Inlet B averaged 0.15 mg/dscm (0.06×10^{-3} gr/dscf), or 1.3×10^{-3} kg/hr (2.9×10^{-3} lb/hr). At the outlet of the mesh-pad mist eliminator, hexavalent chromium emissions averaged 0.010 mg/dscm (0.005×10^{-3} gr/dscf), or 0.25×10^{-3} kg/hr (0.55×10^{-3} lb/hr).

TABLE 2. AVERAGE OPERATING PARAMETERS DURING EACH EMISSIONS TEST RUN AT PRECISION ENGINEERING, SEATTLE, WASHINGTON

Run No.	Tank No.	Operating voltage, V	Operating current, A	Temperature of plating solution, °C (°F)	Surface area plated, m^2 (ft^2)
1	1A	7.0	4,300	140	368 (3,960)
	1B	7.0	3,700	140	
	2A	7.6	2,300	140	167 (1,800)
	2B	7.6	1,400	140	
	7A	--	--	140	332 (3,570)
	7B	8.0	7,000	140	
2	1A	6.4	3,600	140	368 (3,960)
	1B	6.3	3,400	140	
	2A	7.2	1,700	140	167 (1,800)
	2B	7.4	1,850	140	
	7A	6.6	1,300	140	469 (5,050)
	7B	6.4	2,000	140	
3	1A	6.4	2,970	140	260 (2,800)
	1B	6.4	2,800	140	
	2A	7.7	2,000	140	167 (1,800)
	2B	7.8	1,700	140	
	7A	6.0	1,000	140	474 (5,100)
	7B	7.3	7,200	140	

TABLE 3a. PERFORMANCE DATA FOR THE MESH-PAD MIST ELIMINATOR AT PRECISION ENGINEERING, SEATTLE, WASHINGTON (TOTAL CHROMIUM TEST RESULTS)

	Inlet A				Inlet B				Outlet (C)				
		Total chromium emissions				Total chromium emissions				Total chromium emissions			
Run No.	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	% Efficiency[a]
1	67,000	0.31	4.8	0.429	42,000	0.15	1.4	0.200	109,000	0.013	0.32	0.018	94.8
2	42,000	0.29	4.4	0.419	28,700	0.14	1.3	0.181	70,700	0.011	0.25	0.014	95.6
3	38,000	0.45	7.5	0.789	32,800	0.15	1.2	0.146	70,700	0.009	0.23	0.013	97.4
AVG	**49,000**	**0.35**	**5.6**	**0.546**	**34,500**	**0.15**	**1.3**	**0.176**	**83,500**	**0.011**	**0.27**	**0.015**	**95.9**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run. Because there were two inlet sampling locations, efficiencies were determined by using the sums of the two inlet mass emission rates.

TABLE 3b. PERFORMANCE DATA FOR THE MESH-PAD MIST ELIMINATOR AT PRECISION ENGINEERING, SEATTLE, WASHINGTON (HEXAVALENT CHROMIUM TEST RESULTS)

	Inlet A				Inlet B				Outlet (C)				
		Hexavalent chromium emissions				Hexavalent chromium emissions				Hexavalent chromium emissions			
Run No.	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	% Efficiency[a]
1	67,000	0.29	4.6	0.411	42,000	0.15	1.4	0.200	109,000	0.014	0.34	0.019	94.3
2	42,000	0.28	4.2	0.400	28,700	0.13	1.1	0.153	70,700	0.009	0.22	0.012	95.8
3	38,000	0.44	7.2	0.758	32,800	0.17	1.4	0.171	70,700	0.008	0.20	0.011	97.7
AVG	**49,000**	**0.34**	**5.3**	**0.523**	**34,500**	**0.15**	**1.3**	**0.175**	**83,500**	**0.010**	**0.25**	**0.014**	**95.9**

[a]Efficiencies are calculated from mass emission rates, and the average is based on averaging efficiencies for each run. Because there were two inlet sampling locations, efficiencies were determined by using the sums of the two inlet mass emission rates.

In calculating the overall removal efficiency of the mesh-pad mist eliminator, the total mass emission rates for Inlets A and B were compared to the outlet mass emission rate. The apparent effectiveness of the moisture extractors is indicated by the inlet loading values, which, despite the relatively high process current, are unusually low. The removal efficiency averaged 95.9 percent for both total chromium and hexavalent chromium. The average total current applied to the tanks during outlet testing was 83,500 Ah. Therefore, the process emission rates based on total and hexavalent chromium measurements were 0.015 mg/Ah (2.3×10^{-4} gr/Ah) and 0.014 mg/Ah (2.2×10^{-4} gr/Ah).

4.1.2 Mesh-Pad Mist Eliminator--Monroe Auto Equipment, Hartwell, Georgia[7]

Source testing was conducted at Monroe Auto Equipment, Hartwell, Georgia, on December 18 - 20, 1991, to evaluate the performance of a composite mesh-pad mist eliminator. Emissions testing was performed by IEA, Inc., of Research Triangle Park, North Carolina, and observed by a representative of the U.S. EPA. The Monroe Auto Equipment plating operation uses a chemical fume suppressant to inhibit misting. Therefore, testing was performed with and without the fume suppressant in the plating bath.

Monroe Auto Equipment performs hard chromium electroplating of shock absorbers of various sizes. The plating line is typically operated 5 days per week and 16 hours per day.

4.1.2.1 Process Description.[7,8] The shock absorber rods are loaded into a carrier, six at a time, and the carrier is conveyed from tank to tank through the plating line. There is one chromium electroplating tank in the plating line; it is 1.4 m (4.5 ft) wide by 9.1 m (30 ft) long by 0.91 m (3.0 ft) deep and holds about 11,400 L (3,000 gal) of plating solution. The plating solution in the tank contains chromic acid in a concentration of 240 g/L (32 oz/gal). The normal operating bath temperature is 54°C (130°F). The plating tank is equipped with heating and cooling systems and is air agitated to maintain a uniform plating bath temperature and composition. The tank is serviced by an 11,000 A, 12 V rectifier and is operated at a current ranging from 3,300 A to 10,000 A depending on the length of the shock absorber rods.

4.1.2.2 Air Pollution Control.[2,7,9] The chromium emissions from the plating tank are exhausted to a mesh-pad mist eliminator system consisting of two sets of double-sided chevron blades followed by a series of three mesh pads. The mesh pads were manufactured by Kimre, Inc.* The control system, a Spectra V, manufactured by KCH Services, Inc.*, was installed in November of 1991.

The first pad in the series of pads is a coarse mesh that typically consists of material woven from strands of fiber with the same fiber diameter, which varies between 0.04 and 0.09 cm (16 and 37 mils). This pad removes the majority of the chromic acid mist particles. The second pad (the composite mesh pad) serves to enlarge the size of the particles that penetrate the first pad, and these larger particles then impinge on the back side of the second pad. This pad is comprised of layers of material with fiber diameters typically ranging from 0.005 to 0.04 cm (2 to 16 mils). The material layers in the center of this second pad contain the smallest diameter fibers, with the layers on either side of the center containing progressively larger diameter fibers. The purpose of the third pad, which is identical to the first pad, is to remove any reentrained droplets carried over from the second pad.

The mesh-pad mist eliminator system is designed to accommodate a flow rate of 800 m^3/min (28,000 ft^3/min) and has a design pressure drop across the entire system of 1.3 kPa (5.25 in. w.c.). The control system is operated dry but is equipped

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*Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

with a spray system to wash the individual pads when the pressure drop across the system increases.

During the emissions testing, a chemical fume suppressant (an M & T Fumetrol 210 combination foam blanket and wetting agent*) was used during half of the emissions test runs. The foam is designed to inhibit chromic acid misting from the plating bath by trapping the mist in the foam layer. The wetting agent inhibits misting by lowering the surface tension of the plating bath, allowing the gases to escape at the surface with less of a bursting effect.

4.1.2.3 Process Conditions During Testing.[7] Six emissions test runs were conducted at the inlet and outlet of the mesh-pad mist eliminator system to characterize the overall performance. Each test run was approximately two hours in duration. Test Runs 1, 3, and 4 were performed when no fume suppressant was used, and test Runs 2, 5, and 6 were performed when the combination foam blanket and wetting agent was used in the bath. Table 4 presents the average operating parameters (voltage, current, and temperature of the plating solution) monitored during each test run.

The pressure drop across the mesh-pad mist eliminator system did not increase during any of the test runs; therefore, no washing of the pads was necessary. The foam blanket used during test Runs 2, 5, and 6 was maintained at a thickness between 3 and 8 cm (1 and 3 in.) with the heavier layers in the corners of the tank.

4.1.2.4 Results of Emissions Testing.[7] Table 5 presents the performance data for the mesh-pad mist eliminator system tested at Monroe Auto Equipment. Emissions measured at the inlet

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*Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

TABLE 4. AVERAGE OPERATING PARAMETERS MONITORED DURING EACH EMISSIONS TEST RUN AT MONROE AUTO EQUIPMENT, HARTWELL, GEORGIA

Run No.	Operating voltage, V	Operating current, A	Temperature of plating solution, °C (°F)
1	6.4	6,800	141
2	6.4	6,800	141
3	6.4	6,800	141
4	6.3	6,800	140
5	7.2	10,100	144
6	7.2	10,200	143

when a fume suppressant was not used on the plating bath averaged 0.95 mg/dscm (4.2×10^{-4} gr/dscf), or 41.6×10^{-3} kg/hr (91.7×10^{-3} lb/hr). Emissions measured at the outlet of the mesh-pad mist eliminator system when a fume suppressant was not used averaged 0.011 mg/dscm (0.5×10^{-5} gr/dscf), or 0.52×10^{-3} kg/hr (1.1×10^{-3} lb/hr). The removal efficiency of the mesh-pad mist eliminator control system in the absence of a fume suppressant averaged 98.7 percent. The average total current applied to the electroplating tank during outlet testing averaged 13,600 Ah. Therefore, the process emission rate, based on total chromium measurements, was 0.079 mg/Ah (1×10^{-3} gr/Ah).

When a fume suppressant was used, emissions measured at the inlet to the mesh-pad mist eliminator system ranged from 0.17 mg/dscm to 0.60 mg/dscm (8×10^{-5} to 26×10^{-5} gr/dscf), or 7.35×10^{-3} to 26.3×10^{-3} kg/hr (16.2×10^{-3} to 60.0×10^{-3} lb/hr). Emissions measured at the inlet when the foam blanket was used averaged 0.38 mg/dscm (16×10^{-5} gr/dscf), or 16.7×10^{-3} kg/hr (36.9×10^{-3} lb/hr).

The average of emissions measured at the outlet of the control device when the fume suppressant was used was

TABLE 5. PERFORMANCE DATA FOR THE MESH-PAD MIST ELIMINATOR AT MONROE AUTO EQUIPMENT, HARTWELL, GEORGIA

	Inlet				Outlet				
		Total chromium emissions				Total chromium emissions			
Run No.	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	Process current, Ah	mg/dscm	kg/hr (10^{-3})	mg/Ah	% Efficiency[a]
Without Fume Suppressant									
1	13,600	0.97	41.7	6.14	13,600	0.009	0.39	0.063	99.1
3	13,600	1.06	47.1	6.94	13,600	0.012	0.56	0.083	98.8
4	13,600	0.82	35.9	5.28	13,600	0.013	0.61	0.090	98.3
AVG	**13,600**	**0.95**	**41.6**	**6.12**	**13,600**	**0.011**	**0.52**	**0.079**	**98.7**
With Fume Suppressant									
2	13,600	0.17	7.35	1.08	13,600	0.005	0.23	0.035	96.9
5	20,200	0.60	26.3	2.60	20,200	0.007	0.31	0.033	98.8
6	20,400	0.36	16.6	1.63	20,400	0.012	0.54	0.056	96.7
AVG	**18,100**	**0.38**	**16.7**	**1.77**	**18,100**	**0.008**	**0.36**	**0.041**	**97.5**

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

0.008 mg/dscm (0.3 x 10^{-5} gr/dscf), or 0.36 x 10^{-3} kg/hr (0.79 x 10^{-3} lb/hr). The removal efficiency of the mesh-pad mist eliminator system when a fume suppressant was used averaged 97.5 percent. The average total current applied to the tank during outlet testing was 18,100 Ah. Therefore, the process emission rate, based on total chromium measurements, was 0.041 mg/Ah (1 x 10^{-3} gr/Ah).

The data presented in Table 5 indicate a lower emission rate at the inlet when the combination foam blanket and wetting agent was present in the plating tank. These decreased inlet concentrations may have resulted in slightly lower mesh-pad mist eliminator chromium removal efficiencies for the runs associated with the use of the fume suppressant. However, the performance of the overall system remained the same, as indicated by the outlet concentration levels for all six runs. This suggests that use of the fume suppressant represents a redundant level of control.

4.1.3 Packed-Bed Scrubber/Mesh-Pad Mist Eliminator System--Remco Hydraulics, Inc., Willits, California[10]

In February 1989, Remco Hydraulics, Inc. installed a control system consisting of a packed-bed scrubber with a chevron-blade section to control emissions from their chromium electroplating operations. Emission tests showed that this control system could not achieve California's proposed hexavalent chromium standard of 0.006 mg/Ah. The system was then modified by eliminating the chevron-blade section and installing a two-stage mesh-pad mist eliminator. The modified system was tested in August 1989 but again failed to meet the proposed standard. It was suspected that bypass problems due to seal degradation were probably contributing to the inadequate performance levels. Both mesh pads were replaced with new pads, which were installed in a housing with a double seal system to eliminate the bypass problems. A series of spray nozzles was added to the unit for continuous pad irrigation. Emissions testing was conducted

June, 1991, and the control system met the required emission level.

The U.S. EPA directed the source testing of the packed-bed scrubber/mesh-pad mist eliminator system at Remco Hydraulics, Inc., Willits, California on June 19-21, 1991. The performance of the emission control system, which incorporates the use of a composite mesh pad, was determined by testing at the inlet and outlet of the system.

Remco is a large job shop that performs hard chromium electroplating of hydraulic cylinders, shock absorbers, offshore equipment, and accumulators. The shop typically operates 5 days per week, 16 hours per day, and 52 weeks per year.

4.1.3.1 Process Description.[10] There are seven hard chromium electroplating tanks at this facility. Table 6 presents the descriptions and maximum operating parameters for each of these tanks. The plating solution in each tank consists of chromic acid at a concentration of 240 g/L (32 oz/gal), and sulfuric acid, a catalyst, at a concentration of 2.4 g/L (0.32 oz/gal). The normal operating bath temperature range is 49°C to 54°C (120°F to 130°F). All tanks are equipped with heating and cooling systems and are air agitated to maintain uniform plating bath temperature and composition. Tanks 1 and 2 are divided into two cells with one rectifier used to control the current flow in each cell. Tanks 3 through 5 are each controlled by one rectifier, and Tanks 6 and 7 are each controlled by two rectifiers.

4.1.3.2 Air Pollution Control.[10] Tanks 1 and 2 are equipped with double-sided hoods and the round tanks (Nos. 3 through 7) are equipped with circular hoods. During the tests, the ventilation system appeared to be effective in directing the mist from the plating tanks to the control device. The chromium emissions from the plating tanks are exhausted to the packed-bed scrubber/mesh-pad mist eliminator system located on a mezzanine beside the plating tanks. The capture and control system was

TABLE 6. DIMENSIONS AND OPERATING PARAMETERS FOR THE SEVEN HARD CHROMIUM PLATING TANKS AT REMCO HYDRAULICS, INC., WILLITS, CALIFORNIA

Tank No.	Dimensions, (l, w, d) or (dia, ht), m (ft)	Capacity, L (gal)	Maximum rated voltage per cell, V	Maximum rated current per cell, A
1	4.1, 1.5, 2.1 (13.3, 4.9, 7.0)	11,360 (3,000)	2 @ 15	10,000; 3,000
2	3.7, 1.7, 2.1 (12.0, 5.5, 6.9)	11,360 (3,000)	2 @ 15	12,000; 3,000
3	0.91, 9.4 (3.0, 31.0)	6,060 (1,600)	15	8,000
4	1.2, 11.6 (4.0, 38.0)	13,250 (3,500)	15	16,000
5	0.91, 6.1 (3.0, 20.0)	4,000 (1,060)	15	8,000
6	1.2, 15.2 (4.0, 50.0)	17,790 (4,700)	2 @ 15	2 @ 12,000
7[a]	1.2, 18.3 (4.0, 60.0)	21,580 (5,700)	2 @ 15	2 @ 12,000

[a]Plating tank was not operated during the emission test.

manufactured by Duall Industries, Inc.* The mesh pads were manufactured by Kimre, Inc.*

Packing depth in more conventional scrubbers is about 0.30 m (1.0 ft). The scrubber at this facility has a packed-bed 1.8 m (6.0 ft) deep, followed by the mesh-pad mist eliminator section located directly behind the scrubber. Because of the extended depth of the packed-bed, the scrubber is also equipped with an overhead spray system in which spray nozzles are used to ensure sufficient wetting of the bed packing media. The unusually deep packed bed was installed to meet the State of California's proposed regulation governing hexavalent chromium emissions.

Figure 2 presents a detailed schematic of the control system. The plating tanks are ventilated by a 50-hp fan located downstream of the scrubber. The design airflow rate of the scrubber is 850 m^3/min (30,000 ft^3/min). The scrubbing water flow rate is approximately 1,140 L/min (300 gal/min). The design pressure drop across the entire control system (packed-bed scrubber and mesh-pad mist eliminator) is 1.5 kPa (6.0 in. w.c.).

Within the scrubber system, the velocity of the gas stream is reduced to less than 150 m/min (500 ft/min), and the gas stream is humidified by a stream of water, which is sprayed countercurrent to the gas flow through 22 spray nozzles. The saturated gas stream then passes through a packed bed consisting of spherical polypropylene packing. The bed is approximately 2.4 m (8.0 ft) high, 3.0 m (10 ft) wide, and 1.8 m (6.0 ft) deep. The design pressure drop across the bed packing media is 0.30 kPa (1.2 in. w.c.). Entrained mist and water droplets impinge on the packing and drain to the recirculation tank. A series of 5 water lines with 10 spray nozzles per line are located over the packed

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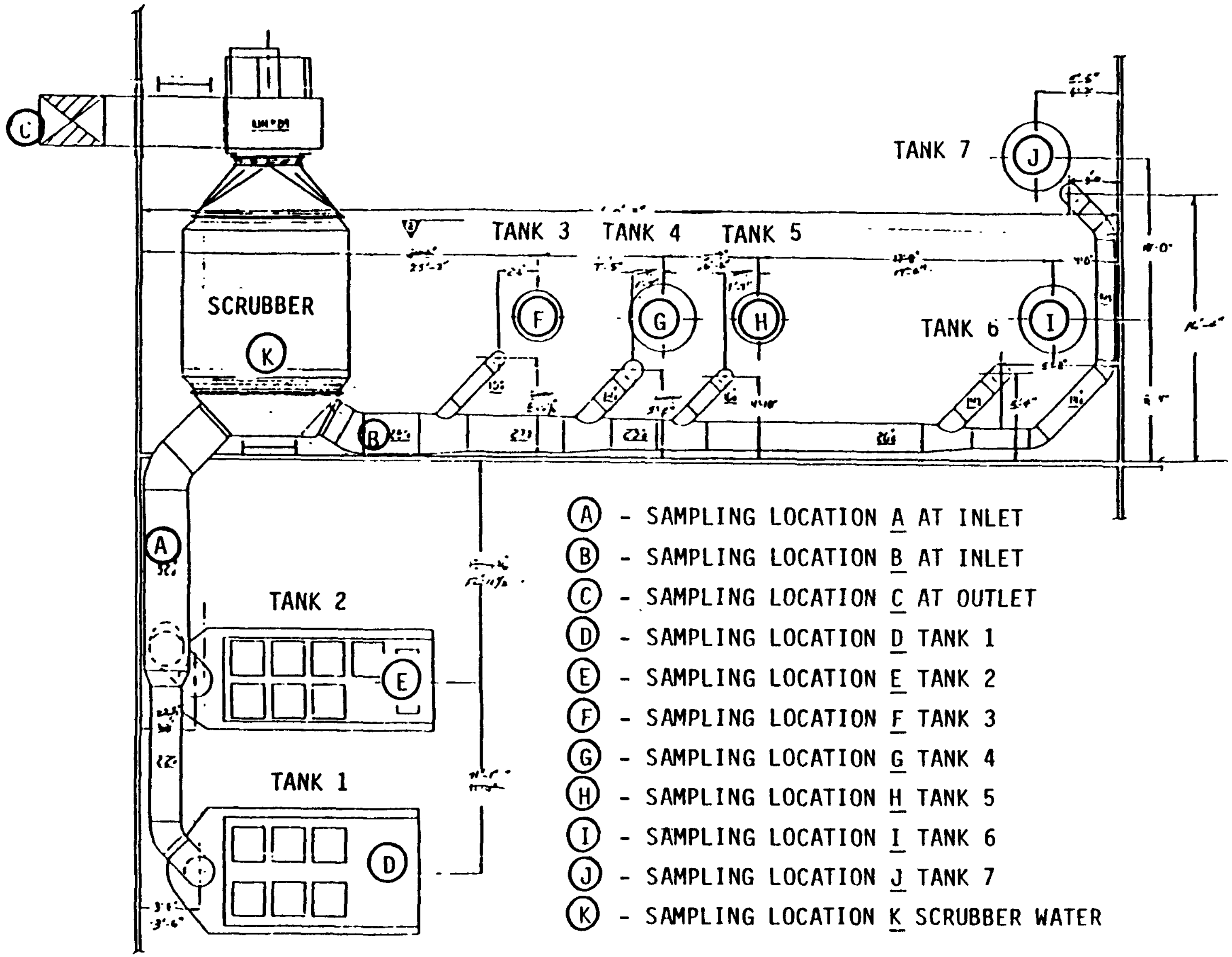

Figure 2. Schematic of control system at Remco Hydraulics, Inc., Willits, California.

bed. The spray system is used for complete wetting of the packing to prevent chromium buildup and to aid in chromium removal.

Behind the packed bed, a mist elimination section removes entrained water droplets. The first stage of this section allows large droplets to settle by gravity to the bottom of the scrubber. The next stage consists of a composite mesh pad followed by a backup mesh pad. In the composite mesh pad, the fibers in the center of the pad are 0.01 to 0.02 cm (4 to 8 mils) in diameter. The diameters of the fibers in the layers on either side of the center range from 0.04 to 0.09 cm (16 to 37 mils). Small particles that escaped the packed bed coalesce into large droplets as they pass through the inner layers of the pad. The enlarged particles are then removed in the back section of the composite pad or in the backup mesh pad. The backup mesh pad has multiple layers of material with fibers 0.9 cm (37 mils) in diameter. Each of the mesh pads is split into two sections, each approximately 2.4 m (8 ft) high and 0.09 m (3.7 ft) wide. The composite mesh pad is 16.5 cm (6.5 in.) thick, and the backup pad is 6.1 cm (2.4 in.) thick. The design pressure drop across the mesh pads is 1.2 kPa (4.75 in. w.c.). The design of the mesh-pad section specified continuous irrigation of the composite mesh pad. The backup pad is designed to be washed down on an as-needed basis.

4.1.3.3 Process Conditions During Testing.[10] Three mass emission test runs were conducted simultaneously at the inlet and outlet of the packed-bed scrubber/mesh-pad mist eliminator system to characterize the overall performance of the control system. Six of the seven chromium electroplating tanks ducted to the control system were in operation, and the process was operating normally during the tests. Table 7 presents the average operating parameters monitored during each emissions test run.

Prior to testing, the exhaust rate through the scrubber was determined to be less than half of the design air flow rate. Modifications made to increase the exhaust rate included

TABLE 7. AVERAGE OPERATING PARAMETERS MONITORED DURING EACH EMISSIONS TEST RUN AT REMCO HYDRAULICS, INC., WILLITS, CALIFORNIA

Run No.	Tank No.	Surface area plated, m^2 (ft^2)	Operating voltage, V	Operating current, A	Temperature of plating solution, °C (°F)
1	1-A	1.4 (15)	8.0	8,600	52 (126)
	1-B	0.95 (10)	8.3	2,700	52 (126)
	2-A	1.9 (20)	9.0	8,800	53 (127)
	2-B	1.1 (12)	8.0	2,700	53 (127)
	3	3.3 (36)	7.7	6,300	51 (124)
	4	3.3 (36)	12.1	10,900	59 (139)
	5	3.3 (36)	7.1	7,300	56 (133)
	6	4.8 (51)	11.9	7,400	57 (134)
			11.8	5,700	57 (134)
2	1-A	1.4 (15)	8.0	8,500	52 (126)
	1-B	0.95 (10)	8.4	2,700	53 (127)
	2-A	1.9 (20)	9.6	9,400	52 (126)
	2-B	1.1 (12)	8.0	2,700	52 (126)
	3	3.3 (36)	7.4	5,800	52 (125)
	4	3.3 (36)	11.4	10,600	59 (138)
	5	3.3 (36)	7.0	7,400	55 (131)
	6	4.8 (51)	11.5	7,100	58 (137)
			11.5	5,800	58 (137)
3	1-A	1.4 (15)	8.0	8,300	49 (121)
	1-B	0.95 (10)	8.4	2,700	49 (121)
	2-A	1.9 (20)	9.6	9,600	51 (123)
	2-B	1.1 (12)	8.0	2,700	51 (123)
	3	3.3 (36)	7.7	6,000	49 (121)
	4	3.3 (36)	11.2	10,400	57 (135)
	5	3.3 (36)	7.2	7,300	53 (127)
	6	4.8 (51)	11.4	6,700	52 (125)
			11.2	5,400	52 (125)

increasing the fan speed and shutting down the recirculation sprays to the composite mesh pad. These procedures increased the exhaust rate to approximately 84 percent of the design rate, allowing the scrubber to operate within its intended gas velocity range. The adjustments also resulted in the capture efficiency of the ventilation system being sufficient to service all six of the operating plating tanks. The shutting down of the recirculation sprays to the composite mesh pad lowered the pressure drop across the pad to about 50 percent of the design value. Nevertheless, the scrubber/mist eliminator system was operating at or near optimal conditions during the course of the testing. Because the unit was designed to have continuous washdown, the vendor was contacted to determine the potential effects on the performance of the unit if only periodic washdown were used. The vendor advised that periodic washdown would be sufficient but recommended that the pressure drop across the unit be closely monitored to minimize the plugging potential. The pressure drop was monitored throughout the testing period and no increase in pressure drop was observed.

During emissions testing, dummy rods were plated in each of the tanks. The total surface area of the parts plated during each emission test run is given in Table 7.

Pressure drops across the packing media and mesh pads were monitored during each test run. The average pressure drops across the packing media and mesh pads were 0.30 kPa (1.2 in. w.c.) and 0.60 kPa (2.3 in. w.c.), respectively.

4.1.3.4. Results of Emissions Testing.[10] Measurements to determine emissions concentrations at the inlet to the scrubber system were made at two locations. Measurements taken at Inlet A represent emissions vented from Tanks 1 and 2, while Inlet B readings measured emissions vented from the remaining 4 tanks.

Performance data for the control system are summarized in Tables 8a and 8b. Total chromium emissions measured at inlet A of the control device averaged 131 mg/dscm (0.057 gr/dscf), or

TABLE 8a. PERFORMANCE DATA FOR THE PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEM AT REMCO HYDRAULICS, INC., WILLITS, CALIFORNIA (TOTAL CHROMIUM TEST RESULTS)

		Inlet A				Inlet B				Outlet			
		Total chromium				Total chromium				Total chromium			
Run No.	Process current, Ah	mg/dscm	kg/hr	mg/Ah	Process current, Ah	mg/dscm	kg/hr	mg/Ah	Process current, Ah	mg/dscm	kg/hr	mg/Ah	% Efficiency[a]
1	136,800	150	3.16	139	229,700	1.09	0.018	0.47	381,400	0.006	2.55×10^{-4}	0.004	99.992
2	140,500	109	2.30	98.3	221,300	1.83	0.030	0.82	376,200	0.003	1.38×10^{-4}	0.002	99.994
3	139,100	134	2.95	127	213,700	15.6[b]	0.268[b]	7.53[b]	366,700	0.009	3.52×10^{-4}	0.006	
AVG	138,800	131	2.80	121	225,500	1.46	0.024	0.65	374,800	0.006	2.48×10^{-4}	0.004	99.993

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

[b]During Run 3 at Inlet B, it was suspected that the probe may have contacted the duct wall. Therefore, the values obtained for Run 3 at Inlet B were not used to calculate averages or efficiency.

TABLE 8b. PERFORMANCE DATA FOR THE PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEM AT REMCO HYDRAULICS, INC., WILLITS, CALIFORNIA (HEXAVALENT CHROMIUM TEST RESULTS)

		Inlet A				Inlet B				Outlet			
		Hexavalent chromium				Hexavalent chromium				Hexavalent chromium			
Run No.	Process current, Ah	mg/dscm	kg/hr	mg/Ah	Process current, Ah	mg/dscm	kg/hr	mg/Ah	Process current, Ah	mg/dscm	kg/hr	mg/Ah	% Efficiency[a]
1	136,800	156	3.28	144	229,700	1.20	0.020	0.52	381,400	0.006	2.35×10^{-4}	0.004	99.993
2	140,500	118	2.50	107	221,300	1.85	0.031	0.83	376,200	0.003	1.38×10^{-4}	0.002	99.995
3	139,100	145	3.19	138	213,700	16.9[b]	0.292[b]	8.20[b]	366,700	0.009	3.59×10^{-4}	0.006	
AVG	138,800	140	2.99	130	225,500	1.52	0.025	0.68	374,800	0.006	2.44×10^{-4}	0.004	99.994

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

[b]During Run 3 at Inlet B, it was suspected that the probe may have contacted the duct wall. Therefore, the values obtained for Run 3 at Inlet B were not used to calculate averages or efficiency.

2.80 kg/hr (6.18 lb/hr). Hexavalent chromium emissions at inlet A averaged 140 mg/dscm (0.061 gr/dscf), or 2.99 kg/hr (6.59 lb/hr). At the inlet B location, total chromium emissions averaged 1.46 mg/dscm (6.38×10^{-4} gr/dscf), or 0.024 kg/hr (0.053 lb/hr). Hexavalent chromium emissions at inlet B averaged 1.52 mg/dscm (6.66×10^{-4} gr/dscf), or 0.025 kg/hr (0.056 lb/hr). The relatively high inlet loadings observed during this test are more than likely attributable to the large tank capacities and the large number of parts being plated during the test.

Emissions measured at the outlet of the packed-bed scrubber/mesh-pad mist eliminator system averaged 0.006 mg/dscm (3.0×10^{-6} gr/dscf) for both total and hexavalent chromium, or 2.5×10^{-4} kg/hr (5.5×10^{-4} lb/hr) for total chromium and 2.4×10^{-4} kg/hr (5.4×10^{-4} lb/hr) for hexavalent chromium. The removal efficiency of the control system averaged 99.99 percent. The average total current applied to the six electroplating tanks during outlet testing was 374,700 Ah. Therefore, the process emission rate, based on total and hexavalent chromium measurements, was 0.004 mg/Ah (6.2×10^{-5} gr/Ah).

4.1.3.5 Discussion of Packed-Bed Scrubber/Mesh-Pad Mist Eliminator Performance. As discussed in Section 4.1.3.3, recirculation sprays to the composite mesh pad were shut down during testing to help increase the exhaust rate. During emissions testing and for a period of time following the tests, only periodic washdown of the composite mesh pad was used. A few months after the unit was tested, an increase in pressure drop was observed, indicating that the composite mesh pad was plugged. The pad had to be taken apart and cleaned, layer by layer. Once the unit was put back on line, continuous irrigation of the composite mesh pad was initiated, and no increases in pressure drop have been observed in the months since. Apparently, the high-pressure periodic spray was not able to penetrate to the finer layers in the center of the pad. Continuous irrigation with the low-pressure wash appears to prevent the buildup of chromium within these finer layers, thus eliminating the plugging problem.

As shown on Tables 8a and 8b, total and hexavalent chromium emissions were lower at Inlet B, which services four tanks, than they were at Inlet A, which services two tanks. This can be explained by the fact that the four tanks vented by Inlet B are all circular tanks with depths ranging from 6 to 18 m (20 to 60 ft). Inlet A vents two rectangular, horizontal tanks, each approximately 2 m (7 ft) deep. More chromium will be emitted when a part is electroplated in a shallow horizontal tank than when that part is electroplated in a deep vertical tank. In a shallow tank, the hydrogen gas is evolved closer to the surface of the plating solution and the agitation effect is much greater than with the hydrogen gas generated in a deeper tank.

4.1.4 Discussion of Composite Mesh Pad Performance.

Table 9 presents the performance data for the composite mesh pad systems tested at Precision Engineering, Monroe Auto Equipment, and Remco Hydraulics, Inc. A graphical illustration of the outlet concentrations for each plant is shown in Figure 3. The data from Monroe differentiate the tests done with a foam blanket present in the plating bath from the tests done without a foam blanket in the bath. The mesh-pad units at Monroe and Precision are identical in design with the exception of an improvement in the seal system around the pads in the unit at Monroe. These mesh-pad units consist of a series of three mesh pads with the composite pad as the second pad in the control system. The air pollution control unit tested at Remco consisted of a packed-bed scrubber followed by two mesh pads, with the composite mesh pad positioned first.

The extremely high inlet concentrations measured at Remco resulted in a very high percent reduction for the unit compared to the percent reductions observed at Monroe and Precision. The inlet loading at Precision was lower than the other units tested because a moisture extractor was located prior to the inlet test location. Test data from another hard chromium plating facility

TABLE 9. PERFORMANCE DATA FOR COMPOSITE MESH-PAD MIST ELIMINATORS

Plant	Chromium concentration, mg/dscm, Inlet	Chromium concentration, mg/dscm, Outlet	Outlet process emission rate, mg/Ah	Current loading, Ah	Percent reduction, %
Precision	0.278	0.011	0.014	83,500	95.9
Monroe, no foam blanket	0.951	0.011	0.079	13,600	98.7
Monroe, with foam blanket	0.377	0.008	0.041	18,100	97.5
Remco	73.2	0.006	0.004	374,800	99.99

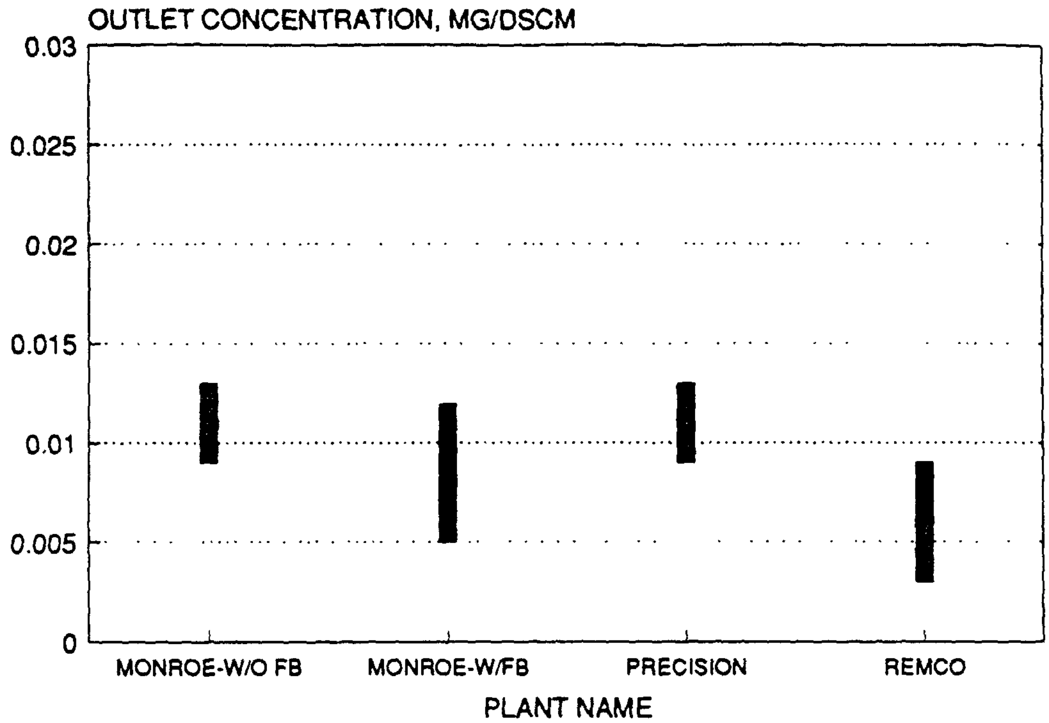

Figure 3. Outlet chromium concentration data for composite mesh-pad mist eliminator systems.

indicate that moisture extractors are capable of removing approximately 85 percent of the chromium mist entering the device.[11] The test data presented in Table 9 suggest that the higher the inlet concentration, the greater the percent reduction attainable and the lower the process emission rate. On the other hand, regardless of the variations in the inlet loadings, the outlet concentration levels are relatively constant. Figure 4 illustrates the lack of correlation between inlet loadings and outlet concentration levels. This suggests that outlet concentration levels are a better measure of the performance of the units than process emission rates or percent reductions.

The relationship between inlet loading and percent reduction is shown in Figures 5 and 6. A regression analyses was performed on the data from Monroe and Precision to determine if a linear relationship existed between inlet loadings and control efficiencies. The correlation coefficients for both inlet concentration and inlet mass rate were very good: r=0.82 and r=0.85, respectively. The data from Remco were not included because of the excessively high inlet loadings. The data in Figures 4 and 5 suggest that at an inlet concentration of about 1.2 mg/dscm, or a mass emission rate of 0.05 kg/hr, the dependency on inlet loadings no longer exists and the percent reduction is at a relatively constant level regardless of the inlet loading. This phenomena is expected since 100 percent control or greater can never be achieved regardless of the inlet loading. The high correlation coefficients further support the assumption that inlet loadings have an effect on the performance efficiencies of the control systems. As shown in Figure 4, outlet concentration levels are independent of inlet loadings, and so can be used as reliable indicators of control device performance.

Process emission rates, mg/Ah, also are not valid measures of control device performance. Inlet loadings to the control system are strongly dependent upon the amount of current applied to the plating tank(s). As discussed above, the outlet

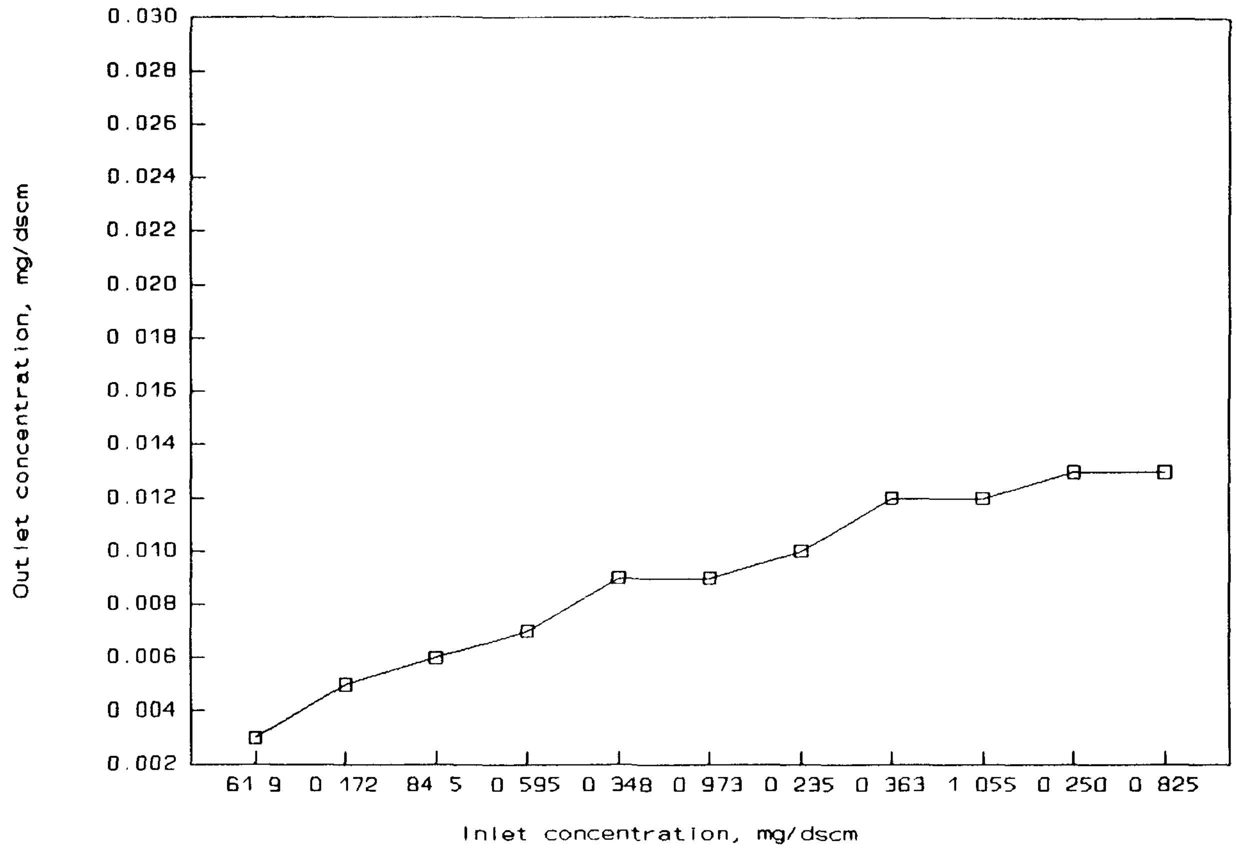

Figure 4. Composite mesh-pad mist eliminator data - inlet vs outlet concentration.

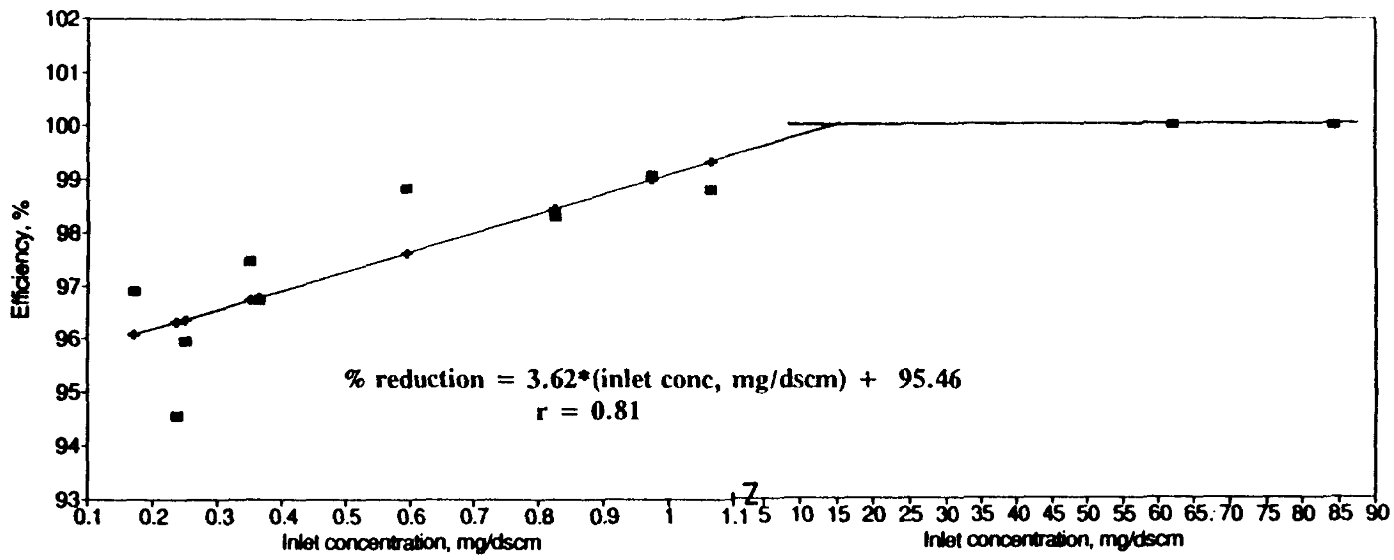

Figure 5. Composite mesh-pad mist eliminator data - efficiency versus inlet concentration.

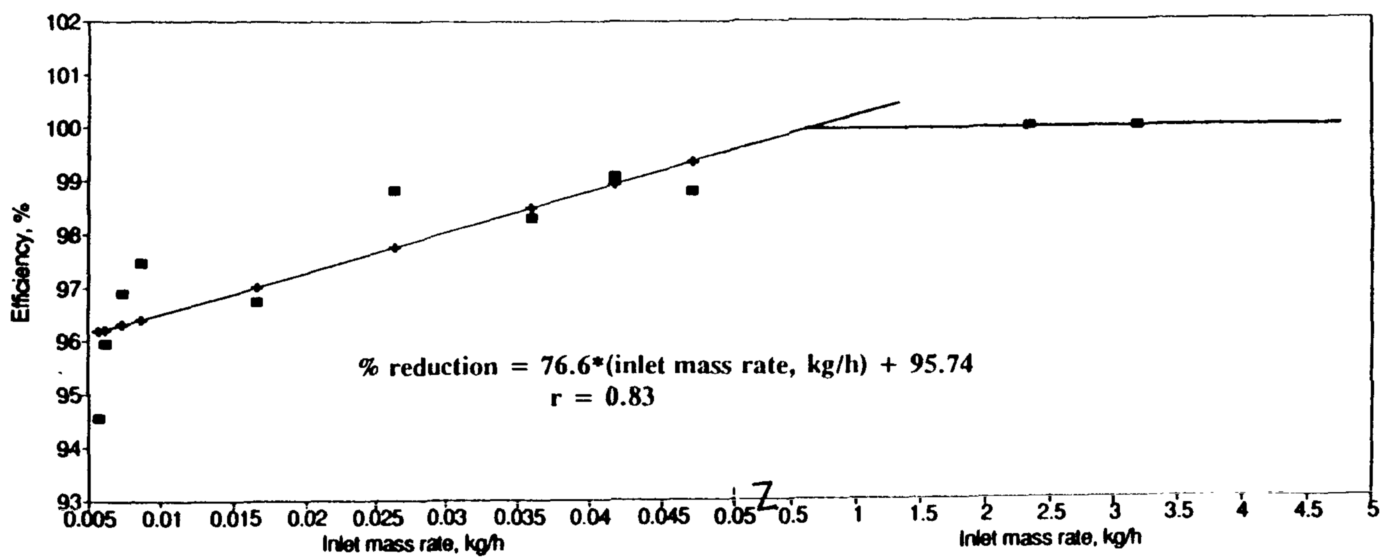

Figure 6. Composite mesh-pad mist eliminator data - efficiency versus inlet mass rate.

concentration levels are independent of the inlet loading. Therefore, it follows that the outlet concentrations are not dependent upon the current applied to the plating tank(s). Constant outlet concentrations result in high process emission rates for operations with low current loadings and low process emission rates for operations with high current loadings. For example, as shown in Table 9, Remco had the highest current loading of the units tested (374,800 Ah). This high current loading produced the lowest process emission rate (0.004 mg/Ah). Monroe (with no foam blanket) had the lowest current loading (13,600 Ah) and the highest process emission rate (0.079 mg/Ah). However, the outlet concentration levels for both the Remco and Monroe units were relatively constant (0.006 and 0.011 mg/dscm, respectively). Thus, process emission rates are not reliable indicators of control device performance.

The data presented in Figure 3 and Table 9 might suggest that the unit at Remco represents a higher level of control than the units at Monroe and Precision. The finest material layers in the composite mesh pad at Remco were woven with a smaller diameter fiber than the material used in the composite pads in the Precision and Monroe units. The difference in the fiber diameters could have contributed to the difference in the performance levels. However, as noted in Section 4.1.3.5, the unit at Remco developed a plugging problem after a few months of use. Even though the problem has been corrected, and the unit has been operating without any increase in pressure drop, some concern still exists regarding the long term maintenance requirements for this unit. In addition, the outlet emission levels are very low for all the units, and some data overlap exists between the outlet concentration levels measured at Remco and those measured at Monroe when a foam blanket was present in the plating bath. Therefore, the data from all three composite mesh-pad systems tested were determined to represent one control level.

Based on the outlet chromium concentration ranges for each composite mesh-pad system tested, as shown in Figure 3, it appears that composite mesh-pad systems can achieve outlet chromium concentrations of less than 0.015 mg/dscm (6.6×10^{-6} gr/dscf). The outlet concentrations for these systems ranged from 0.003 to 0.013 mg/dscm (1.3×10^{-6} to 5.7×10^{-6} gr/dscf) with an overall average of 0.009 mg/dscm (3.9×10^{-6} gr/dscf).

4.2 Fiber-Bed Mist Eliminator Tests--Naval Aviation Depot, Alameda, California[12]

The Naval Energy and Environmental Support Activity (NEESA) conducted chromium emission tests on three fiber-bed mist eliminator systems used to control chromium emissions from plating and chromic acid anodizing operations at Building 32, Naval Aviation Depot, Alameda, California. The tests were performed on April 15 - 18, 1991. The medium-size plating shop performs hard chromium electroplating of marine hardware and chromic acid anodizing of naval aircraft parts.

4.2.1 Process Description.[13]

There are seven hard chromium plating tanks and two chromic acid anodizing tanks at this facility. Table 10 presents the dimensions and capacities for each process tank. The hard chromium plating solution in each plating tank consists of chromic acid at a concentration of 240 g/L (32 oz/gal) and sulfuric acid, a catalyst, at a concentration of 2.4 g/L (0.32 oz/gal). The normal operating temperature of the plating baths is 60°C (140°F). Tanks 1, 4, 5, 6, and 7 are each equipped with a 2,500-A rectifier. Tanks 2 and 3 are each equipped with a 5,000-A rectifier.

The chromic acid anodizing solution in each anodizing tank consists of chromic acid at a concentration of 67 g/L (9 oz/gal). The normal operating temperature of these baths is 60°C (140°F). The anodizing tanks (8 and 9) are equipped with a 2,000-A and a 1,500-A rectifier, respectively.

TABLE 10. CHROMIUM ELECTROPLATING AND CHROMIC ACID ANODIZING TANK SPECIFICATIONS AT THE NAVAL AVIATION DEPOT, ALAMEDA, CALIFORNIA

Type/ Tank No.	Dimensions, (l,w,d), m (ft)	Capacity, L (gal)[a]
Hard chromium plating		
1	2.4, 1.2, 1.8 (8.0, 4.0, 6.0)	5,000 (1,320)
2	2.4, 1.2, 1.8 (8.0, 4.0, 6.0)	5,000 (1,320)
3	4.3, 1.2, 1.8 (14.0, 4.0, 6.0)	8,720 (2,300)
4	1.8, 0.9, 1.8 (6.0, 2.8, 6.0)	2,620 (690)
5	1.8, 0.9, 1.8 (6.0, 2.8, 6.0)	2,620 (690)
6	1.8, 0.9, 1.8 (6.0, 2.8, 6.0)	2,620 (690)
7	1.8, 0.9, 1.8 (6.0, 2.8, 6.0)	2,620 (690)
Chromic acid anodizing		
8	4.9, 1.2, 1.5 (16.0, 4.0, 5.0)	8,140 (2,150)
9	2.4, 1.2, 1.5 (8.0, 4.0, 5.0)	4,090 (1,080)

[a]Assumes a free board space of 15 cm (6 in.).

All of the plating and anodizing tanks are equipped with heating and cooling systems to maintain uniform solution temperatures. Overhead hoists are used to transport parts in and out of the plating and anodizing tanks.

4.2.2 Air Pollution Control.[12-14]

Each of the plating and anodizing tanks is equipped with double-sided draft hoods. Three identical control systems are used to control chromium emissions from the plating and anodizing tanks. Each control system consists of a vertical-flow, single packed-bed scrubber unit with chevron-blade mist eliminators preceding and following the scrubber. The packed-bed scrubber units were installed by Viron International Corporation* in 1990. Following treatment in these units, the gas streams are ducted to fiber-bed mist eliminators. Figure 7 presents a schematic of a typical fiber-bed mist eliminator.

Three of the hard chromium plating tanks (1 through 3) are commonly ducted to one control system. The remaining four plating tanks (4 through 7) are commonly ducted to a second control system, and the two anodizing tanks (8 and 9) are commonly ducted to a third control system. For purposes of discussion, the control systems will be designated as Line G (anodizing tanks), Line L (three plating tanks), and Line M (four plating tanks). The ventilation rates for Lines G, L, and M are 680 actual m^3/min (24,000 actual ft^3/min), 700 actual m^3/min (24,800 actual ft^3/min), and 400 actual m^3/min (14,300 actual ft^3/min), respectively.

The fiber-bed mist eliminators, manufactured by CECO Filters, Inc.* and installed in 1990, are located on the roof of the plating shop. Booster fans are used following each packed-bed scrubber to aid in maintaining the appropriate gas flow rate

*Mention of trade names or commercial products is not intended to constitute endorsement or recommendation for use.

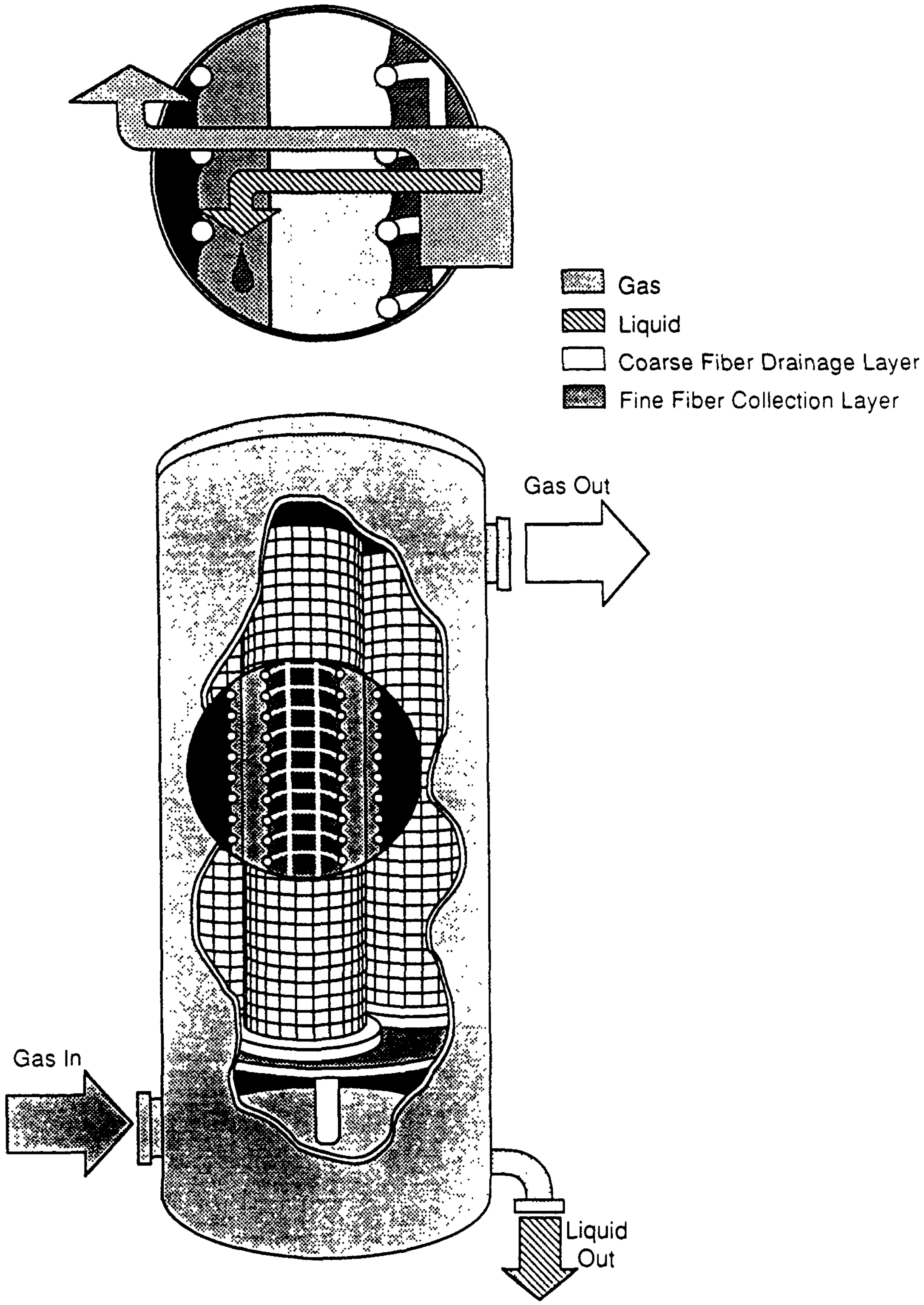

Figure 7. Schematic of a typical fiber-bed mist eliminator.

to the fiber-bed mist eliminators. The fiber-bed units are designed for horizontal, concurrent gas flow through the beds. Inertial impaction and Brownian diffusion are the principal mechanisms used to remove the small chromic acid mist droplets that escape the packed-bed scrubber. The design gas flow rate of the fiber-bed unit for line G is 680 m^3/min (24,000 ft^3/min). For lines L and M, the fiber bed design gas flow rates are 700 m^3/min (24,800 ft^3/min) and 400 m^3/min (14,300 ft^3/min), respectively. The design pressure drop across the beds in each unit is 1.7 kPa (7 in. w.c.). The fiber-bed units on lines G and L are designed for a cross-sectional velocity of 6.1 m/min (20 ft/min) and the unit on line M is designed for 7.0 m/min (23 ft/min).

The fiber-bed units have a special patented nested filter design. Each fiber-bed unit contains between four and six cylindrical metal cages, and each cage consists of two cylindrical filter elements. Within each metal cage, one filter element fits inside the other element. The outer element has an outside diameter of 81 cm (32 in.), an inside diameter of 71 cm (28 in.), and a radial thickness of 5.1 cm (2 in.). The inner element has an outside diameter of 56 cm (22 in.), an inside diameter of 46 cm (18 in.), and a radial thickness of 5.1 cm (2 in.). Due to the difference between the inside diameter of the outer element and the outside diameter of the inner element, there is a 7.6 cm (3 in.) space between the two filters. Both of the filter elements in each cage are 3.7 m (12 ft) high. The individual fibers that comprise the filter elements are glass.

There are six cylindrical cages or 12 filter elements in the units controlling lines G and L, and four cages or 8 filter elements in the unit on line M.

Each fiber-bed mist eliminator is equipped with spray nozzles at the bottom of the unit to allow for periodic cleaning of the filter media, which helps to prevent plugging of the unit. The nozzles are operated for approximately 5 minutes every 4 hours. Water is sprayed at a rate of about 9.5 L/hr

(2.5 gal/hr) for the larger units on lines G and L, and at a rate of about 4.7 L/hr (1.3 gal/hr) for the smaller unit on line M.

4.2.3 Process Conditions During Testing.[12]

4.2.3.1 Exhaust Line G. Four four-hour chromium emissions test runs were performed at the outlet of the control unit on exhaust line G, which ventilates two chromic acid anodizing tanks. During the testing period, one of the tanks contained four aluminum sheets, each with a surface area of 3.4 m^2 (36.5 ft^2). The other tank contained one aluminum sheet with a surface area of 3.4 m^2 (36.5 ft^2) and a row of (unspecified) parts. Average total current applied to the two anodizing tanks during testing ranged from 4,000 to 5,100 Ah.

4.2.3.2 Exhaust Line L. Two three-hour and one four-hour emission test runs were conducted at the outlet of the control unit on line L, which ventilates three hard chromium plating tanks. During the tests, each of the tanks contained four parts to be electroplated, and each part had a surface area of 0.7 m^2 (7.6 ft^2). Average total current applied to the three tanks during testing ranged from 29,400 to 42,600 Ah.

4.2.3.3 Exhaust Line M. Line M pulls air from four hard chromium plating tanks. One eight-hour emission test run was performed at the outlet of the fiber-bed mist eliminator controlling the line. In addition, two four-hour emission test runs were performed simultaneously at the inlet and outlet of the fiber-bed mist eliminator. During the tests, each tank contained four small parts, each with a surface area of 0.1 m^2 (1.5 ft^2). Current applied to the four tanks during inlet testing ranged from 37,400 to 37,600 Ah. The current ranged from 37,400 to 37,600 Ah for the outlet test runs that were conducted in conjunction with the inlet runs. The current applied to the tank during the eight-hour run at the outlet was 75,100 Ah.

4.2.4 Results of Emissions Testing.[12]

Table 11 presents the performance data for each of the fiber-bed mist eliminator scrubber systems tested at the Naval Aviation Depot. Emissions measured at the outlet of the fiber-

TABLE 11. PERFORMANCE DATA FOR THREE SCRUBBER/FIBER-BED MIST ELIMINATOR SYSTEMS AT THE NAVAL AVIATION DEPOT, ALAMEDA, CALIFORNIA.[a]

	Inlet total chromium emissions[b]				Outlet total chromium emissions				
Run No.	Process current, Ah	mg/dscm (10^{-3})	kg/hr (10^{-3})	mg/Ah (10^{-3})	Process current, Ah	mg/dscm (10^{-3})	kg/hr (10^{-3})	mg/Ah (10^{-3})	% Efficiency[c]
					Exhaust Line G				
1					3,990	0.083	<0.004	<4.1	
2					3,990	0.086	<0.004	<4.4	
3					5,100	0.104	<0.005	<3.9	
4					5,100	0.109	<0.005	<4.2	
AVG					4,540	0.095	<0.005	<4.1	
					Exhaust Line L				
1					29,400	0.127	<0.007	<0.7	
2					29,400	0.374	0.019	<1.9	
3					42,600	0.097	<0.005	<0.4	
AVG					33,800	0.199	<0.010	<1.0	
					Exhaust Line M				
1					75,100	0.358	0.011	1.2	
2	37,600	140	4.14	440	37,600	0.112	<0.004	<0.4	99.9
3	37,400	200	5.31	567	37,400	0.099	<0.003	<0.3	99.9
AVG	37,500	170	4.73	504	50,000	0.190	<0.006	<0.6	99.9

[a]Each emission control system controls a ventilation exhaust line. Line G exhausts emissions from chromic acid anodizing tanks; lines L and G each exhaust emissions from hard chromium plating tanks.

[b]No inlet testing was performed on the control units for lines G or L. For line M, two emission test runs were conducted between the packed-bed scrubber and the fiber-bed mist eliminator.

[c]Efficiencies are calculated from mass emission rates (kg/hr), and the average is based on averaging efficiencies for each run.

bed mist eliminator system controlling exhaust line G averaged 9.5×10^{-5} mg/dscm (4.2×10^{-8} gr/dscf), or $<0.5 \times 10^{-5}$ kg/hr ($<1.1 \times 10^{-5}$ lb/hr). The average total current applied to the anodizing tanks exhausted to line G was 4,540 Ah, resulting in a total chromium process emission rate of $<4.1 \times 10^{-3}$ mg/Ah ($<6.3 \times 10^{-5}$ gr/Ah). No inlet measurements were made at line G and, therefore, no removal efficiencies could be determined.

At the outlet of the control system for line L, emissions averaged 2.0×10^{-4} mg/dscm (8.7×10^{-8} gr/dscf), or $<1.0 \times 10^{-5}$ kg/hr ($<2.2 \times 10^{-5}$ lb/hr). The average total current applied to the tanks exhausted by line L was 33,800 Ah. Therefore, the total chromium process emission rate from the control system was $<1.0 \times 10^{-3}$ mg/Ah ($<1.5 \times 10^{-5}$ gr/Ah). As with line G, there was no inlet testing performed.

For line M, emissions were measured between the packed-bed scrubber and the fiber-bed mist eliminator. These measurements are representative of inlet conditions for the fiber-bed mist eliminator and averaged 0.17 mg/dscm (7.4×10^{-5} gr/dscf), or 4.73×10^{-3} kg/hr (10.4×10^{-3} lb/hr). Emissions measured at the outlet of the fiber-bed mist eliminator averaged 1.9×10^{-4} mg/dscm (8.3×10^{-8} gr/dscf), or $<0.6 \times 10^{-5}$ kg/hr ($<1.3 \times 10^{-5}$ lb/hr). The removal efficiency of the fiber-bed mist eliminator averaged 99.9 percent. The average total current applied to the tanks serviced by Line M during outlet testing was 50,000 Ah. Therefore, the outlet total chromium process emission rate was $<6.0 \times 10^{-4}$ mg/Ah ($<9.3 \times 10^{-6}$ gr/Ah).

4.2.5 <u>Discussion of Fiber-Bed Mist Eliminator Performance</u>.

There were no adverse operational factors identified during emissions testing of the fiber-bed mist eliminators at the Alameda Facility. The control devices performed well, and the emission testing demonstrated that fiber-bed mist eliminators are capable of achieving outlet chromium concentrations of 3.7×10^{-4} mg/dscm (1.6×10^{-7} gr/dscf) or less.

Figure 8 is a graphical presentation of the outlet chromium concentration levels measured from each of the three fiber-bed

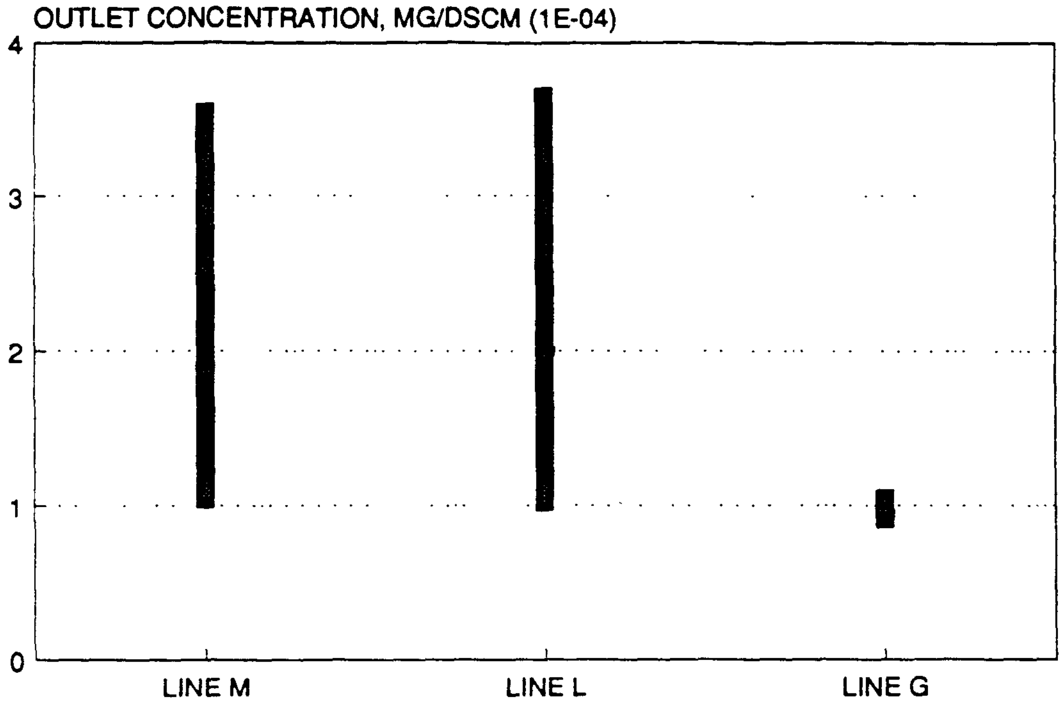

Figure 8. Fiber-bed mist eliminator outlet concentrations.

mist eliminators tested. The concentration range shown in Figure 8 for Exhaust Lines L and M are much wider than those shown for Exhaust Line G. A review of the individual test runs for Lines L and M shows that in each case, the results for one test run were much higher than those for the other two test runs. No explanations for these high values were given in the test report, nor was any process condition identified that might account for these results. It is suspected that these high values may have resulted from sampling errors (e.g., probe contact with the duct wall during sampling or cross contamination during recovery of the sample). Because of the relatively small amounts of chromium present in the outlet stack gas, even minor errors made during sampling or recovery can invalidate the entire test run. Therefore, the abnormally high results obtained in the test runs from Lines L and M were disregarded. When these high test run results are eliminated, the test data from the remaining runs for all lines show a high level of consistency in the performance of the units across a fairly wide range of inlet loadings.

Figure 9 presents the results of the outlet test runs (excluding the high test run values discussed above) for each fiber-bed mist eliminator tested. The consistency in the data for these runs was expected because the filter system in the fiber-bed mist eliminators is similar in operation to other impaction-type constant outlet control systems that were tested previously. The emission test results suggest fiber-bed mist eliminators are capable of achieving outlet concentrations of 1×10^{-4} mg/dscm (4.4×10^{-8} gr/dscf) with corresponding removal efficiencies greater than 99.9 percent.

An important factor to consider in the evaluation of fiber-bed mist eliminators is the tendency of the units to plug. At the facility tested, no operational problems with the fiber-bed mist eliminators were identified. As stated previously, the fiber-bed mist eliminators at this facility are located

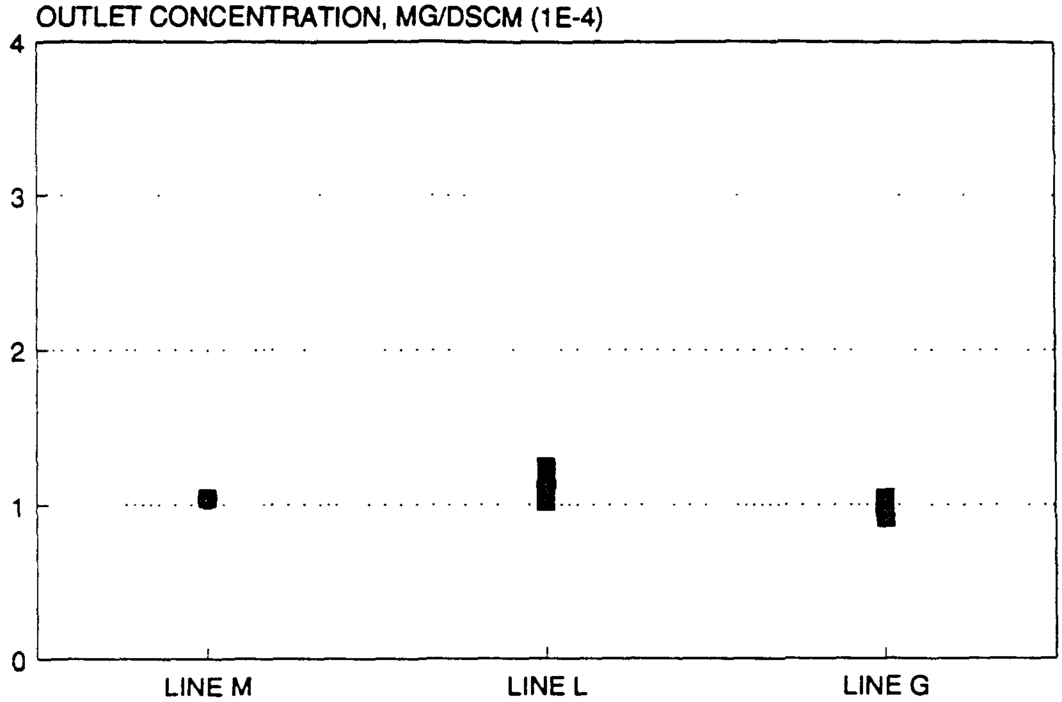

Figure 9. Fiber-bed mist eliminator outlet concentrations without high test values.

downstream of packed-bed scrubbers. These packed-bed scrubbers significantly reduce the inlet loading to the fiber beds, which decreases the tendency of the units to plug. Most vendors do not recommend fiber-bed mist eliminators as the first stage of the control system because of their tendency to plug. It is recommended that a coarse filtering device be installed upstream of the units to prevent plugging and operational problems that may arise as a result of plugging of the filter media.

4.3 Summary of Emission Test Results

The outlet chromium emission concentrations for all of the mist eliminators tested, as well as the average outlet chromium concentrations achieved by typical packed-bed scrubbers, are presented in Figure 10. The composite mesh-pad systems tested achieved average outlet concentrations of 0.009 mg/dscm (0.004×10^{-3} gr/dscf). Fiber-bed mist eliminators are capable of achieving outlet concentrations of 0.0001 mg/dscm (0.004×10^{-5} gr/dscf). The average outlet chromium concentration for traditional packed-bed scrubbers is 0.024 mg/dscm (0.010×10^{-3} gr/dscf).[5] The better performance of the mist eliminators is attributable to the higher surface area-to-volume ratios of the mesh pads and fiber beds compared to those of the scrubber packing materials. For mesh pads, the surface area-to-volume ratio ranges from 100 to 2,620 m^2/m^3 (31 to 800 ft^2/ft^3).[2] Fiber beds have a typical surface area-to-volume ratio of 35,380 m^2/m^3 (10,800 ft^2/ft^3).[3] The surface area-to-volume ratios for scrubber packing ranges from 98 to 140 m^2/m^3 (30 to 45 ft^2/ft^3).[15]

As shown in Figure 10, the performance of fiber-bed mist eliminators is significantly better than the performance of composite mesh-pad systems. The higher performance of fiber-bed mist eliminators is also attributable to the higher surface area-to-volume ratios. As shown above, the ratios for fiber beds are 14 to 350 times higher than those for mesh pads. However, fiber-bed mist eliminators have more stringent maintenance requirements

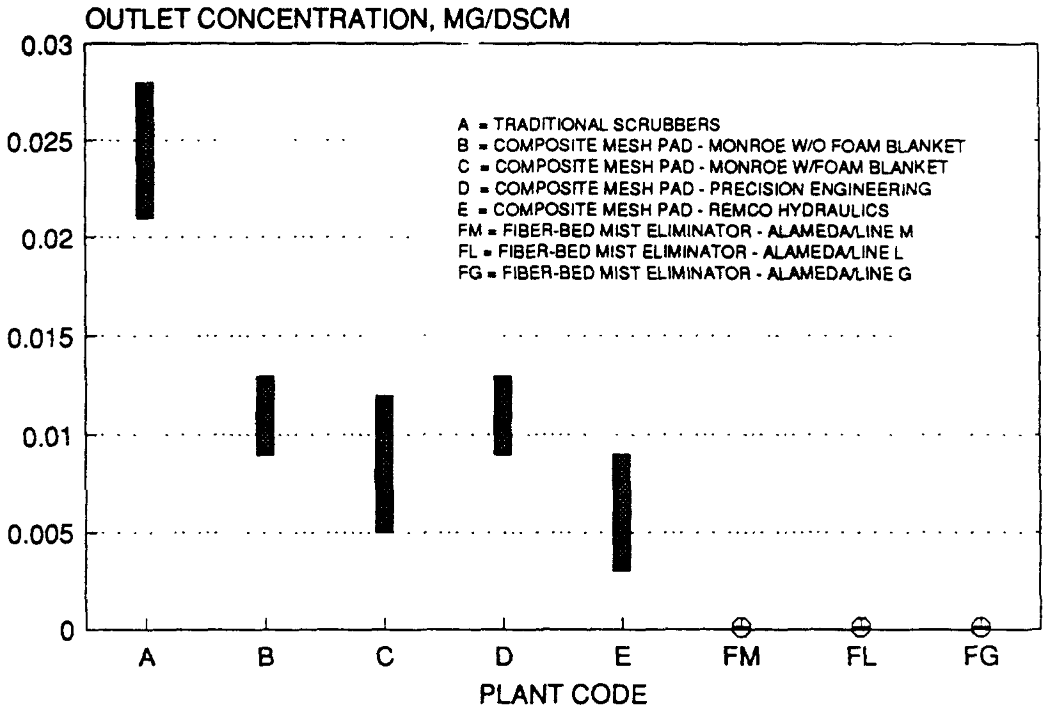

Figure 10. Performance data for mist eliminator systems.

than composite mesh-pad systems and are recommended for use only as a "polishing", or final stage control device. A coarse control system (e.g., packed-bed scrubber, chevron-blade mist eliminator) should be located upstream of the fiber-bed mist eliminator to reduce the loading and prevent the unit from plugging. Composite mesh-pad systems can be used without any other control system to control emissions of chromic acid mist, as these systems incorporate staged particle removal within the unit to prevent plugging of the pads.

5.0 ENVIRONMENTAL AND COST IMPACTS

This section presents the environmental and cost impacts associated with the use of mesh-pad mist eliminators, packed-bed scrubber/mesh-pad mist eliminator systems, and fiber-bed mist eliminators in hard chromium electroplating operations. The impacts are presented on a model plant basis. Air pollution, energy, water pollution, and solid waste impacts associated with the use of these technologies for reducing hexavalent chromium emissions from electroplating operations are discussed in this section. Capital and annualized cost impacts attributable to the operation of these technologies, and a summary of economic impacts are also presented. Impacts relating to the use of mesh-pad mist eliminators, packed-bed scrubber/mesh-pad mist eliminator systems, and fiber-bed mist eliminators are based on the hard chromium plating model plant parameters in Table 12.

5.1 Air Pollution Impacts

The level of emissions control assigned to each of the new control technologies for hard chromium plating operations is based on the percent reduction achievable by well-maintained units at average inlet loadings. The achievable reductions have been determined by the emissions tests described in Section 4. While these tests show that higher emissions reductions are attainable, a performance level of 99.8 percent has been assigned to each of the new control technologies for hard chromium plating to account for the variability in inlet loadings. (Units with

TABLE 12. PARAMETERS FOR THE HARD CHROMIUM ELECTROPLATING MODEL PLANTS

	Plant Size		
Model operation	Small	Medium	Large
Operating time, hr/yr	2,000	3,500	6,000
Percent time electrodes energized, percent	70	70	80
Total ampere-hours per year, Ah/yr	5.0×10^6	42×10^6	160×10^6
Number 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)
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)
Uncontrolled hexavalent chromium emission rate, kg/yr (lb/yr)	50 (110)	420 (926)	1,600 (3,530)
Number of operations nationwide	1,080	310	150

high inlet loadings will achieve greater emissions reductions than units with low inlet loadings).

Table 13 shows the hexavalent chromium emissions associated with uncontrolled hard chromium electroplating model plants and emissions from the same model plants controlled with traditional packed-bed scrubbers or one of the new emission control technologies described in this document for hard chromium plating operations. As shown in Table 13, when mesh-pad mist eliminators with mesh pads in series, packed-bed scrubber/mesh-pad mist eliminator systems, or fiber-bed mist eliminators are used, emissions from the model plants are reduced by 80 percent over the reduction achieved with the use of typical packed-bed scrubbers with control levels of 99 percent.

5.2 Energy Impacts

The energy impacts associated with the operation of mist eliminators and scrubbers result from an increase in the fan horsepower necessary to overcome the pressure drop across the control devices and to operate the recirculation pumps on the packed-bed scrubbers and some mesh-pad mist eliminators. The basic capture system is considered to be part of the baseline operation. These capture systems are used to comply with health and safety regulations. The fan horsepower requirements for the basic capture system for hard chromium electroplating model plants are presented in Table 14. This table also presents the increases in electrical use (over the basic capture system alone) attributable to the use of packed-bed scrubbers, mist eliminators with mesh pads in series, packed-bed scrubber/mesh-pad mist eliminator systems, and fiber-bed mist eliminators.

The energy requirements to operate one of the new control technologies are equal to the electrical use for the basic capture system plus the increase in electrical use over the basic capture system for the control device. A mist eliminator with mesh pads in series has total energy requirements ranging from

TABLE 13. HEXAVALENT CHROMIUM EMISSION ESTIMATES ASSOCIATED WITH THE USE OF PACKED-BED SCRUBBERS AND NEW EMISSION CONTROL TECHNOLOGIES AT HARD CHROMIUM ELECTROPLATING MODEL PLANTS

	Emission estimates, kg/yr (lb/yr)		
	Small	Medium	Large
Uncontrolled	50 (110)	420 (926)	1,600 (3,530)
Single packed-bed scrubber[a]	0.5 (1.1)	4.2 (9.3)	16 (35.3)
Mist eliminator with mesh pads in series[b]	0.10 (0.22)	0.84 (1.85)	3.20 (7.06)
Packed-bed scrubber/mesh-pad mist eliminator system[b]	0.10 (0.22)	0.84 (1.85)	3.20 (7.06)
Fiber-bed mist eliminator[b]	0.10 (0.22)	0.84 (1.85)	3.20 (7.06)

[a]Single packed-bed scrubber that reduces uncontrolled emissions by 99 percent.
[b]New control technology that reduces uncontrolled emissions by 99.8 percent.

TABLE 14. ANNUAL ENERGY REQUIREMENTS ATTRIBUTABLE TO THE USE OF PACKED-BED SCRUBBERS AND NEW EMISSION CONTROL TECHNOLOGIES AT HARD CHROMIUM PLATING MODEL PLANTS

	Small	Medium	Large
Operating parameters			
Total ventilation rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2,000 (70,000)
Operating time, hr/yr	2,000	3,500	6,000
Basic capture system			
Number of fans	1	1	2
Individual fan sizes, hp	10	40	2 @ 40
Total fan size, hp	10	40	80
Electrical use, kWh/yr	14,900	104,400	358,100
Control Device			
Packed-bed scrubber			
Number of control devices	1	1	2
Individual fan sizes, hp	15	60	2 @ 60
Total fan size, hp	15	60	120
Increase in energy requirement over basic capture system to operate fans, hp	5	20	40
Individual pump sizes, hp	1.5	3.0	2 @ 3.0
Total pump size, hp	1.5	3.0	6.0
Total additional energy requirement, hp	6.5	23	46
Increase in electrical use over basic capture system alone, kWh/yr[a]	9,700	60,100	205,900
Mist eliminator with mesh pads in series			
Number of control devices	1	1	2
Individual fan sizes, hp	25	100	2 @ 100
Total fan size, hp	25	100	200
Increase in energy requirement over basic capture system to operate fans, hp	15	60	120
Increase in electrical use over basic capture system alone, kWh/yr[a]	22,400	156,700	537,100

(continued)

TABLE 14. (continued)

	Small	Medium	Large
Packed-bed scrubber/mesh-pad mist eliminator system			
Number of control devices	1	1	2
Individual fan sizes, hp	30	100	2 @ 100
Total fan sizes, hp	30	100	200
Increase in energy requirement over basic capture system to operate fans, hp	20	60	120
Individual pump sizes, hp	3	7.5	2 @ 7.5
Total pump size, hp	3	7.5	15
Total additional energy requirement, hp	23	67.5	135
Increase in electrical use over basic capture system alone, kWh/yr[a]	34,300	176,200	604,300
Fiber-bed mist eliminator			
Number of control devices	1	1	2
Individual fan sizes, hp	40	125	2 @ 125
Total fan size, hp	40	125	250
Increase in energy requirement over basic system to operate fans, hp	30	85	170
Increase in electrical use over basic capture system alone, kWh/yr[a]	44,800	221,900	760,900

[a]Numbers were rounded to the nearest 100 kWh.

37.3 MWh/yr for the small model plant to 895 MWh/yr for the large model plant. This range represents an increase of approximately 150 percent over the uncontrolled level and approximately 52 to 59 percent over the energy required to operate a typical packed-bed scrubber.

The total energy required to operate a packed-bed scrubber/mesh-pad mist eliminator system ranges from 49.2 MWh/yr for the small model plant to 962 MWh/yr for the large model plant. This is an increase of approximately 170 to 230 percent compared to the uncontrolled level and approximately 71 to 100 percent compared to using a typical packed-bed scrubber.

For fiber-bed mist eliminators, the total energy requirements range from 59.7 MWh/yr for the small hard chromium plating model plant to 1,120 MWh/yr for the large model plant. This is an increase of approximately 210 to 300 percent over the uncontrolled (basic capture system alone) level and approximately 98 to 140 percent over the energy requirements for operating a typical packed-bed scrubber.

5.3 Wastewater Impacts

Use of each of the three new emission control technologies for hard chromium plating operations results in the generation of wastewater that requires reuse, treatment, or disposal. However, based on available information, it is assumed that all wastewater generated by the control devices can be drained to the plating tanks to make up for evaporation losses, as is typically the practice with other control technologies currently used in the industry.

5.4 Solid Waste Impacts

One potential source of solid waste from hard chromium plating operations is the sludge produced by wastewater treatment operations. As noted in the previous section, wastewater generated by the three new control technologies for hard chromium plating is assumed to be recirculated and reused in the process. This recirculation minimizes the wastewater treatment throughput, and therefore, the quantities of sludge generated are not significant.

The use of mist eliminators and packed-bed scrubbers results in some solid waste impacts because of the need to replace mesh pads, scrubber-bed packing, and fiber-bed material. Estimates for replacement frequency of scrubber-packing material, mesh pads, and fiber-bed material are shown in Table 15 along with the volumes of solid waste attributable to the use of these materials.

Annual solid waste generation attributable to the use of mist eliminators with mesh pads in series ranges from 0.19 m^3/yr (6.7 ft^3/yr) for the small model plant to 1.0 m^3/yr (35 ft^3/yr) for the large model plant, an increase of about 140 to 150 percent over the solid waste attributable to the use of single packed-bed scrubbers.

The use of packed-bed scrubber/mesh-pad mist eliminator systems results in the generation of solid waste attributable to bed packing as well as mesh pad materials. In this case, annual solid waste volumes for the model plants would range from 0.45 m^3/yr (16 ft^3/yr) to 2.6 m^3/yr (92 ft^3/yr), representing an increase of 460 to 520 percent compared to the waste generated when using single packed-bed scrubbers alone.

The quantities of solid waste generated annually as a result of using a fiber-bed mist eliminator range from 0.42 m^3/yr (15 ft^3/yr) for the small model plant to 2.6 m^3/yr (92 ft^3/yr) for the large model plant. This represents an increase of 420 to 520 percent over the solid waste generated by model plants using single packed-bed scrubbers.

As discussed below under cost impacts, disposal practices associated with these solid wastes often include the compaction of the materials for packing and shipping purposes. For purposes of cost impact calculations, a compaction factor of 50 percent was assumed for bed packing and mesh-pad material. Therefore, from a practical standpoint, the solid waste volumes discussed above may be halved.

TABLE 15. SOLID WASTE IMPACTS ASSOCIATED WITH THE USE OF PACKED-BED SCRUBBERS AND NEW EMISSION CONTROL TECHNOLOGIES AT HARD CHROMIUM ELECTROPLATING MODEL PLANTS

	Hard chromium plating model plants		
	Small	Medium	Large
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
Annualized volume, m^3/yr (ft^3/yr)	0.08 (2.8)	0.21 (7.4)	0.42 (15)
Mist eliminators with mesh pads in series			
Total volume of mesh pad material, m^3 (ft^3)	0.95 (34)	2.6 (92)	5.2 (184)
Frequency of replacement, yr	5	5	5
Annualized volume, m^3/yr (ft^3/yr)	0.19 (6.7)	0.52 (18)	1.0 (35)
Packed-bed scrubbers/mesh-pad mist eliminator systems			
Total volume of packing material, m^3 (ft^3)[a]	2.3 (81)	6.7 (237)	13 (459)
Total volume of mesh pad material, m^3 (ft^3)	1.1 (39)	3.3 (117)	6.7 (237)
Frequency of replacement of packing material, yr	10	10	10
Frequency of replacement of mesh pads, yr	5	5	5
Annualized total volume of material, m^3/yr (ft^3/yr)	0.45 (16)	1.3 (46)	2.6 (92)
Fiber-bed mist eliminators			
Total volume of packing material, m^3 (ft^3)	2.1 (74)	6.4 (226)	13 (459)
Frequency of replacement, yr	5	5	5
Annualized volume, m^3/yr (ft^3/yr)	0.42 (15)	1.3 (46)	2.6 (92)

[a]Based on a packing-bed depth of 0.9 m (3 ft)

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. This one-time occurrence is treated as a component of the retrofit capital cost for existing facilities.

5.5 Model Plant Cost Impacts

This section presents installed capital and net annualized cost estimates associated with the implementation of the new emission control technologies at new and existing electroplating operations. (Net annualized costs incorporate chromic acid recovery credits.) Replacement costs, a component of annualized costs, include disposal and transportation of the used impaction material. Disposal costs are based on the assumption that the waste material is compacted to 50 percent of its original volume. For purposes of comparison, capital and net annualized cost estimates for single packed-bed scrubbers are presented along with the costs associated with the use of the new emission control technologies. Tables 16 and 17 present these capital and net annualized costs for new and existing hard chromium electroplating model plants. The basis for the development of model plant costs is presented in Appendix B. Detailed cost breakdowns for each of the control technologies is presented in Appendix C.

All costs are presented on a model plant basis. Costs are presented in 1988 dollars to facilitate comparison with costs of control technologies presented in the Background Information Document for Chromium Emissions from Chromium Electroplating and Chromic Acid Anodizing Operations.[5]

5.5.1 Mesh-Pad Mist Eliminators with Mesh Pads in Series.

Table 16 shows that the capital costs for mesh-pad mist eliminators with mesh pads in series range from $27,200 to $143,600 for new plants, and $34,000 to $179,500 for existing plants. These costs represent a savings of 3 to 26 percent when

TABLE 16. CAPITAL COSTS OF SINGLE PACKED-BED SCRUBBERS AND NEW CONTROL TECHNOLOGIES FOR NEW AND EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)[5,16-18]

	Model plant size					
	Small		Medium		Large	
Control technology	New	Existing	New	Existing	New	Existing
Single packed-bed scrubber	36,700	45,900	74,200	92,800	148,400	185,500
Mesh-pad mist eliminator with mesh pads in series	27,200	34,000	71,800	89,800	143,600	179,500
Packed-bed scrubber/mesh-pad mist eliminator system	58,100	72,600	97,800	122,200	195,600	244,500
Fiber-bed mist eliminator	114,600	126,100	228,600	251,500	502,800	688,300

TABLE 17. NET ANNUALIZED COSTS OF SINGLE PACKED-BED SCRUBBERS AND NEW CONTROL TECHNOLOGIES FOR NEW AND EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)[5,16-18]

	Model plant size					
	Small		Medium		Large	
Control technology	New	Existing	New	Existing	New	Existing
Single packed-bed scrubber	9,700	11,100	18,600	21,500	38,800	44,600
Mesh-pad mist eliminator with mesh pads in series	13,500	14,900	32,800	36,400	76,700	84,100
Packed-bed scrubber/mesh-pad mist eliminator system	17,000	19,300	31,800	35,700	72,100	80,000
Fiber-bed mist eliminator	28,900	30,700	66,200	69,800	149,200	156,300

compared to the capital costs of single packed-bed scrubbers installed at new or existing plants.

As shown in Table 17, the net annualized costs of operating this control technology are $13,500 to $76,700 for new plants, and $14,900 to $84,100 for existing model plants. For new plants, the costs are 40 to 100 percent higher than the costs of operating single packed-bed scrubbers; for existing plants, the costs are 30 to 90 percent higher.

5.5.2 Packed-Bed Scrubber/Mesh-Pad Mist Eliminator System.

As shown in Table 16, capital costs of installing packed-bed scrubber/mesh-pad mist eliminator systems are $58,100 to $195,600 for new model plants, and $72,600 to $244,500 for existing model plants. These costs are from 30 to 60 percent higher than the capital costs associated with the installation of single packed-bed scrubbers at these model plants.

Table 17 shows that the net annualized costs of operating packed-bed scrubber/mesh-pad mist eliminator systems range from $17,000 to $72,100 for new model plants, and $19,300 to $80,000 for existing model plants. For new plants, the operating costs are 70 to 90 percent more than the costs associated with the use of single packed-bed scrubbers. For existing plants, the operating costs are 70 to 80 percent higher.

5.5.3 Fiber-Bed Mist Eliminators.

As shown in Table 16, the model plant capital costs of fiber-bed mist eliminators for new plants are approximately $114,600 to $457,100. This is approximately 210 percent more than the capital costs of $36,700 to $148,400 for single packed-bed scrubbers. For existing plants, single packed-bed scrubber capital costs range from $45,900 to $185,500, and fiber-bed mist eliminator costs are $126,100 to $502,800, a difference of about 170 percent.

Table 17 shows that the net annualized costs for single packed-bed scrubbers at new plants range from $9,700 to $38,800. Net annualized costs for fiber-bed mist eliminators in these same plants are $28,900 to $149,200, an increase of about 200 to

280 percent. For existing model plants, the net annualized costs for fiber-bed mist eliminators ($30,700 to $156,300) are 180 to 250 percent higher than the costs for single packed-bed scrubbers ($11,100 to $44,600).

As discussed in Sections 3.2 and 4.2.5, most vendors do not recommend fiber-bed mist eliminators as the first stage of the control system because of their tendency to plug. It is recommended that a coarse filtering device be provided upstream of the fiber beds to prevent plugging and operational problems that may arise from plugging of the fiber-bed media. Packed-bed scrubbers or serially positioned mesh pads are commonly used to reduce the inlet loading to the fiber beds. To obtain representative cost estimates for this control systems approach, costs for typical packed-bed scrubbers or mesh-pad systems should be combined with costs for fiber-bed mist eliminators.

5.6 Summary of Economic Impacts

An economic impact analysis of the new emission control technologies used in the hard chromium electroplating industry was performed by the U.S. Environmental Protection Agency. The results of this analysis are contained in a separate report, Economic Impact Assessment of Emerging Technologies for Controlling Chromium Emissions from Chromium Electroplating Operations.[19] The report estimates the impact of control costs for a composite mesh-pad mist eliminator, a packed-bed scrubber/mesh-pad mist eliminator system, and a fiber-bed mist eliminator on the costs of chromium electroplating and on the prices of hard chromium-electroplated products.

Three product groups were chosen to demonstrate the economic impacts associated with the use of the three new emission control technologies. The product groups are automobile components (e.g., valves, piston rings, seals), industrial rolls, and hydraulic cylinders used in backhoes. When single packed-bed scrubbers are used to control chromium emissions, the resulting end product price increases are insignificant. The analyses shows that price increases attributable to the use of any of the new emission control technologies would be greater than those associated with single packed-bed scrubbers. However, these increases are still negligible - less than one-half of one percent of the prices of the two end products (automobiles, and backhoes) and less than one percent for industrial rolls. The effect on end product price is relatively minor because electroplating is generally performed on components of the end product, and the cost increase for this operation is small compared to the price of the end product.

There would be some impact on small businesses. Use of the packed-bed scrubber/mesh-pad mist eliminator system or the fiber-bed mist eliminator would create capital availability problems for some (about 11 percent) of the smallest hard chromium electroplating shops. These problems would not be quite as severe for these shops when the single packed-bed scrubber or the composite mesh-pad mist eliminator are used. The impact on earnings, resulting from the use of the three new emission control technologies, would cause 3 to 13 percent of the small plants to close, with fiber-bed mist eliminators resulting in the greatest number of closures, and composite mesh-pad mist eliminators having the least impact. Between 1 and 2 percent of small plants would be expected to close due to the impacts of single packed-bed scrubbers.

Table 18 presents a summary of the estimated impacts of the use of the control technologies on electroplating costs. The results of the analysis indicate that increases in electroplating costs would range from about 2 percent for large plants to 36 percent for small plants when composite mesh-pad mist eliminators are used. The use of packed-bed scrubber/mesh-pad mist eliminators would result in electroplating cost increases ranging from about 2 percent for large plants to 46 percent for small plants. Estimates for electroplating cost increases range from 4 percent for large plants to 75 percent for small plants when fiber-bed mist eliminators are used. When single packed-bed scrubbers are used, electroplating cost increases range from

TABLE 18. ESTIMATED PERCENT CHANGE IN HARD CHROMIUM ELECTROPLATING COST OF THREE END PRODUCTS ATTRIBUTABLE TO VARIOUS CONTROL TECHNOLOGIES (1988 DOLLARS)[19]

	Percent price increase, %								
	Automobiles model plant size			Industrial rolls[a] model plant size			Hydraulic cylinders[b] model plant size		
Control technology	small	medium	large	small	medium	large	small	medium	large
Composite mesh-pad mist eliminator	12.5	3.9	3.4	10.9-18.3	3.3-5.6	2.1-3.5	18.0-36.0	5.6-11.1	3.5-7.1
Packed-bed scrubber/mesh-pad mist eliminator system	16.1	3.8	3.2	14.1-23.6	3.3-5.5	2.0-3.4	23.5-46.4	5.5-10.9	3.4-6.8
Fiber-bed mist eliminator	25.9	7.3	6.1	22.7-38.1	6.3-10.5	3.8-6.3	37.4-74.9	10.5-21.0	6.3-12.6
Single packed-bed scrubber	9.4	2.4	2.0	8.3-13.9	2.1-3.5	1.2-2.1	13.6-27.3	3.5-6.9	2.1-4.1

[a]Ranges include percent increases in electroplating costs at $0.009/cm^2 to $0.06/cm^2 ($0.06/in.^{2} to $0.40/in.^{2})
[b]Ranges include percent increases in electroplating costs at $0.005/cm^2 to $0.009/cm^2 ($0.03/in.^{2} to $0.06/in.^{2})

2 percent for large plants to 27 percent for small plants.

Estimates of the changes in final product prices attributable to increases in electroplating costs when new control technologies are used are presented in Table 19. The final products are hard chromium-plated parts for a representative automobile and a typical backhoe using hard chromium-electroplated hydraulic cylinders. As stated in Table 19, price increases for industrial roll end products can not be easily estimated because of their wide diversity. However, for most industrial rolls, the cost of electroplating is less than 10 percent of the final product price, and use of the new control technologies would increase the price of the end products by less than 1 percent.[19]

6.0 CONCLUSIONS/SUMMARY

In terms of performance, composite mesh-pad systems and fiber-bed mist eliminators achieved higher performance levels than those achieved by packed-bed scrubbers. The performance levels for fiber-bed mist eliminators were higher than those for composite mesh-pad systems. However, the economic impacts associated with the use of fiber-bed mist eliminators are much greater than the impacts attributable to the use of either composite mesh-pad systems or traditional packed-bed scrubbers. Furthermore, the economic impacts presented for fiber-bed mist eliminators were based only on costs of the fiber-bed mist eliminator itself. As discussed in Section 4.3, the relatively high performance level of the fiber-bed mist eliminator was due, in part, to the inlet load reduction attributable to the use of the coarse control system upstream of the fiber-bed mist eliminator. If the costs for the upstream control system were included in the cost of control for fiber-bed mist eliminators, the economic impact would be even greater, particularly for small businesses. The economic impacts for composite mesh-pad systems are not significantly different than those for traditional packed-bed scrubbers.

TABLE 19. ESTIMATED CHANGE IN PRICE OF FINAL PRODUCTS ATTRIBUTABLE TO THE INCREASE IN HARD CHROMIUM ELECTROPLATING COSTS WHEN USING VARIOUS CONTROL TECHNOLOGIES (1988 DOLLARS)[19]

Control technology	Estimated price increase, $								
	Automobiles[a] model plant size			Industrial rolls[b] model plant size			Hydraulic cylinders- backhoe[c] model plant size		
	small	medium	large	small	medium	large	small	medium	large
Composite mesh-pad mist eliminator	13.22	4.09	2.61	--	--	--	24.80	7.59	4.81
Packed-bed scrubber/mesh-pad mist eliminator system	17.04	4.02	2.50	--	--	--	31.97	7.46	4.60
Fiber-bed mist eliminator	27.48	7.70	4.68	--	--	--	51.55	14.29	8.62
Single packed-bed scrubber	10.00	2.54	1.52	--	--	--	18.76	4.71	2.80

[a]Price increases are based on a representative automobile, the Oldsmobile Cutlass/Ciera (six model years in the 1980's).

[b]Amount of price increase for final products cannot be readily estimated for industrial rolls. The electroplating cost as a percentage of the price of the final product can differ for rolls with the exact same plating costs because of variations in roll thickness (not plating thickness) prior to plating or in the quality of the steel substrate. Industrial rolls themselves are an intermediate, rather than a final, product.

[c]Final product costs are based on a representative backhoe with 11 hydraulic cylinders and a list price of $37,000.

The composite mesh-pad systems are economically viable control options for all sizes of hard chromium electroplating operations, as indicated by the increased use of these systems. The use of fiber-bed mist eliminators, on the other hand, is limited to a few, very large hard chromium electroplating operations. It appears that, of the two new emission control techniques, composite mesh-pad systems represent the more reasonable approach to controlling emissions of chromic acid mist from all hard chromium plating operations.

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APPENDIX A. SUMMARIES OF EMISSIONS TEST DATA AND PROCESS OPERATING PARAMETERS

The results of chromium emissions tests for four hard chromium electroplating operations are presented in this section.

TABLE A-1. SUMMARY OF EMISSIONS TEST DATA

Plant: Precision Engineering, Seattle, WA
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks
Test location: Mesh-pad mist eliminator - Inlet A

Data	Run No. 1	Run No. 2	Run No. 3	Average of series
General				
Date	12/17/91	12/18/91	12/19/91	--
Sampling time, min	360	240	240	--
Isokinetic rate, %	99	98	93	--
Process rate, Ah/hr	11,200	10,500	9,500	10,400
Total current, Ah	67,000	42,000	38,000	49,000
Gas stream data				
Temperature, ^{o}C (^{o}F)	21 (70)	21 (69)	21 (70)	21 (70)
Moisture, %	0.98	1.1	1.2	1.1
Actual flow rate, m^3/min (ft^3/min)	265 (9,340)	261 (9,230)	281 (9,920)	269 (9,500)
Standard flow rate, dscm/min (dscf/min)	258 (9,120)	252 (8,900)	278 (9,800)	263 (9,280)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	308 (0.135)	289 (0.126)	450 (0.197)	349 (0.152)
kg/hr (lb/hr) (10^{-3})	4.8 (10.5)	4.4 (9.6)	7.5 (16.5)	5.6 (12.2)
mg/Ah (gr/Ah)	0.429 (0.007)	0.419 (0.006)	0.789 (0.012)	0.546 (0.008)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	294 (0.128)	280 (0.122)	435 (0.190)	336 (0.147)
kg/hr (lb/hr) (10^{-3})	4.6 (10.0)	4.2 (9.3)	7.2 (16.0)	5.3 (11.8)
mg/Ah (gr/Ah)	0.411 (0.006)	0.400 (0.006)	0.758 (0.012)	0.523 (0.008)

TABLE A-2. SUMMARY OF EMISSIONS TEST DATA

Plant: Precision Engineering, Seattle, WA
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks
Test location: Mesh-pad mist eliminator - Inlet B

Data	Run No. 1	Run No. 2	Run No. 3	Average of series
General				
Date	12/17/91	12/18/91	12/19/91	--
Sampling time, min	360	240	240	--
Isokinetic rate, %	101	89	98	--
Process rate, Ah/hr	7,000	7,180	8,200	7,460
Total current, Ah	42,000	28,700	32,800	34,500
Gas stream data				
Temperature, ^{o}C (^{o}F)	21 (69)	21 (70)	20 (68)	21 (69)
Moisture, %	0.67	0.65	0.94	0.75
Actual flow rate, m^3/min (ft^3/min)	153 (5,410)	157 (5,530)	141 (4,980)	150 (5,310)
Standard flow rate, dscm/min (dscf/min)	150 (5,300)	152 (5,360)	140 (4,950)	147 (5,200)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	151 (0.066)	145 (0.063)	148 (0.065)	148 (0.065)
kg/hr (lb/hr) (10^{-3})	1.4 (3.0)	1.3 (2.9)	1.2 (2.7)	1.3 (2.9)
mg/Ah (gr/Ah)	0.200 (0.003)	0.181 (0.003)	0.146 (0.002)	0.176 (0.003)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	153 (0.067)	125 (0.055)	168 (0.073)	149 (0.065)
kg/hr (lb/hr) (10^{-3})	1.4 (3.0)	1.1 (2.5)	1.4 (3.1)	1.3 (2.9)
mg/Ah (gr/Ah)	0.200 (0.003)	0.153 (0.002)	0.171 (0.003)	0.175 (0.003)

TABLE A-3. SUMMARY OF EMISSIONS TEST DATA

Plant: Precision Engineering, Seattle, WA
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks
Test location: Mesh-pad mist eliminator - Outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of series
General				
Date	12/17/91	12/18/91	12/19/91	--
Sampling time, min	360	240	240	--
Isokinetic rate, %	105	99	99	--
Process rate, Ah/hr	18,200	17,700	17,700	17,900
Total current, Ah	109,000	70,700	70,700	83,500
Gas stream data				
Temperature, ^{o}C (^{o}F)	22 (72)	22 (72)	22 (72)	22 (72)
Moisture, %	0.97	1.1	0.90	0.99
Actual flow rate, m^3/min (ft^3/min)	410 (14,470)	410 (14,480)	421 (14,860)	414 (14,610)
Standard flow rate, dscm/min (dscf/min)	404 (14,270)	399 (14,100)	422 (14,890)	408 (14,420)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	13.1 (0.006)	10.5 (0.005)	8.9 (0.004)	10.8 (0.005)
kg/hr (lb/hr) (10^{-3})	0.32 (0.70)	0.25 (0.55)	0.23 (0.50)	0.27 (0.58)
mg/Ah (gr/Ah)	0.018 ($2.7x10^{-4}$)	0.014 ($2.2x10^{-4}$)	0.013 ($2.0x10^{-4}$)	0.015 ($2.3x10^{-4}$)
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	13.9 (0.006)	9.3 (0.004)	7.8 (0.003)	10.3 (0.005)
kg/hr (lb/hr) (10^{-3})	0.34 (0.75)	0.22 (0.49)	0.20 (0.43)	0.25 (0.55)
mg/Ah (gr/Ah)	0.019 ($2.9x10^{-4}$)	0.012 ($1.9x10^{-4}$)	0.011 ($1.7x10^{-4}$)	0.014 ($2.2x10^{-4}$)

TABLE A-4. SUMMARY OF EMISSIONS TEST DATA

Plant: Monroe Auto Equipment, Hartwell, GA
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mesh-pad mist eliminator inlet, without foam blanket

Data	Run No. 1	Run No. 3	Run No. 4	Average of test series
General				
Date	12/18/91	12/19/91	12/19/91	---
Sampling time, min	120	120	120	---
Isokinetic rate, %	99.1	97.4	97.6	---
Process rate, Ah/hr	6,800	6,800	6,800	6,800
Total current, Ah	13,600	13,600	13,600	13,600
Gas stream data				
Temperature, ^{o}C (^{o}F)	23 (74)	19 (66)	21 (69)	21 (70)
Moisture, %	1.4	1.3	1.4	1.4
Actual flow rate, m^3/min (ft^3/min)	736 (26,000)	755 (26,700)	739 (26,100)	743 (26,200)
Standard flow rate, dscm/min (dscf/min)	715 (25,200)	746 (26,300)	726 (25,600)	729 (25,700)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	973 (0.425)	1,055 (0.459)	825 (0.361)	951 (0.416)
kg/hr (lb/hr) (10^{-3})	41.7 (92.0)	47.1 (104)	35.9 (79.2)	41.6 (91.7)
mg/Ah (gr/Ah)	6.14 (0.095)	6.94 (0.107)	5.28 (0.081)	6.12 (0.094)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-5. SUMMARY OF EMISSIONS TEST DATA

Plant: Monroe Auto Equipment, Hartwell, GA
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mesh-pad mist eliminator inlet, with foam blanket

Data	Run No. 2	Run No. 5	Run No. 6	Average of test series
General				
Date	12/18/91	12/19/91	12/20/91	---
Sampling time, min	120	120	120	---
Isokinetic rate, %	99.8	97.3	94.2	---
Process rate, Ah/hr	6,800	10,100	10,200	9,000
Total current, Ah	13,600	20,200	20,400	18,100
Gas stream data				
Temperature, °C (°F)	23 (73)	20 (68)	21 (69)	21 (70)
Moisture, %	0.8	1.2	1.3	1.1
Actual flow rate, m^3/min (ft^3/min)	725 (25,600)	747 (26,400)	773 (27,300)	748 (26,400)
Standard flow rate, dscm/min (dscf/min)	711 (25,100)	736 (26,000)	759 (26,800)	735 (26,000)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	172 (0.075)	595 (0.260)	363 (0.159)	377 (0.165)
kg/hr (lb/hr) (10^{-3})	7.35 (16.2)	26.3 (57.9)	16.6 (36.5)	16.7 (36.9)
mg/Ah (gr/Ah)	1.08 (0.017)	2.60 (0.040)	1.63 (0.025)	1.77 (0.027)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-6. SUMMARY OF EMISSIONS TEST DATA

Plant: Monroe Auto Equipment, Hartwell, GA
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mesh-pad mist eliminator outlet, without foam blanket

Data	Run No. 1	Run No. 3	Run No. 4	Average of test series
General				
Date	12/18/91	12/19/91	12/19/91	--
Sampling time, min	125	125	125	--
Isokinetic rate, %	96.4	96.8	95.9	--
Process rate, Ah/hr	6,500	6,500	6,500	6,500
Total current, Ah	13,600	13,600	13,600	13,600
Gas stream data				
Temperature, ^{o}C (^{o}F)	24 (75)	19 (66)	21 (69)	21 (69)
Moisture, %	0.6	0.7	0.7	0.6
Actual flow rate, m^3/min (ft^3/min)	776 (27,400)	773 (27,300)	765 (27,000)	771 (27,200)
Standard flow rate, dscm/min (dscf/min)	764 (27,000)	774 (27,300)	759 (26,800)	766 (27,000)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	9 (0.004)	12 (0.005)	13 (0.006)	11 (0.005)
kg/hr (lb/hr) (10^{-3})	0.39 (0.86)	0.56 (1.2)	0.61 (1.3)	0.52 (1.1)
mg/Ah (gr/Ah)	0.063 (0.001)	0.083 (0.001)	0.090 (0.001)	0.079 (0.001)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-7. SUMMARY OF EMISSIONS TEST DATA

Plant: Monroe Auto Equipment, Hartwell, GA
Operation: Hard chromium electroplating
Emission source: One hard chromium electroplating tank
Test location: Mesh-pad mist eliminator outlet, with foam blanket

Data	Run No. 2	Run No. 5	Run No. 6	Average of test series
General				
Date	12/18/91	12/19/91	12/20/91	--
Sampling time, min	125	125	125	--
Isokinetic rate, %	96.0	96.6	97.4	--
Process rate, Ah/hr	6,500	9,700	9,800	8,700
Total current, Ah	13,600	20,200	20,400	18,100
Gas stream data				
Temperature, °C (°F)	22 (72)	19 (67)	20 (68)	20 (68)
Moisture, %	0.6	0.6	0.6	0.6
Actual flow rate, m^3/min (ft^3/min)	764 (27,000)	769 (27,100)	763 (26,900)	765 (27,000)
Standard flow rate, dscm/min (dscf/min)	756 (26,700)	768 (27,100)	760 (26,800)	761 (26,900)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	5 (0.002)	7 (0.003)	12 (0.005)	8 (0.003)
kg/hr (lb/hr) (10^{-3})	0.23 (0.51)	0.31 (0.68)	0.54 (1.2)	0.36 (0.79)
mg/Ah (gr/Ah)	0.035 (0.001)	0.033 (<0.001)	0.056 (0.001)	0.041 (0.001)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-8. SUMMARY OF EMISSIONS TEST DATA

Plant: Remco Hydraulics, Inc., Willits, CA
Operation: Hard chromium electroplating
Emission source: Two hard chromium electroplating tanks
Test location: Scrubber/mesh-pad mist eliminator - Inlet (A)

Data	Run No. 1	Run No. 2	Run No. 3	Average of series
General				
Date	06/19/91	06/20/91	06/21/91	--
Sampling time, min	360	360	360	--
Isokinetic rate, %	96.0	95.1	95.9	--
Process rate, Ah/hr	22,800	23,400	23,200	23,100
Total current, Ah	136,800	140,500	139,100	138,800
Gas stream data				
Temperature, °C (°F)	24 (75)	22 (71)	21 (69)	22 (72)
Moisture, %	0.78	1.17	1.19	1.05
Actual flow rate, m^3/min (ft^3/min)	375 (13,200)	378 (13,300)	391 (13,800)	381 (13,500)
Standard flow rate, dscm/min (dscf/min)	351 (12,400)	354 (12,500)	368 (13,000)	358 (12,600)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf)	150 (0.065)	109 (0.047)	134 (0.058)	131 (0.057)
kg/hr (lb/hr)	3.16 (6.96)	2.30 (5.08)	2.95 (6.50)	2.80 (6.18)
mg/Ah (gr/Ah)	139 (2.15)	98.3 (1.52)	127 (1.96)	121 (1.87)
Hexavalent chromium				
mg/dscm (gr/dscf)	156 (0.068)	118 (0.052)	145 (0.063)	140 (0.061)
kg/hr (lb/hr)	3.28 (7.23)	2.50 (5.51)	3.19 (7.04)	2.99 (6.59)
mg/Ah (gr/Ah)	144 (2.22)	107 (1.65)	138 (2.13)	130 (2.01)

TABLE A-9. SUMMARY OF EMISSIONS TEST DATA

Plant: Remco Hydraulics, Inc., Willits, CA
Operation: Hard chromium electroplating
Emission source: Four hard chromium electroplating tanks
Test location: Scrubber/mesh-pad mist eliminator - Inlet (B)

Data	Run No. 1	Run No. 2	Run No. 3[a]	Series average
General				
Date	06/19/91	06/20/91	06/21/91	--
Sampling time, min	360	360	360	--
Isokinetic rate, %	98.0	96.9	91.6	
Process rate, Ah/hr	38,300	36,900	35,600	37,600
Total current, Ah	229,700	221,300	213,700	225,500
Gas stream data				
Temperature, °C (°F)	24 (75)	23 (74)	21 (69)	24 (75)
Moisture, %	1.21	1.35	1.31	1.28
Actual flow rate, m^3/min (ft^3/min)	297 (10,500)	298 (10,500)	306 (10,800)	298 (10,500)
Standard flow rate, dscm/min (dscf/min)	277 (9,780)	277 (9,780)	287 (10,100)	277 (9,780)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf)(10^{-3})	1,090 (0.477)	1,830 (0.798)	15,600 (6.80)	1,460 (0.638)
kg/hr (lb/hr) (10^{-3})	18.1 (39.9)	30.3 (66.9)	268 (591)	24.2 (53.4)
mg/Ah (gr/Ah)	0.473 (0.007)	0.821 (0.013)	7.53 (0.116)	0.647 (0.010)
Hexavalent chromium				
mg/dscm (gr/dscf)(10^{-3})	1,200 (0.524)	1,850 (0.810)	16,900 (7.39)	1,520 (0.666)
kg/hr (lb/hr) (10^{-3})	19.8 (43.7)	30.8 (67.8)	292 (643)	25.3 (55.8)
mg/Ah (gr/Ah)	0.52 (0.008)	0.83 (0.013)	8.20 (0.127)	0.68 (0.010)

[a]Results for this run not included in average; it is suspected that the probe may have contacted the duct wall during testing.

TABLE A-10. SUMMARY OF EMISSIONS TEST DATA

Plant: Remco Hydraulics, Inc., Willits, CA
Operation: Hard chromium electroplating
Emission source: Six hard chromium electroplating tanks
Test location: Scrubber/mesh-pad mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	06/19/91	06/20/91	06/21/91	--
Sampling time, min	360	360	360	--
Isokinetic rate, %	99.0	98.9	99.8	
Process rate, Ah/hr	63,600	62,700	61,100	62,500
Total current, Ah	381,400	376,200	366,700	374,800
Gas stream data				
Temperature, °C (°F)	22 (72)	22 (72)	21 (69)	22 (72)
Moisture, %	1.74	1.93	1.97	1.88
Actual flow rate, m^3/min (ft^3/min)	726 (25,600)	716 (25,300)	734 (25,900)	725 (25,600)
Standard flow rate, dscm/min (dscf/min)	680 (24,000)	671 (23,700)	690 (24,400)	680 (24,000)
Chromium emissions				
Total chromium				
mg/dscm (gr/dscf) (10^{-3})	6.24 (0.003)	3.44 (0.002)	8.50 (0.004)	6.06 (0.003)
kg/hr (lb/hr) (10^{-3})	0.255 (0.562)	0.138 (0.305)	0.352 (0.777)	0.248 (0.548)
mg/Ah (gr/Ah)	0.004 (6.2×10^{-5})	0.002 (3.1×10^{-5})	0.006 (9.3×10^{-5})	0.004 (6.2×10^{-5})
Hexavalent chromium				
mg/dscm (gr/dscf) (10^{-3})	5.90 (0.003)	3.45 (0.002)	8.69 (0.004)	6.01 (0.003)
kg/hr (lb/hr) (10^{-3})	0.235 (0.518)	0.138 (0.305)	0.359 (0.792)	0.244 (0.538)
mg/Ah (gr/Ah)	0.004 (6.2×10^{-5})	0.002 (3.1×10^{-5})	0.006 (9.3×10^{-5})	0.004 (6.2×10^{-5})

TABLE A-11. SUMMARY OF EMISSIONS TEST DATA

Plant: Building 32 - Naval Aviation Depot, Alameda, CA.
Operation: Chromic acid anodizing
Emission source: Two chromic acid anodizing tanks - Line G
Test location: Fiber-bed mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Run No. 4	Average of test series
General					
Date	04/15/91	04/15/91	04/16/91	04/16/91	--
Sampling time, min	240	240	240	240	--
Isokinetic rate, %	103	101	105	104	--
Process rate, Ah/hr	996	996	1,270	1,270	1,130
Total current, Ah	3,990	3,990	5,100	5,100	4,540
Gas stream data					
Temperature, °C (°F)	18 (65)	18 (65)	19 (66)	19 (67)	19 (66)
Moisture, %	1.8	1.7	1.9	1.9	1.8
Actual flow rate, m^3/min (ft^3/min)	826 (29,200)	864 (30,500)	814 (28,800)	829 (29,300)	833 (29,400)
Standard flow rate, dscm/min (dscf/min)	813 (28,700)	852 (30,100)	800 (28,300)	813 (28,700)	820 (28,900)
Chromium emissions[a]					
Total chromium					
mg/dscm (gr/dscf)	$8.3x10^{-5}$ ($3.6x10^{-8}$)	$8.6x10^{-5}$ ($3.7x10^{-8}$)	$1.0x10^{-4}$ ($4.5x10^{-8}$)	$1.1x10^{-4}$ ($4.8x10^{-8}$)	$9.5x10^{-5}$ ($4.2x10^{-8}$)
kg/hr (lb/hr) (10^{-3})	<0.004 (<0.009)	<0.004 (<0.010)	<0.005 (<0.011)	<0.005 (<0.011)	<0.005 (<0.011)
mg/Ah (gr/Ah)	$<4.1x10^{-3}$ ($<6.3x10^{-5}$)	$<4.4x10^{-3}$ ($<6.8x10^{-5}$)	$<3.9x10^{-3}$ ($<6.0x10^{-5}$)	$<4.2x10^{-3}$ ($<6.5x10^{-5}$)	$<4.1x10^{-3}$ ($<6.3x10^{-5}$)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-12. SUMMARY OF EMISSIONS TEST DATA

Plant: Building 32 - Naval Aviation Depot, Alameda, CA.
Operation: Hard chromium electroplating
Emission source: Three hard chromium electroplating tanks - Line L
Test location: Fiber-bed mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	04/15/91	04/15/91	04/16/91	--
Sampling time, min	180	180	240	--
Isokinetic rate, %	104	103	104	--
Process rate, Ah/hr	9,810	9,810	10,600	10,100
Total current, Ah	29,400	29,400	42,600	33,800
Gas stream data				
Temperature, ^{o}C (^{o}F)	18 (64)	17 (63)	19 (67)	18 (65)
Moisture, %	1.7	1.6	1.8	1.7
Actual flow rate, m^3/min (ft^3/min)	874 (30,900)	844 (29,800)	828 (29,200)	849 (30,000)
Standard flow rate, dscm/min (dscf/min)	862 (30,400)	835 (29,500)	814 (28,700)	837 (29,600)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf)	1.3×10^{-4} (5.5×10^{-8})	3.7×10^{-4} (1.6×10^{-7})	9.7×10^{-5} (4.2×10^{-8})	2.0×10^{-4} (8.7×10^{-8})
kg/hr (lb/hr) (10^{-3})	<0.007 (<0.015)	0.019 (0.042)	<0.005 (<0.011)	<0.010 (<0.022)
mg/Ah (gr/Ah)	$<7.0 \times 10^{-4}$ ($<1.1 \times 10^{-5}$)	1.9×10^{-3} (2.9×10^{-5})	$<4.0 \times 10^{-4}$ ($<6.2 \times 10^{-6}$)	$<1.0 \times 10^{-3}$ ($<1.5 \times 10^{-5}$)

[a]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-13. SUMMARY OF EMISSIONS TEST DATA

Plant: Building 32 - Naval Aviation Depot, Alameda, CA.
Operation: Hard chromium electroplating
Emission source: Four hard chromium electroplating tanks - Line M
Test location: Fiber-bed mist eliminator inlet/packed-bed scrubber outlet

Data	Run No. 2[a]	Run No. 3	Average of test series
General			
Date	04/17/91	04/18/91	--
Sampling time, min	240	240	--
Isokinetic rate, %	99.6	103	--
Process rate, Ah/hr	9,410	9,360	9,380
Total current, Ah	37,600	37,400	37,500
Gas stream data			
Temperature, °C (°F)	16 (61)	16 (60)	16 (60)
Moisture, %	1.9	1.8	1.8
Actual flow rate, m^3/min (ft^3/min)	499 (17,600)	458 (16,200)	479 (16,900)
Standard flow rate, dscm/min (dscf/min)	491 (17,400)	453 (16,000)	472 (16,700)
Chromium emissions[b]			
Total chromium			
mg/dscm (gr/dscf)	0.14 (6.1×10^{-5})	0.20 (8.7×10^{-5})	0.17 (7.4×10^{-5})
kg/hr (lb/hr) (10^{-3})	4.14 (9.13)	5.31 (11.7)	4.73 (10.4)
mg/Ah (gr/Ah)	0.440 (0.007)	0.567 (0.009)	0.504 (0.008)

[a]Only two inlet test runs (Nos. 2 and 3) were performed on the control unit for Line M. There is no Inlet Test Run No. 1.
[b]Hexavalent chromium analysis was not performed on collected samples.

TABLE A-14. SUMMARY OF EMISSIONS TEST DATA

Plant: Building 32 - Naval Aviation Depot, Alameda, CA.
Operation: Hard chromium electroplating
Emission source: Four hard chromium electroplating tanks - Line M
Test location: Fiber-bed mist eliminator outlet

Data	Run No. 1	Run No. 2	Run No. 3	Average of test series
General				
Date	04/17/91	04/17/91	04/18/91	--
Sampling time, min	480	240	240	--
Isokinetic rate, %	104	105	105	--
Process rate, Ah/hr	9,390	9,410	9,360	9,390
Total current, Ah	75,100	37,600	37,400	50,000
Gas stream data				
Temperature, °C (°F)	18 (64)	19 (66)	18 (64)	18 (64)
Moisture, %	1.8	1.9	1.6	1.8
Actual flow rate, m^3/min (ft^3/min)	532 (18,800)	530 (18,700)	545 (19,200)	536 (18,900)
Standard flow rate, dscm/min (dscf/min)	525 (18,500)	522 (18,400)	540 (19,100)	529 (18,700)
Chromium emissions[a]				
Total chromium				
mg/dscm (gr/dscf)	3.6×10^{-4} (1.6×10^{-7})	1.1×10^{-4} (4.9×10^{-8})	9.9×10^{-5} (4.3×10^{-8})	1.9×10^{-4} (8.3×10^{-8})
kg/hr (lb/hr) (10^{-3})	0.011 (0.024)	<0.004 (<0.009)	<0.003 (<0.007)	<0.006 (<0.013)
mg/Ah (gr/Ah)	1.2×10^{-3} (1.9×10^{-5})	$<4.0 \times 10^{-4}$ ($<6.2 \times 10^{-6}$)	$<3.0 \times 10^{-4}$ ($<4.6 \times 10^{-6}$)	$<6.0 \times 10^{-4}$ ($<9.3 \times 10^{-6}$)

[a]Hexavalent chromium analysis was not performed on collected samples.

APPENDIX B. BASIS FOR THE DEVELOPMENT OF MODEL PLANT COSTS FOR NEW EMISSION CONTROL TECHNOLOGIES

This section presents the methodologies for development of capital and annualized costs of new emission control technologies used to control chromium emissions from hard chromium electroplating model plants.

APPENDIX B. BASIS FOR THE DEVELOPMENT OF MODEL PLANT COSTS FOR NEW EMISSION CONTROL TECHNOLOGIES

Capital and annualized costs are presented in this section on a model plant basis. Each model plant is composed of model tanks of various sizes. Figures B-1 and B-2 present plan views of the model plant configurations and ventilation system specifications. Table B-1 presents model plant parameters upon which installed capital and annualized costs are based. Cost factors used to calculate annualized costs are shown in Table B-2. Costs provided by vendors were converted to appropriate year dollars using ratios of the following Chemical Engineering plant indices: November 1988, 347.8; September 1990, 360.2. Data sources used to calculate capital and annualized costs are presented in Table B-3.

B.1 MIST ELIMINATORS WITH MESH PADS IN SERIES.

The mist eliminators with mesh pads in series incorporate the use of a composite mesh pad in the design. It consists of a double set of chevron blades followed by three mesh pads in series.

Vendor C provided cost data for mist eliminators with mesh pads in series based on the model plant information presented in Table B-1.[9] Table B-4 presents the capital cost estimates. Vendor C also provided operating parameters (e.g., fan and washdown water pump horsepower requirements, washdown frequency, water consumption rates, maintenance hours, and the life expectancy of the units) that were used to calculate annualized costs.[9]

B.1.1 Unit Costs

This section presents estimates of installed capital and annualized costs for the two different sizes of mist eliminators with mesh pads in series specified in the model plants.

B.1.1.1 Capital Costs. Table B-5 presents capital costs for the two different sizes of mist eliminators with mesh pads in series specified in the model plants. As indicated in Table B-5, Unit A represents a design gas flow rate of 340 m^3/min (12,000 ft^3/min), and Unit B represents a design gas flow rate of 990 m^3/min (35,000 ft^3/min). The capital costs include (1) the purchased cost of the control device and cost for auxiliaries such as inlet and outlet transition zones, exhaust fans and motors, and stack; (2) direct installation costs for erection, electrical panels and wiring, instrumentation and controls, and piping; and (3) startup costs. Installation costs are based on the assumption that no major structural modifications are necessary. The purchased equipment cost includes taxes and freight costs, which are assumed to be 3 and 5 percent of the base equipment cost, respectively.[3] The startup cost is assumed to be 1 percent of the purchased equipment cost.[3]

B.1.1.2 Annualized Costs. Table B-6 presents annualized costs for the two sizes of mist eliminators with mesh pads in series specified in the model plants. The annualized costs include direct operating costs such as utilities; labor and maintenance materials; mesh-pad replacement; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs.

Utility costs include the costs of electricity and water required to operate the mist eliminators with mesh pads in series. The increase in annual electrical cost results from the additional horsepower needed by the fan to overcome the pressure drop added to the ventilation system by the control device. The incremental fan electrical costs were calculated based on the following equation:

Fan electrical cost, \$/yr = [(0.746 kW/hp)(hp)(t)](c)

where:

kW = kilowatt

hp = horsepower requirement

t = operating time, hr/yr

c = electrical cost, \$0.0461/kWh[6]

Water consumption costs are associated with the washdown of the chevron blades and mesh pads. The chevron blades are washed down every 8 hours. The mist eliminator with mesh pads in series consists of three pads. Each pad is washed down at different time intervals. Pad 1 is washed down every 8 hours; pad 2 is washed down every 24 hours; and pad 3 is washed down every 120 hours. The amount of washdown water required is equal to the sum of washdown water required for the chevron blades and each pad.

The washdown water is assumed to be supplied through the main water source for the plant. Typically, the main source of water can provide adequate pressure to wash down the mist eliminator. The water costs were calculated using the following equation:

$$\text{Water cost, \$/yr} = [(V)(F)_{\text{chevron blade}}(S)](C) + [(V)(F)_{\text{pad 1}}(S)](C) + [(V)(F)_{\text{pad 2}}(S)](C) + [(V)(F)_{\text{pad 3}}(S)](C)$$

where:

V = volume of water per washdown, L (gal)

F = frequency of washdown, No. of times/8-hr shift

S = number of 8-hour shifts per year, No./yr

C = water cost, \$0.20/1,000 L (\$0.77/1,000 gal)[7]

The costs of replacement mesh pads were included in the annualized costs because the life expectancy of these materials is less than the life expectancy of the control device. The life expectancy of the mesh pads is 5 years and the replacement cost of the pads is \$6,710 m^3 (190/ft^3). Annualized mesh pad replacement costs include the actual replacement costs as well as the disposal and transportation costs associated with the used materials. The replacement costs of the pads were calculated based on the following equation:

$$\text{Replacement costs, \$/yr} = [(V)(C)(CRF_m)]$$

where:

V = volume of mesh pad material per unit, m^3 (ft^3)

C = cost of mesh pads, \$/m^3 (\$/ft^3)

CRF_m = capital recovery factor of 0.264, based on an interest rate of 10 percent and a depreciable life of 5 years for the mesh pads

The disposal and transportation costs for the used pads were calculated as follows:

$$\text{Disposal and transportation costs, \$/yr} = [(N)(dc + tc)(CRF_m)]$$

where:

N = number of 55-gal drums, V/Vd, rounded to the next higher whole number

V = volume of mesh pad material disposed for each control device assuming 50 percent compaction, m^3 (ft^3)

Vd = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3)

dc = disposal cost, \$50.00 + 10 percent tax/drum[5]

tc = transportation cost, \$40.000/drum[5]

CRF_m = capital recovery factor of 0.264, based on an interest rate of 10 percent and a depreciable life of 5 years for the mesh pad

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 an assumption that it requires 0.5 hour per day for the operator to perform routine maintenance and turn the control device on and off. The labor rate was assumed to be $8.37/hour.[1,2] The operator labor is independent of control device size and number of operating hours per day. The supervisor labor cost is assumed to be 15 percent of the operator labor cost.[3]

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 operation and a maintenance labor rate of $9.21/hour.[1,2] Maintenance labor is independent of the control device size. The annual cost of maintenance materials is assumed to be 100 percent of the maintenance labor cost.[3]

Indirect costs include overhead, property taxes, insurance, and administration. The overhead cost was calculated based on 60 percent of the sum of the operator, supervisor, and maintenance labor plus any material costs.[3] Property taxes, insurance, and administration were collectively assumed to be 4 percent of the total capital cost.[3]

Capital recovery costs associated with the mesh-pad mist eliminator unit(s) were calculated using the following equation:[3]

$$CRC = [TCC][(i\{1+i\}^n)/(\{1+i\}^n-1)]$$

where:

CRC = capital recovery cost, $/yr

TCC = total capital cost of control device(s), $

i = annual interest rate, 10 percent

n = depreciable life, 10 years[9]

B.1.2 Model Plant Costs

This section presents the installed capital and annualized costs of applying mist eliminators with mesh pads in series to small, medium, and large hard chromium plating model plants. Model plant costs were compiled for new and existing plants. The capital costs for ventilation hoods and ductwork were not included in the capital costs for control devices because plants must typically install ventilation hoods and ductwork to comply with occupational health standards that regulate employee exposure to chromium emissions in the workplace.

B.1.2.1 New Facility Costs

B.1.2.1.1 Model plant capital costs. Table B-7 presents the purchased equipment, installation, startup, and total capital costs of mist eliminators with mesh pads in series for the hard chromium plating model plants. The capital cost estimates were compiled from Table B-5 as described below.

Small model plant = Column A costs
Medium model plant = Column B costs
Large model plant = 2(Column B) costs

B.1.2.1.2 Model plant annualized control costs. The annualized costs for the model plants are presented in Table B-8. The annualized cost estimates, with the exception of the labor requirements, indirect costs, and chromic acid recovery credits, were compiled from Table B-6 as described below.

Small model plant = Column A costs
Medium model plant = Column B costs
Large model plant = 2 (Column B) costs

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 for each additional control device, instead of increasing the labor requirement by 100 percent. For example, for the model large hard chromium plating plant, which requires a total of two control devices, the operator and maintenance labor requirement was calculated as follows:

Operator and maintenance labor, \$/yr = 4,740 + (0.3)(4,740) = \$6,160
[instead of (2)(4,740) = \$9,480]

The maintenance material cost, which is based on 100 percent of the maintenance labor for each control device, was assumed to increase 100 percent for each additional control device for the model plants and can be computed from Table B-6.

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, supervisor, and maintenance labor plus the material costs for each model plant. The property taxes, insurance, and administration are equal to 4 percent of the total capital cost for each model plant. For example, for the model large hard chromium plating plant, the indirect costs were calculated as follows:

overhead — taxes, ins., adm.

Indirect costs, \$/yr = 0.60[(1.3)(\$4,740)+2(\$4,140)]+[0.04(\$143,600)]
= \$8,700 + \$5,700 = \$14,400

The chromic acid recovery credits are calculated based on the estimated removal efficiency for mist eliminators with mesh pads in series and 100 percent recovery of the chromic acid captured by the control device. 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)

C = cost of chromic acid (CrO_3), \$3.28/kg (\$1.49/lb)[8]

B.1.2.2 Existing Facilities Costs. Retrofit costs for each model plant include costs for ductwork modifications and for removal and disposal of existing control devices. Actual retrofit costs will vary and depend on site specific factors such as plant layout, control device configuration, and adequacy of existing fan capacity. The retrofit cost estimates presented here are believed to be representative of expenditures that existing facilities would incur.

B.1.2.2.1 Model plant retrofit capital costs. Based on information from vendors of scrubbers and mist eliminators (chevron-blade and mesh-pad), the average increase in the total capital cost to retrofit an existing facility is 25 percent.[13] Therefore, the estimated retrofit capital costs of mesh-pad mist eliminator units for model small, medium, and large plants are \$34,000, \$89,800, and \$179,500, respectively.

B.1.2.2.2 Model plant retrofit annualized costs. Total annualized retrofit costs of mesh-pad mist eliminator units for each model hard chromium plating plant are shown in Table B-9. The annualized retrofit costs are the same as the annualized costs of a new control system except for the capital recovery costs and indirect costs, because these costs are a function of the installed capital cost. Capital recovery costs for a retrofit situation are higher because the installed capital costs for retrofit control systems are 25 percent higher than those for new systems. Indirect costs include overhead, taxes, insurance, and administration. Taxes, insurance, and administration are based on 4 percent of the capital costs; thus, these costs are also higher for retrofit than for new facilities.

B.2. PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEM

Capital cost estimates for the packed-bed scrubber/mesh-pad mist eliminator systems applied to two model plants were obtained from two control device vendors (designated as Vendors A and C).[4,10,14] Table B-10 presents the capital cost estimates from both vendors. The vendors also provided operating parameters (e.g., fan and recirculation pump motor horsepower requirements, water consumption rates, and operator and maintenance hours that were used to calculate annualized costs. The costs presented here are based on Vendor A's estimates only because they are more comprehensive than Vendor C's estimates. Vendor C's installation costs are significantly lower than Vendor A's installation costs, which are consistent with previous estimates for other control devices. A mesh pad useful life of 3 years was assumed by Vendor A and a life of 10 years was estimated by Vendor C. For purposes of this analysis, a life of 5 years was considered to be realistic.

Model plant capital costs based on Vendor C's estimates are $25,000 to $62,000 lower than costs based on Vendor A's estimates. Model plant annualized costs based on Vendor C's estimates are $9,000 to $26,000 lower than costs based on Vendor A's estimates.

B.2.1 Unit Costs

This section presents the installed capital and annualized cost estimates for the two different sizes of packed-bed scrubber/mesh-pad mist eliminator systems specified in the model plants.

B.2.1.1 Capital Costs. Table B-11 presents the capital costs for the two different sizes of packed-bed scrubber/mesh-pad mist eliminator systems specified in the model plants. As indicated in Table B-11, Unit A represents a design gas flow rate of 340 m^3/min (12,000 ft^3/min), and Unit B represents a design gas flow rate of 990 m^3/min (35,000 ft^3/min). The capital costs include the purchase cost of the control device and auxiliaries such as inlet and outlet transition zones, exhaust fans and motors, recirculation tank, recirculation pump and motor, packing material, mesh pads, and stack; direct installation costs for erection, electrical panels and wiring, instrumentation and controls, and piping; and startup costs. Installation costs are based on the assumption that no major structural modifications are necessary. The purchased equipment cost also includes taxes and freight costs, which are assumed to be 3 and 5 percent of the base equipment cost, respectively.[3] The startup cost is assumed to be 1 percent of the purchased equipment cost.[3]

B.2.1.2 Annualized Costs. Table B-12 presents the annualized costs for the two different sizes of packed-bed scrubber/mesh-pad mist eliminator systems specified in the model plants. The annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and materials; packing material and mesh pad replacement; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs.

Utility costs include the costs of electricity and water required to operate the packed-bed scrubber/mesh-pad mist eliminator system. The annual electrical cost results from the additional horsepower needed to operate the fan motor to overcome the pressure drop added to the ventilation system by the control device and the horsepower needed to operate the scrubber recirculation pumps. The incremental fan and recirculation pump electrical costs were calculated using the following equation:

$$\text{Electrical cost, \$/yr} = [(0.746\ \text{kW/hp})(\text{hp})_f(t)](c) + [(0.746\ \text{kW/hp})(\text{hp})_p(t)](c)$$

where,

kW = kilowatt

$(\text{hp})_f$ = incremental horsepower of fan motor

$(\text{hp})_p$ = horsepower requirement of pump motor

t = operating time, hr/yr

c = electrical cost, $0.0461/kWh[6]

Water consumption costs were calculated based on the assumption that scrubber water is 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. The water costs were calculated using the following equation:

$$\text{Water cost, \$/yr} = [(v)(f) + (FR)(60\ \text{min/hr})(t)](c)$$

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

c = water cost, $0.20/1,000 L ($0.77/1,000 gal)[7]

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 per day and a labor rate of $8.37/hour.[1,2] Based on vendor estimates, the operator labor is independent of both the control device size and the number of operating hours per day because the amount of time required to inspect and startup 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.[3]

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 operation and a maintenance labor rate of $9.21/hour.[1,2] Based on vendor estimates, the 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 annual cost of maintenance materials is assumed to be 100 percent of the maintenance labor cost.[3]

The costs of replacement packing and mesh pad materials were included in the annualized costs because the life expectancy of these materials is less than the life expectancy of the control device. The life expectancy of the packing is 10 years and the replacement cost of the packing material is \$640/m^3 (\$18/ft^3). The life expectancy of the mesh pads is 5 years and replacement costs are \$9,700 for the 12,000 ft^3/min unit and \$15,500 for the 35,000 ft^3/min unit.[4] Annualized packing and mesh pad replacement costs include the replacement costs as well as the disposal and transportation costs associated with the used materials. The replacement costs of the packing for the packed-bed scrubber were calculated based on the following equation:

$$\text{Replacement costs, \$/yr} = [(N)(C)(V)(CRF_p)]$$

where:

N = number of beds per unit

C = cost of packing, \$/m^3 (\$/ft^3)

V = volume of packing in each bed, m^3 (ft^3)

CRF_p = capital recovery factor of 0.163, based on an interest rate of 10 percent and a depreciable life of 10 years for the packing

The replacement costs of the mesh pads were calculated using the following equation:

$$\text{Replacement costs, \$/yr} = [(N)(C)(CRF_m)]$$

where:

N = number of mesh pads

C = cost of each mesh pad, \$/pad

CRF_m = capital recovery factor of 0.264, based on an interest rate of 10 percent and a depreciable life of 5 years for the mesh pads

The disposal and transportation costs for the used packing and mesh pad materials were calculated as follows:

Disposal and transportation costs, \$/yr = [(N)(dc + tc)(CRF)]

where:

N = number of 55-gal drums, V/Vd, rounded to the next higher whole number

V = volume of packing or mesh pad material disposed for each control device assuming 50 percent compaction, m^3 (ft^3)

Vd = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3)

dc = disposal cost, \$50.00 + 10 percent tax/drum[5]

tc = transportation cost, \$40.00/drum[5]

CRF_p = capital recovery factor of 0.163 for scrubber packing, based on an interest rate of 10 percent and a depreciable life of 10 years

CRF_m = capital recovery factor of 0.264 for mesh pads, based on an interest rate of 10 percent and a depreciable life of 5 years

Indirect costs include overhead, property taxes, insurance, and administration. The overhead cost was calculated based on 60 percent of the sum of the operator, supervisor, and maintenance labor plus any material costs.[3] Property taxes, insurance, and administration were collectively assumed to be 4 percent of the total capital cost.[3]

Capital recovery costs associated with the packed-bed scrubber/mesh-pad unit(s), which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[3]

$$CRC = [TCC][(i\{1+i\}^n)/(\{1+i\}^n-1)]$$

where,

CRC = capital recovery cost, \$/yr

TCC = total capital cost of control device(s), $

i = annual interest rate, 10 percent

n = depreciable life, 20 yr

B.2.2. Model Plant Costs

This section presents the installed capital and annualized costs of applying packed-bed scrubber/mesh-pad mist eliminator systems to model small, medium, and large hard chromium plating plants. Model plant costs were compiled for new and existing plants. The capital costs for ventilation hoods and ductwork were not included in the capital costs for control devices because plants must typically install ventilation hoods and ductwork to comply with occupational health standards that regulate employee exposure to chromium emissions in the workplace.

B.2.2.1 New Facility Costs

B.2.2.1.1. Model plant capital costs. Table B-13 presents the purchased equipment, installation, startup, and total capital costs of packed-bed scrubber/mesh-pad mist eliminator systems for the hard chromium plating model plants. The capital cost estimates were compiled from Table B-11 as described below.

Small model plant = Column A costs

Medium model plant = Column B costs

Large model plant = 2 (Column B costs)

B.2.2.1.2. Model plant annualized control costs. The annualized costs for the model plants are presented in Table B-14. The annualized cost estimates, with the exception of the labor requirements, indirect costs, and chromic acid recovery credits, were compiled from Table B-12 as described below.

Small model plant = Column A costs

Medium model plant = Column B_1 costs

Large model plant = 2 (Column B_2 costs)

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 for each additional control device, instead of increasing the labor requirement by 100 percent. For example, for the model new large hard chromium plating plant, which requires a total of two control devices, the operator and maintenance labor requirement was calculated as follows:

Operator and maintenance labor, \$/yr = 3,010 + (0.3)(3,010) = \$3,910 [instead of (2)(3,010) = \$6,020]

The maintenance material cost, which is based on 100 percent of the maintenance labor for each control device, was assumed to increase 100 percent for each additional control device for the model plants and can be computed from Table B-12.

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, supervisor, and maintenance labor plus the material costs for each model plant.[3] The property taxes, insurance, and administration are equal to 4 percent of the total capital cost for each model plant. For example, for the model new large hard chromium plating plant, the indirect costs were calculated as follows:

```
                                        overhead                taxes, ins., adm
Indirect costs, $/yr = 0.60[(1.3)($3,010) + 2($1,800)] + [0.04($195,600)]
  = $4,510 + $7,820 = $12,330
```

The chromic acid recovery credits are calculated based on the estimated removal efficiency for the packed-bed scrubber/mesh-pad mist eliminator system and 100 percent recovery of the chromic acid captured by the control device. 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)

c = cost of chromic acid (CrO_3), \$3.28/kg (\$1.49/lb)[8]

The chromic acid recovery credits shown in Tables B-14 and B-15 are based on a control efficiency of 99.8 percent.

B.2.2.2 Existing Facility Costs. The retrofit costs for each model plant include costs for ductwork modifications and for removal and disposal of existing control devices. Actual retrofit costs will vary and depend on the particular facility, its layout, and present control level. Based on site visit information on the plant layout and location of the existing control devices, the retrofit cost estimates presented here are believed to be representative of expenditures that existing facilities would incur.

B.2.2.2.1 Model plant retrofit capital costs. Based on information from control device vendors of scrubbers and mist eliminators (chevron-blade and mesh-pad), the average increase in the total capital cost to retrofit an existing facility was 25 percent.[13] Therefore, the estimated retrofit capital costs of packed-bed scrubber/mesh-pad mist eliminator systems for the model small, medium, and large plants are \$72,600, \$122,200, and \$244,500, respectively.

B.2.2.2.2 Model plant retrofit annualized costs. Total annualized retrofit costs of packed-bed scrubber/mesh-pad mist eliminator systems for each model hard chromium plating plant are shown in Table B-15. The annualized retrofit costs are the same as the annualized costs of a new control system except for the capital recovery costs and indirect costs, because these costs are a function of the installed capital cost. Capital recovery costs for a retrofit situation are higher than those for new systems because the installed capital costs for retrofit control systems are 25 percent higher than those for new systems. Indirect costs include overhead, taxes, insurance, and administration. Taxes, insurance, and administration are based on 4 percent of the capital costs; thus, these costs are also higher for retrofit than for new facilities.

B.3 FIBER-BED MIST ELIMINATOR

Cost data for fiber-bed mist eliminators were obtained from two vendors. Table B-16 presents capital cost estimates provided by these vendors. Estimates of total installed capital costs were obtained for the two different sizes of fiber-bed mist eliminators specified in the model plants from CECO Filters, Inc. (CECO).[11] CECO also provided information on operating parameters (e.g., fan motor horsepower requirements, water consumption rates, operator and maintenance hours, and the life expectancy of the control device and fiber elements) that were used to calculate annualized costs.[11,12] The second vendor, Monsanto Enviro-Chem (Monsanto), also provided cost data on fiber-bed mist eliminators.[15] However, because Monsanto only sells the fiber-bed mist eliminators and is not involved in the installations, incomplete cost information was obtained. Therefore, the cost estimates provided here are based on CECO estimates only since they were comparable to the capital cost estimates that were provided by Monsanto.

B.3.1 Unit Costs

This section presents the installed capital and annualized cost estimates for the two different sizes of fiber-bed mist eliminators specified in the model plants.

B.3.1.1 Capital Costs. Table B-17 presents capital cost estimates for the two different sizes of fiber-bed mist eliminators specified in the model plants. As indicated in Table B-17, Unit A represents a design gas flow rate of 340 m^3/min (12,000 ft^3/min) and Unit B represents a design gas flow rate of 990 m^3/min (35,000 ft^3/min). The capital costs for fiber-bed mist eliminators include the purchase cost of the control device and auxiliaries such as exhaust fans, motors, inlet and outlet transitions, and stack; direct installation costs for electrical panels and wiring, instrumentation and controls, and piping; modification costs associated with the modification of the existing ventilation system; indirect costs for erection, engineering services, contractor fees, and contingencies; and startup costs. Installation costs are based on the assumption that no major structural modifications are necessary. Modifications to the existing ventilation system will be required because fiber-bed mist eliminators must be installed on the ground beside the plating shop instead of on the roof due to the height and weight of the units. The cost to modify the existing ductwork is assumed to be 3 percent of the total purchased equipment cost, which is based on the ductwork cost for the original ventilation system. The purchased equipment cost also includes taxes and freight costs, which are assumed to be 3 and 5 percent of the base equipment costs, respectively.[3] The startup cost is assumed to be 1 percent of the purchase equipment cost.[3]

B.3.1.2 Annualized Costs. Table B-18 presents annualized costs for fiber-bed mist eliminators. The annualized costs include direct operating costs such as utilities; operator, supervisor, and maintenance labor and materials; fiber element replacement costs; indirect operating costs such as overhead, property taxes, insurance and administration; and capital recovery costs.

Utility costs include the costs of electricity and water required to operate fiber-bed mist eliminators. 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. The incremental fan electrical costs were calculated using the following equation:

$$\text{Electrical cost, \$/yr} = [(\frac{0.746 \text{ kW}}{\text{hp}})(\text{hp})(\text{t})](\text{c})$$

where:

kW = kilowatt

hp = incremental horsepower of fan motor

t = operating time, hr/yr

c = electrical cost, $0.0461 per kWh[6]

For example, the fiber-bed mist eliminator that is sized for an exhaust gas flow rate of 340 actual m^3/min (12,000 actual ft^3/min) requires an additional 30 hp to operate the fan, and the fiber-bed mist eliminator operates 2,000 hr/yr. Therefore, the annual electrical cost to operate the fan is:

$$[\frac{0.746 \text{ kW}}{\text{hp}}][30 \text{ hp}][2{,}000 \text{ hr/yr}][\frac{\$0.0461}{\text{kWh}}] = \$2{,}060\text{/yr}$$

Water consumption costs are associated with the washdown of the prefilter located before the mist eliminator and the fiber elements in the fiber-bed mist eliminator. For purposes of this analysis, it was assumed that water for washdown is recycled to the process. Water costs are calculated using the following equation:

$$\text{Water cost, \$/yr} = [(N)(S)(FR_{FB})(t_{FB}) + (FR_{PF})(60)(t_{PF})](C)$$

where:

N = No. of washdowns per 8-hr shifts

S = No. of 8-hr shifts per yr

FR_{FB} = water flow rate for fiber-bed section, L/min (gal/min)

t_{FB} = duration of washdown, min

FR_{PF} = water flow rate for prefilter, L/min (gal/min)
t_{PF} = operating time per year, hr/yr
C = water cost, $0.20/1,000 L ($0.77/1,000 gal)[7]

For example, for the fiber-bed mist eliminator used in the example above, the fiber elements are washed down once every 8 hours at a water flow rate of 2.6 L/min (0.7 gal/min) for 60 minutes, and the prefilter is sprayed continuously with water at a rate of 5.3 L/min (1.4 gal/min). The fiber-bed mist eliminator operates 2,000 hr/yr. Therefore, the annual water cost for this unit is:

[(1)(250) (0.7 gal/min) (60 min) + (1.4 gal/min) (60 min/h) (2,000 h/yr)] ($0.77/gal) = $140/yr

The total annual cost of utilities for the mist eliminator is equal to the sum of the electrical and water costs, which is $2,200/yr.

The cost of replacement fiber material was included in the annualized costs because the life expectancy of the fiber material is less than the life expectancy of the control device. The life expectancy of the fiber material is 5 years and the replacement cost of each fiber element is $3,000.[11] Annualized fiber material replacement costs include the replacement cost of the fiber material and the transportation and disposal costs associated with the used fiber material. The replacement costs of the fiber material were calculated based on the following equation:

Replacement costs, $/yr = [(N)(C)](CRF)

where:

N = No. of fiber elements per unit[11]
C = cost of fiber material, $3,000/element[11]
CRF = capital recovery factor of 0.264, based on an interest rate of 10 percent and a depreciable life of 5 years for the fiber elements

The transportation and disposal costs for the fiber material were calculated based on the following equation:

Disposal and transportation cost, \$/yr = [(N)(dc) + (N)(tc)] (CRF)

where:

N = No. of 55-gal drums, V/Vd, rounded up to the nearest whole number

V = volume of fiber material disposed for each control device compacted by 50 percent, m^3 (ft^3)

Vd = volume of 55-gal drum, 0.21 m^3 (7.35 ft^3)

dc = disposal cost, \$50.00/drum (plus 10 percent tax)[5]

tc = transportation cost, \$40.00/drum[5]

CRF = capital recovery factor of 0.264, based on an interest rate of 10 percent and a depreciable life of 5 years for the fiber material

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 per 2,000 hours of control device operation and a labor rate of \$8.37/hour.[1] The supervision labor cost is assumed to be 15 percent of the operator labor cost.[3]

The annual cost of maintenance labor for each control device is based on vendor estimates per 2,000 hours of control device operation and a maintenance labor rate of \$9.21/hour.[1,2] The annual cost of materials is assumed to be 100 percent of the maintenance labor cost.[3]

Indirect costs include overhead, property taxes, insurance, and administration. The overhead cost was calculated based on 60 percent of the operator, supervisor, and maintenance labor plus any material costs.[3] Property taxes, insurance, and administration were assumed to be 4 percent of the total capital cost.[3]

Capital recovery costs, which are the costs of capital spread over the depreciable life of the control device, were calculated using the following equation:[3]

$$CRC = [TCC][(i(1+i)^n/(1+i)^n-1)]$$

where:

CRC = capital recovery costs, \$/yr

TCC = total capital cost, \$

i = annual interest rate, 10 percent

n = depreciable life of unit, 20 years

B.3.2 Model Plant Costs

This section presents estimates of installed capital and annualized costs of applying fiber-bed mist eliminators to small, medium, and large hard chromium plating plants. Model plant costs were compiled for new and existing plants. The capital costs for ventilation hoods and ductwork are not included in the capital costs for control devices because plants must typically install ventilation hoods and ductwork to comply with occupational health standards that regulate employee exposure to chromium emissions in the workplace.

B.3.2.1 New Facility Costs

B.3.2.1.1 Model plant capital costs. Table B-19 presents the purchased equipment, installation, modification, startup, and total capital costs of fiber-bed mist eliminators for the hard chromium plating model plants. The capital cost estimates for the small and medium model plants are the same as the costs presented in Columns A and B, respectively, of Table B-17. The capital cost estimates for the large model plant are equal to two times the cost presented in Column B of Table B-17.

B.3.2.1.2. Model plant annualized control costs. The annualized costs associated with the use of fiber-bed mist eliminators for the hard chromium plating model plants are presented in Table B-20. The annualized cost estimates, with the exception of the labor requirements and indirect costs for the large model plant, were compiled from Table B-18 as follows: (1) the annualized costs for the small and medium model plants are the same as those presented in Columns A and B_1 respectively; and (2) the large model plant costs are equal to two times the costs presented in Column B_2.

The operator, supervisor, and maintenance labor requirements for the large model plant were calculated based on the assumption that the labor required to operate more than one control device increased the labor requirement by only 30 percent for each additional control device, instead of increasing the labor requirement by 100 percent. Therefore, the labor cost for the large model plant, which operates two control devices, was calculated as follows:

Operator and maintenance labor, \$/yr = (1.3) (\$7,220) + (1.3) (\$2,650) = \$12,800

The maintenance material cost, which is based on 100 percent of the maintenance labor for each control device, was assumed to increase 100 percent for the additional control device at the large model plant, and can be computed directly from Table B-18 as described above.

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 for each model plant. The property taxes, insurance, and administration are equal to 4 percent of the total capital cost for each model plant. Therefore, for the large model plant, the indirect costs were calculated as follows:

Indirect costs, \$/yr = 0.6 [1.3(9,870) + 2 (2,650)] + 0.04 [2 (234,600)] = \$10,880 + \$18,800 = \$29,600/yr

The chromic acid recovery credits are calculated based on the estimated removal efficiency for fiber-bed mist eliminators and 100 percent recovery of the chromic acid captured by the control device. 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, 99.8 percent

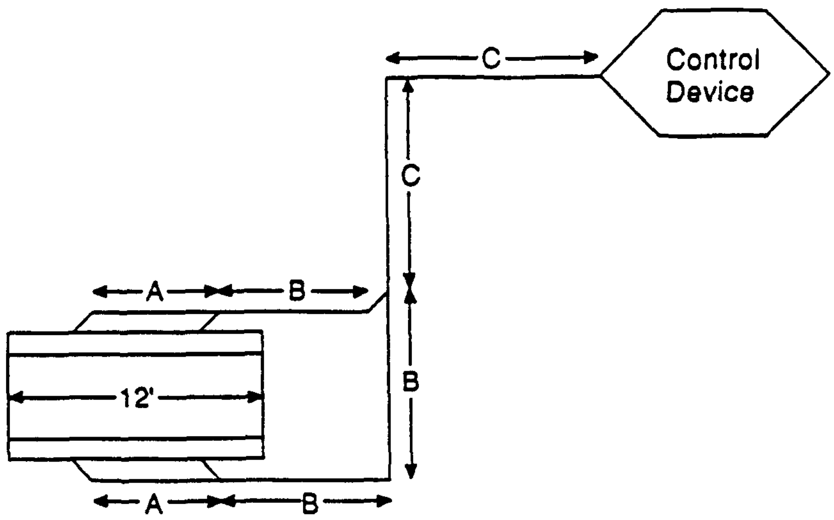
1.923 = ratio of chromic acid molecular weight (100) to hexavalent chromium molecular weight (52)

C = cost of chromic acid (CrO_3), \$3.28/kg (\$1.59/lb)[8]

B.3.2.2 <u>Existing Facilities Costs</u>. The retrofit costs for each model plant include costs for ductwork modifications and for the removal and disposal of existing control devices. Actual retrofit costs will vary and depend on the particular facility, its layout, and present control level. Based on site visit information on the plant layout and location of the existing control devices, the retrofit cost estimates presented here are believed to be representative of expenditures that existing facilities would incur.

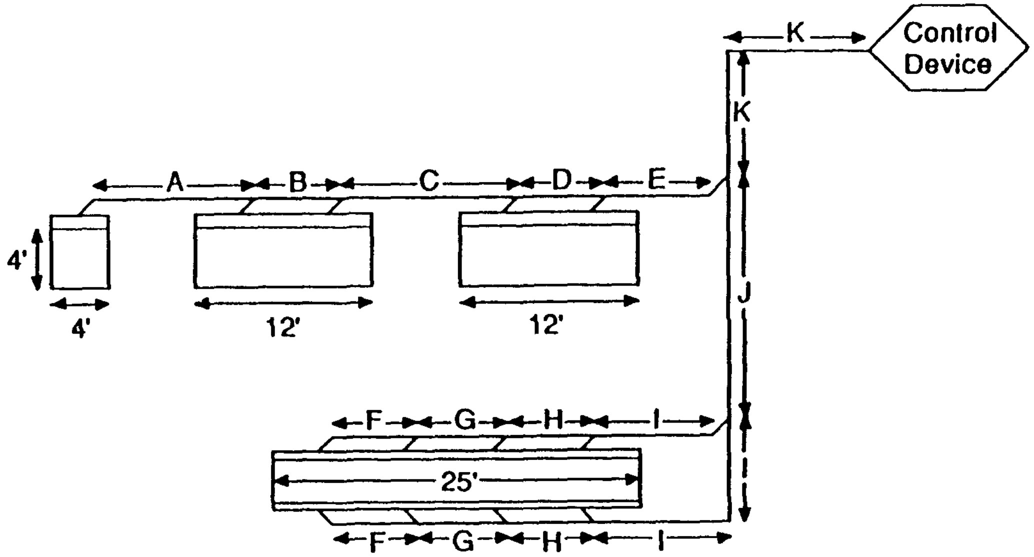
B.3.2.2.1 <u>Model plant retrofit capital costs</u>. Based on information from control device vendors of scrubbers and mist eliminators (chevron-blade and mesh-pad), the average increase in the total capital cost to retrofit an existing facility was 25 percent.[13] This corresponds to an 8 percent increase in the total capital cost for fiber-bed mist eliminators. Therefore, a 10 percent increase in the total capital cost for fiber-bed mist eliminators was used for calculating retrofit costs for the model plants. The estimated retrofit capital costs of fiber-bed mist eliminators for the small, medium, and large model plants are $129,400, $258,100, and $516,100, respectively.

B.3.2.2.2 Model plant retrofit annualized costs. Total annualized retrofit costs of fiber-bed mist eliminators for each hard chromium plating model plant are shown in Table B-21. The annualized retrofit costs are the same as the annualized costs of a new control system except for the capital recovery costs and indirect costs because these costs are a function of the installed capital cost. Capital recovery costs for a retrofit situation are higher because the installed capital costs for retrofit control systems are 10 percent higher than those for new systems. Indirect costs include overhead, taxes, insurance, and administration. Taxes, insurance, and administration are based on 4 percent of the capital costs; thus, these costs are also higher for retrofit than for new facilities.



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 B-1. Plan view and ductwork specifications for the small hard chromium plating model plants.



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 B-2. Plan view and ductwork specifications for the medium and large hard chromium model plants.

TABLE B-1. PARAMETERS FOR THE HARD CHROMIUM ELECTROPLATING MODEL PLANTS

	Plant Size		
Model operation	Small	Medium	Large
Operating time, hr/yr	2,000	3,500	6,000
Percent time electrodes energized, percent	70	70	80
Total ampere-hours per year, Ah/yr	5.0×10^6	42×10^6	160×10^6
Number 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)
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)
No. of control devices	1	1	2
Control device configuration	Figure B-1	Figure B-2	Figure B-2
Size of each control device, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	2 @ 990 (35,000)
Uncontrolled hexavalent chromium emission rate, kg/yr	50 (110)	420 (926)	1,600 (3,530)

TABLE B-2. ANNUAL OPERATING COST FACTORS FOR MESH-PAD MIST ELIMINATORS, PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS, AND FIBER-BED MIST ELIMINATORS

Cost categories	Cost factors
Direct operating costs	
1. Operating labor	
a. Operator[1,2]	$8.37/man-hr
b. Supervisor[3]	15 percent of 1a
2. Maintenance	
a. Labor[1-3]	$9.21/hr
b. Materials[4]	100 percent of 2a
3. Replacement parts, packing material	16.3 percent of the total replacement cost[a]
4. Replacement parts, mesh pads or fiber material	26.4 percent of the total replacement cost[b]
5. Transportation and disposal of used packing material and mesh pads[5]	$50/drum disposal (plus 10 percent tax) $40/drum transportation
6. Utilities	
a. Electricity[6]	$0.0461/kWh
b. Water[7]	$0.77/1,000 gal
Indirect operating costs	
7. Overhead[3]	60 percent of 1a + 1b + 2a + 2b
8. Property tax[3]	1 percent of capital cost
9. Insurance[3]	1 percent of capital cost
10. Administration[3]	2 percent of capital cost
11. Capital recovery[3]	11.7 percent of capital cost of packed-bed scrubber/mesh-pad mist eliminator system[c]
Credits	
Chromic acid recovery[8]	$3.28/kg

[a]Based on an interest rate of 10 percent and a scrubber packing life of 10 years.
[b]Based on an interest rate of 10 percent and a mesh-pad life of 5 years.
[c]Based on an interest rate of 10 percent and an equipment life of 20 years.

TABLE B-3. CAPITAL AND ANNUALIZED COST DATA SOURCES FOR MESH-PAD MIST ELIMINATORS, PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS, AND FIBER-BED MIST ELIMINATORS

Cost item	Source	Date	Ref.
A. Capital Costs			
1. Mesh-pad mist eliminator	Vendor C	October 1990	9
2. Extended packed-bed scrubber	Vendor A	October 1990	4, 10
3. Fiber-bed mist eliminator	CECO Filters, Inc.	September 1989	11, 12
B. Annualized Costs			
1. Electricity	Department of Energy	October 1988	6
2. Water	American Water Works Association	March 1989	7
3. Chromic acid	Ashland Chemical Company	June 1989	8
4. Labor			
a. Operator	Bureau of Labor Statistics	August 1988, January 1989	1, 2
b. Supervisor and maintenance	EPA/OAQPS/EAB	August 1988, January 1989	1, 2, 3
5. Replacement packing material and mesh pads	Vendor A, EPA/OAQPS/EAB	October 1990, February 1987	3, 4
6. Replacement fiber-bed material	CECO Filters, Inc.	September 1989	11
7. Transportation and disposal of old packing and mesh pads	Chemical Waste Management	April 1989	5
8. Overhead, property tax, insurance, administration	EPA/OAQPS/EAB	February 1987	3
9. Capital recovery	EPA/OAQPS/EAB	February 1987	3

TABLE B-4. CAPITAL COST ESTIMATES PROVIDED BY VENDOR C FOR MIST ELIMINATORS WITH MESH PADS IN SERIES (SEPTEMBER 1990 DOLLARS)[a]

Cost component	Airflow, m^3/min (ft^3/min)	
	340 (12,000)	990 (35,000)
1. Basic mist eliminator cost	15,700	38,850
2. Inlet and outlet transition	720	2,000
3. Fan and motor	5,430	22,180
4. Stack	1,430	2,340
5. Base equipment	23,280	65,370
6. Installation	2,660	2,980
7. Total capital cost	25,940	68,340

[a]All costs were rounded to the nearest $10.

TABLE B-5. CAPITAL COST ESTIMATES OF MIST ELIMINATORS WITH MESH PADS IN SERIES (November 1988 Dollars)

	Mesh-pad mist eliminator size	
	A	B
Control device parameters		
Design gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	990 (35,000)
Pressure drop, kPa (in. w.c.)	1.4 (5.5)	1.4 (5.5)
Fan static pressure, kPa (in. w.c.)[b]	1.4 (5.5)	1.4 (5.5)
Fan motor size, hp (kW)[c]	25 (18)	100 (73)
Cost data		
1. Basic mesh-pad mist eliminator	15,200	37,500
2. Inlet and outlet transitions	800	2,000
3. Fan and motor	5,200	21,400
4. Stack	1,400	2,300
5. Base equipment[d]	22,600	63,200
6. Sales taxes and freight[e]	1,810	5,060
7. Total purchased equipment[f]	24,410	68,260
8. Installation[g]	2,570	2,870
9. Startup[h]	240	680
10. Total capital cost[i]	27,200	71,800

[a]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).
[b]Static pressures are based on the ventilation specifications in Figures 1 and 2 and the pressure drop across the control device.
[c]Vendor C provided motor sizes based on the static pressures and gas flow rates specified above.
[d]Sum of 1 through 4.
[e]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.
[f]Sum of 5 and 6.
[g]Includes all costs associated with installing instrumentation, electrical components, and piping, erection and contingencies; and fee. Assumes that the installation requires no major structural modifications.
[h]One percent of total purchased equipment cost.
[i]Sum of 7, 8, and 9. Costs were rounded to nearest $100.

TABLE B-6. ESTIMATED ANNUALIZED COSTS OF MIST ELIMINATORS WITH MESH PADS IN SERIES (November 1988 Dollars)

	Mesh-pad mist eliminator size		
	A	B_1[a]	B_2[a]
Control device parameters			
Design gas flow rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	990 (35,000)
Operating hours, hr/yr	2,000	3,500	6,000
Incremental fan motor size, hp (kW)[b c]	15 (11)	60 (44)	60 (44)
Total water consumption per year, gal	48,800	85,470	146,280
Maintenance hours, hr/yr[b]	150	262.5	450
Operator labor hours, hr/yr[b]	62.5	62.5	62.5
Life expectancy of unit, yr[b]	10	10	10
Life expectancy of pad material, yr[b]	5	5	5
Cost data[d]			
1. Utilities	1,070	7,290	12,490
2. Operator, supervisor, and maintenance	1,980	3,020	4,740
3. Maintenance materials	1,380	2,420	4,140
4. Mesh-pad replacement[e]	1,780	4,790	4,790
5. Indirect costs[f]	3,110	6,130	8,200
6. Capital recovery	4,430	11,700	11,700
7. Total annualized costs[g]	13,800	35,400	46,100

[a]B_1 is based on a 990 m^3/min (35,000 ft^3/min) unit operating 3,500 h/yr; B_2 is based on the same size unit operating at 6,000 h/yr.
[b]Value of parameter provided by vendor.
[c]The incremental fan size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d]Annualized costs were calculated from the control device parameters provided by the vendor and the operating hours specified above. All costs are rounded to the nearest $10.
[e]Includes cost of mesh pad replacement and transportation and disposal of the used mesh pads with 50 percent compaction.
[f]Includes overhead, property tax, insurance, and administration.
[g]Sum of 1 through 6. Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE B-7. ESTIMATED CAPITAL COSTS OF MESH-PAD MIST ELIMINATOR UNITS FOR NEW AND EXISTING HARD CHROMIUM PLATING MODEL PLANTS[a] (November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Total purchased equipment (TPE)	24,400	68,300	136,500
Installation	2,600	2,900	5,700
Startup (1 percent of TPE)	200	700	1,400
Total capital cost (new)[c]	27,200	71,800	143,600
Total capital cost[d]	34,000	89,800	179,500

[a]All cost data were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs are two times medium model plant costs.
[c]Numbers may not add exactly due to independent rounding.
[d]Based on a 25 percent increase in total capital cost to retrofit an existing facility.

TABLE B-8. ESTIMATED ANNUALIZED COSTS OF MESH-PAD MIST ELIMINATOR UNITS FOR NEW HARD CHROMIUM PLATING MODEL PLANTS[a] (November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Utilities	1,100	7,300	25,000
Operator and maintenance labor[c]	2,000	3,000	6,200
Maintenance materials	1,400	2,400	8,300
Mesh-pad replacement[d]	1,800	4,800	9,600
Indirect costs[e]	3,100	6,100	14,400
Capital recovery	4,400	11,700	23,400
Annualized cost	13,800	35,400	86,800
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[g]	13,500	32,800	76,700

[a]All costs were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs (with the exception of operator and maintenance labor and indirect costs) are equal to two times medium model plant costs.
[c]Includes operator, supervisor, and maintenance labor.
[d]Includes costs of mesh pad replacement and transportation and disposal of old mesh pads with 50 percent compaction.
[e]Includes overhead, property taxes, insurance, and administration.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.
[g]Numbers may not add exactly due to independent rounding.

TABLE B-9. ESTIMATED ANNUALIZED COSTS OF MESH-PAD MIST ELIMINATOR UNITS FOR EXISTING HARD CHROMIUM PLATING MODEL PLANTS[a] (November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Utilities	1,100	7,300	25,000
Operator and maintenance labor[c]	2,000	3,000	6,200
Maintenance materials	1,400	2,400	8,300
Mesh-pad replacement[d]	1,800	4,800	9,600
Indirect costs[e]	3,400	6,900	15,900
Capital recovery	5,500	14,600	29,300
Annualized cost	15,200	39,000	94,200
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[g]	14,900	36,400	84,100

[a]All costs were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs (with the exception of operator and maintenance labor and indirect costs) are equal to two times medium model plant costs.
[c]Includes operator, supervisor, and maintenance labor.
[d]Includes costs of mesh pad replacement and transportation and disposal of old mesh pads with 50 percent compaction.
[e]Includes overhead, property taxes, insurance, and administration.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.
[g]Numbers may not add exactly due to independent rounding.

TABLE B-10. CAPITAL COST ESTIMATES PROVIDED BY VENDORS A AND C FOR PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS, (September 1990 Dollars)[a]

Cost component	Airflow, m^3/min (ft^3/min)			
	Vendor A		Vendor C	
	340 (12,000)	990 (35,000)	340 (12,000)	990 (35,000)
1. Basic extended packed-bed scrubber	16,300	32,880	14,260	36,760
2. Inlet and outlet transition zones	800	2,100	1,070	4,220
3. Fan and motor	10,500	17,600	5,870	16,430
4. Recirculation tank	800	1,200	3,850	6,920
5. Recirculation pump and motor	1,600	2,300	Included in tank cost	
6. Packing material	1,800	4,400	Included in basic cost	
7. Mesh pads	10,000	16,000	Included in basic cost	
8. Stack	1,400	2,600	1,430	2,340
9. Base equipment[b]	43,200	79,080	26,470	66,670
10. Installation	13,000	15,000	2,570	2,980
11. Total capital cost[b]	56,200	94,080	29,040	69,650

[a]All costs were rounded to the nearest $10.
[b]Numbers may not add exactly due to independent rounding.

TABLE B-11. CAPITAL COST ESTIMATES OF PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEM (VENDOR A) (November 1988 Dollars)

	Packed-bed scrubber/mesh-pad unit size	
	A	B
Control device parameters		
Design gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	990 (35,000)
Pressure drop, kPa (in. w.c.)	1.7 (6.8)	1.7 (6.8)
Fan static pressure, kPa (in. w.c.)[b]	2.2 (8.8)	2.8 (11.3)
Fan motor size, hp (kW)[c]	30 (22)	100 (75)
Amount of packing, m^3 (ft^3)	2.3 (80)	6.7 (236)
Amount of mesh pad material, m^3(ft^3)	1.1 (40)	3.3 (118)
Cost data		
1. Basic extended packed-bed scrubber	27,140	51,450
2. Inlet and outlet transitions	770	2,030
3. Fan and motor	10,140	17,000
4. Recirculation tank	770	1,160
5. Recirculation pump and motor	1,540	2,220
6. Stack	1,350	2,510
7. Base equipment[e]	41,710	76,370
8. Sales taxes and freight[f]	3,340	6,110
9. Total purchased equipment[g]	45,050	82,480
10. Installation[h]	12,550	14,480
11. Startup[i]	450	820
12. Total capital cost[j]	58,100	97,800

[a]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).
[b]Static pressures are based on the ventilation specifications in Figures 1 and 2 and the pressure drop across the control device.
[c]Vendor A provided motor sizes based on the static pressures and gas flow rates specified above.
[d]All costs are rounded to the nearest $10.
[e]Sum of 1 through 6.
[f]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.
[g]Sum of 7 and 8.
[h]Includes all costs associated with installing instrumentation, electrical components, and piping, erection and contingencies; and fee. Assumes that the installation requires no major structural modifications.
[i]One percent of total purchased equipment cost.
[j]Sum of 9, 10, and 11. Costs were rounded to nearest $100.

TABLE B-12. ANNUALIZED COSTS OF PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEM (VENDOR A) (November 1988 Dollars)

	Packed-bed scrubber/mesh-pad unit size		
	A	B_1[a]	B_2[a]
Control device parameters			
Design gas flow rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	990 (35,000)
Operating hours, hr/yr	2,000	3,500	6,000
Incremental fan motor size, hp (kW)[b c]	20 (15)	60 (44)	60 (44)
Volume of remote recirculation tank, L (gal)[b]	760 (200)	1,890 (500)	1,890 (500)
Recirculation pump motor, hp (kW)[b]	3 (2.2)	7.5 (5.6)	7.5 (5.6)
Maintenance hours, hr/yr[b]	50	110	195
Operator labor hours, hr/yr[b]	125	125	125
Life expectancy of unit, yr	20	20	20
Life expectancy of packing material, yr	10	10	10
Life expectancy of mesh pads, yr	5	5	5
Cost data[d]			
1. Utilities	1,640	8,310	14,260
2. Operator, supervisor, and maintenance	1,670	2,260	3,010
3. Maintenance materials	460	1,050	1,800
4. Packing material replacement[e]	330	950	950
5. Mesh pad replacement[e]	2,720	4,430	4,430
6. Indirect costs[f]	3,600	5,900	6,800
7. Capital recovery	6,860	11,540	11,540
8. Total annualized costs[g]	17,300	34,400	42,800

[a]B_1 is based on a 990 m^3/min (35,000 ft^3/min) unit operating 3,500 h/yr; B_2 is based on the same size unit operating at 6,000 h/yr.
[b]Value of parameter provided by Vendor A.
[c]The incremental fan size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d]Annualized costs were calculated from the control device parameters provided by the vendor and the operating hours specified above. All costs are rounded to the nearest $10.
[e]Includes cost of replacement and transportation and disposal of the used packing and mesh pads with 50 percent compaction.
[f]Includes overhead, property tax, insurance, and administration.
[g]Sum of 1 through 7. Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE B-13. ESTIMATED CAPITAL COSTS OF PACKED-BED SCRUBBER MESH-PAD MIST ELIMINATOR SYSTEMS FOR NEW AND EXISTING HARD CHROMIUM PLATING MODEL PLANTS (VENDOR A)[a]
(November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Total purchased equipment (TPE)	45,100	82,500	165,000
Installation	12,600	14,500	29,000
Startup (1 percent of TPE)	500	800	1,600
Total capital cost (new)[c]	58,100	97,800	195,600
Total retrofit capital cost[d]	72,600	122,200	244,500

[a]All cost data were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs are two times medium model plant costs.
[c]Numbers may not add exactly due to independent rounding.
[d]Based on a 25 percent increase in total capital cost to retrofit an existing facility.

TABLE B-14. ESTIMATED ANNUALIZED COSTS OF PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS FOR NEW HARD CHROMIUM PLATING MODEL PLANTS (VENDOR A)[a]
(November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Utilities	1,600	8,300	28,500
Operator and maintenance labor[c]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing material replacement[d]	300	1,000	1,900
Mesh pad replacement[d]	2,700	4,400	8,900
Indirect costs[e]	3,600	6,000	12,300
Capital recovery	6,900	11,500	23,100
Annualized cost[g]	17,300	34,400	82,200
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[g]	17,000	31,800	72,100

[a]All cost data were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs (with the exception of operator and maintenance labor and indirect costs) are equal to two times medium model plant costs.
[c]Includes operator, supervisor, and maintenance labor.
[d]Replacement costs include the cost associated with purchasing new material and transportation and disposal of old material with 50 percent compaction.
[e]Includes overhead, property taxes, insurance, and administration.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.
[g]Numbers may not add exactly due to independent rounding.

TABLE B-15. ESTIMATED ANNUALIZED COSTS OF PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS FOR EXISTING HARD CHROMIUM PLATING MODEL PLANTS (VENDOR A)[a]
(November 1988 Dollars)

	Model plant size[b]		
	Small	Medium	Large
Cost data			
Utilities	1,600	8,300	28,500
Operator and maintenance labor[c]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing material replacement[d]	300	1,000	1,900
Mesh pad replacement[d]	2,700	4,400	8,900
Indirect costs[e]	4,200	6,900	14,300
Capital recovery	8,600	14,400	28,900
Annualized cost[g]	19,600	38,300	90,100
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[g]	19,300	35,700	80,000

[a]All cost data were rounded to the nearest $100.
[b]Small model plant costs are based on a unit with a 340 m^3/min (12,000 ft^3/min) gas flow rate; medium model plant costs are based on a unit with a 990 m^3/min (35,000 ft^3/min) gas flow rate; large model plant costs (with the exception of operator and maintenance labor and indirect costs) are equal to two times medium model plant costs.
[c]Includes operator, supervisor, and maintenance labor.
[d]Replacement costs include the cost associated with purchasing new material and transportation and disposal of old material with 50 percent compaction.
[e]Includes overhead, property taxes, insurance, and administration.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.
[g]Numbers may not add exactly due to independent rounding.

TABLE B-16. CAPITAL COST ESTIMATES PROVIDED BY MONSANTO ENVIRO-CHEM AND CECO FILTERS, INC., FOR FIBER-BED MIST ELIMINATORS (1989 DOLLARS)

	12,000 acfm		35,000 acfm	
	Monsanto	CECO	Monsanto	CECO
1. Basic fiber-bed mist eliminator cost	40,000-69,000	66,000	114,000-190,000	141,000
2. Basic cost for prefilter	Not supplied	Included in 1.	Not supplied	Included in 1.
3. Inlet and outlet transition zones	Not supplied	Included in 1.	Not supplied	Included in 1.
4. Fan and motor	Not supplied	10,000	Not supplied	15,000
5. Stack	Not supplied	2,000	Not supplied	3,000
6. Base equipment	40,000-69,000 + costs for 2-5	78,000	114,000-190,000 + costs for 2-5	159,000
7. Installation	Not supplied	30,000	Not supplied	56,000
8. Total capital cost	40,000-69,000 + costs for 2-5 and 7	108,000	114,000-190,000 + costs for 2-5 and 7	215,000

TABLE B-17. ESTIMATED CAPITAL COSTS FOR FIBER-BED MIST ELIMINATORS

	Fiber-bed mist eliminator size	
	A	B
Control device parameters		
Design gas flow rate, m^3/min (ft^3/min)[a]	340 (12,000)	990 (35,000)
Pressure drop, kPa (in. w.c.)	1.5-2.0 (6-8)	1.5-2.0 (6-8)
Fan static pressure, kPa (in. w.c.)[b]	2.0-2.5 (8-10)	2.6-3.1 (10.5-12.5)
Fan motor size, hp (kW)[c]	40 (30)	125 (93)
Cost data		
1. Basic fiber-bed mist eliminator	66,000	141,000
2. Inlet and outlet transitions	Included in 1	Included in 1
3. Fan and motor	10,000	15,000
4. Stack	2,000	3,000
5. Base equipment[d]	78,000	159,000
6. Sales taxes and freight[e]	6,240	12,720
7. Total purchased equipment[f]	84,240	171,720
8. Installation[g]	30,000	56,000
9. Modification[h]	2,500	5,200
10. Startup[i]	840	1,720
11. Total capital cost[j]	117,600	234,600

[a]Gas stream temperature is 27°C (80°F), gas stream moisture content is 2 percent, and altitude is 305 m (1,000 ft).
[b]Static pressures are based on the ventilation specifications in Figures 1 and 2 and the pressure drop across the control device.
[c]CECO Filters, Inc., provided motor sizes based on the static pressures and gas flow rates specified above.
[d]Sum of 1 through 4.
[e]Sales taxes and freight costs are 3 and 5 percent, respectively, of base equipment costs.
[f]Sum of 5 and 6.
[g]Includes all costs associated with installing instrumentation, electrical components, and piping, erection and contingencies; and fee. Assumes that the installation requires no major structural modifications.
[h]Modification costs are the costs associated with modifying the existing ventilation system.
[i]One percent of total purchased equipment cost.
[j]Sum of 7, 8, 9, and 10. Costs were rounded to nearest $100.

TABLE B-18. ANNUALIZED COSTS OF FIBER-BED MIST ELIMINATORS

	Fiber-bed mist eliminator size		
	A	B_1[a]	B_2[a]
Control device parameters			
Design gas flow rate, m^3/min (ft^3/min)	340 (12,000)	990 (35,000)	990 (35,000)
Operating hours, hr/yr	2,000	3,500	6,000
Incremental fan motor size, hp (kW)[b c]	30 (22)	85 (63)	85 (63)
No. of fiber elements[b]	4	12	12
Dimensions of fiber elements, (h,d,rt) m (ft)[b]	6.1, 0.61 0.05 (20.0, 2, 0.17)	6.1, 0.61, 0.05 (20.0, 2, 0.17)	6.1, 0.61 0.05 (20.0, 2, 0.17)
Frequency of washdown, No./8-hr[b]	1	1	1
Duration of washdown, min[b]	60	60	60
Washdown water flowrate, L/min (gal/min)[b]	2.6 (0.7)	7.6 (2.0)	7.6 (2.0)
Washdown of prefilter (continuous), L/min (gal/min)[b]	5.3 (1.4)	23.7 (6.25)	23.7 (6.25)
Maintenance hours, hr/yr[b]	64	168	288
Operator labor hours, hr/yr[b]	250	438	750
Life expectancy of unit, yr[b]	20	20	20
Life expectancy of fiber elements, yr[b]	5	5	5
Cost data[d]			
1. Utilities	2,200	11,280	19,340
2. Operator and maintenance labor[e]	2,990	5,760	9,870
3. Maintenance materials	590	1,550	2,650
4. Fiber element replacement[f]	3,320	9,920	9,920
5. Indirect costs[g]	6,850	13,770	16,890
6. Capital recovery	13,760	27,450	27,450
7. Total annualized costs[h]	29,700	69,700	86,100

[a] B_1 is based on a 990 m^3/min (35,000 ft^3/min) unit operating 3,500 h/yr; B_2 is based on the same size unit operating at 6,000 h/yr.
[b] Value of parameter provided by vendor.
[c] The incremental fan size is the additional horsepower required to operate the control device over the horsepower required to operate the ventilation system.
[d] Annualized costs were calculated from the control device parameters provided by the vendor and the operating hours specified above. All costs are rounded to the nearest $10.
[e] Includes operator, supervisor, and maintenance labor.
[f] Includes cost of fiber replacement and disposal and transportation of old fiber material with 50 percent compaction.
[g] Includes overhead, property tax, insurance, and administration.
[h] Sum of 1 through 6. Numbers may not add exactly due to independent rounding. Cost data were rounded to nearest $100.

TABLE B-19. CAPITAL COSTS OF FIBER-BED MIST ELIMINATORS FOR HARD CHROMIUM PLATING MODEL PLANTS

	Model plant size		
	Small[a]	Medium[b]	Large[c]
Cost data[d]			
Purchased equipment	84,200	171,700	343,400
Installation	30,000	56,000	112,000
Modification	2,500	5,200	10,400
Startup	800	1,700	3,400
Total capital cost[e]	117,600	234,600	469,200

[a]Small model plant costs are from Column A in Table B-21.
[b]Medium model plant costs are from Column B in Table B-21.
[c]Large model plant costs are two times Column B in Table B-21.
[d]Costs were rounded to the nearest $100.
[e]Numbers may not add exactly due to independent rounding.

TABLE B-20. ANNUALIZED COSTS FOR FIBER-BED MIST ELIMINATORS FOR NEW HARD CHROMIUM PLATING MODEL PLANTS

	Model plant size		
	Small[a]	Medium[b]	Large[c]
Cost data[d]			
Utilities	2,200	11,300	38,700
Operator and maintenance labor[e]	3,000	5,800	12,800
Maintenance materials	600	1,600	5,300
Fiber material replacement[f]	3,300	9,900	19,800
Indirect costs[g]	6,900	13,800	29,600
Capital recovery	13,800	27,500	54,900
Annualized cost[h]	29,700	69,700	161,200
Chromic acid recovery[i]	(300)	(2,600)	(10,100)
Net annualized cost[h]	29,400	67,100	151,100

[a]Small model plant costs are equal to the costs presented in Column A of Table B-22.
[b]Medium model plant costs are equal to the costs presented in Column B_1 of Table B-22.
[c]Large model plant costs (with the exception of operator and maintenance labor and indirect costs) are equal to two times the costs presented in Column B_2 of Table B-22.
[d]All costs were rounded to nearest $100.
[e]Includes operator, supervisor, and maintenance labor.
[f]Fiber material replacement costs include the cost associated with purchasing new fiber material and transportation and disposal of the old material with 50 percent compaction.
[g]Includes overhead, property taxes, insurance, and administration.
[h]Numbers may not add exactly due to independent rounding.
[i]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE B-21. ANNUALIZED COSTS FOR FIBER-BED MIST ELIMINATORS FOR EXISTING HARD CHROMIUM PLATING OPERATIONS

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	2,200	11,300	38,700
Operator and maintenance labor[b]	3,000	5,800	12,800
Maintenance materials	600	1,600	5,300
Fiber material replacement[c]	3,300	9,900	19,800
Indirect costs[d]	7,300	14,700	31,500
Capital recovery	15,100	30,200	60,400
Annualized cost[e]	31,600	73,400	168,600
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	31,300	70,800	158,500

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Fiber material replacement costs include the cost associated with purchasing new fiber material and transportation and disposal of the old material with 50 percent compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not add exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

B.4 REFERENCES FOR APPENDIX B

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APPENDIX C. SUMMARY OF MODEL PLANT CAPITAL AND ANNUALIZED COSTS FOR THE NEW EMISSION CONTROL TECHNOLOGIES

Capital and annualized costs are presented here in tabular form for packed-bed scrubbers and the new emission control technologies for hard chromium plating model plants. Costs for new and existing plants are included in the tables.

TABLE C-1. CAPITAL COSTS OF SINGLE PACKED-BED SCRUBBERS FOR HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Purchased equipment	19,500	47,300	94,600
Installation	17,000	26,400	52,900
Startup	200	500	900
Total capital cost[b]	36,700	74,200	148,400
Total retrofit capital cost[c]	45,900	92,800	185,500

[a]Costs were rounded to nearest $100.
[b]Numbers may not total exactly due to independent rounding.
[c]Capital cost estimate representative of an existing facility cost.

TABLE C-2. ANNUALIZED COSTS FOR SINGLE PACKED-BED SCRUBBERS FOR NEW HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	600	3,800	12,900
Operator and maintenance labor[b]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing replacement[c]	100	300	600
Indirect costs[d]	2,800	5,000	10,400
Capital recovery	4,300	8,700	17,400
Annualized cost	10,000	21,200	48,800
Chromic acid recovery[e]	(300)	(2,600)	(10,000)
Net annualized cost[f]	9,700	18,600	38,800

[a] All costs were rounded to nearest $100.
[b] Includes operator, supervisor, and maintenance labor.
[c] Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of the old material with 50% compaction.
[d] Includes overhead, property taxes, insurance, and administration.
[e] Chromic acid recovery credit is based on a control efficiency of 99 percent.
[f] Numbers may not total exactly due to independent rounding.

TABLE C-3. ANNUALIZED COSTS FOR SINGLE PACKED-BED SCRUBBERS FOR EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	600	3,800	12,900
Operator and maintenance labor[b]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing replacement[c]	100	300	600
Indirect costs[d]	3,100	5,700	11,900
Capital recovery	5,400	10,900	21,700
Annualized cost	11,400	24,100	54,600
Chromic acid recovery[e]	(300)	(2,600)	(10,000)
Net annualized cost[f]	11,100	21,500	44,600

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Packing replacement costs include the cost associated with purchasing new packing material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Chromic acid recovery credit is based on a control efficiency of 99 percent.
[f]Numbers may not total exactly due to independent rounding.

TABLE C-4. CAPITAL COSTS OF MESH-PAD MIST ELIMINATORS WITH MESH PADS IN SERIES FOR HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Purchased equipment	24,400	68,300	136,500
Installation	2,600	2,900	5,700
Startup	200	700	1,400
Total capital cost[b]	27,200	71,800	143,600
Total retrofit capital cost[c]	34,000	89,800	179,500

[a]Costs were rounded to nearest $100.
[b]Numbers may not total exactly due to independent rounding.
[c]Capital cost estimate representative of an existing facility cost.

TABLE C-5. ANNUALIZED COSTS FOR MESH-PAD MIST ELIMINATORS WITH MESH PADS IN SERIES FOR NEW HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	1,100	7,300	25,000
Operator and maintenance labor[b]	2,000	3,000	6,200
Maintenance materials	1,400	2,400	8,300
Mesh pad replacement[c]	1,800	4,800	9,600
Indirect costs[d]	3,100	6,100	14,400
Capital recovery	4,400	11,700	23,400
Annualized cost[e]	13,800	35,400	86,800
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	13,500	32,800	76,700

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs include the cost associated with purchasing new mesh pad material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE C-6. ANNUALIZED COSTS FOR MESH-PAD MIST ELIMINATORS WITH MESH PADS IN SERIES FOR EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	1,100	7,300	25,000
Operator and maintenance labor[b]	2,000	3,000	6,200
Maintenance materials	1,400	2,400	8,300
Mesh pad replacement[c]	1,800	4,800	9,600
Indirect costs[d]	3,400	6,900	15,900
Capital recovery	5,500	14,600	29,300
Annualized cost[e]	15,200	39,000	94,200
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	14,900	36,400	84,100

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Mesh pad replacement costs include the cost associated with purchasing new mesh pad material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE C-7. CAPITAL COSTS OF PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS FOR HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Purchased equipment	45,100	82,500	165,000
Installation	12,600	14,500	29,000
Startup	500	800	1,600
Total capital cost[b]	58,100	97,800	195,600
Total retrofit capital cost[c]	72,600	122,200	244,500

[a]Costs were rounded to nearest $100.
[b]Numbers may not total exactly due to independent rounding.
[c]Capital cost estimate representative of an existing facility cost.

TABLE C-8. ANNUALIZED COSTS FOR PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS FOR NEW HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	1,600	8,300	28,500
Operator and maintenance labor[b]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing material replacement[c]	300	1,000	1,900
Mesh pad replacement[c]	2,700	4,400	8,900
Indirect costs[d]	3,600	6,000	12,300
Capital recovery	6,900	11,500	23,100
Annualized cost[e]	17,300	34,400	82,200
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	17,000	31,800	72,100

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Replacement costs include the cost associated with purchasing new material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE C-9. ANNUALIZED COSTS FOR PACKED-BED SCRUBBER/MESH-PAD MIST ELIMINATOR SYSTEMS FOR EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	1,600	8,300	28,500
Operator and maintenance labor[b]	1,700	2,300	3,900
Maintenance materials	500	1,100	3,600
Packing material replacement[c]	300	1,000	1,900
Mesh pad replacement[c]	2,700	4,400	8,900
Indirect costs[d]	4,200	6,900	14,300
Capital recovery	8,600	14,400	28,900
Annualized cost[e]	19,600	38,300	90,100
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	19,300	35,700	80,000

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Replacement costs include the cost associated with purchasing new material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE C-10. CAPITAL COSTS OF FIBER-BED MIST ELIMINATORS FOR HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Purchased equipment	82,000	167,300	334,600
Installation	29,200	54,600	109,100
Modification	2,400	5,100	10,100
Startup	800	1,700	3,300
Total capital cost[b]	114,600	228,600	457,100
Total retrofit capital cost[c]	126,100	251,500	502,800

[a]Costs were rounded to nearest $100.
[b]Numbers may not total exactly due to independent rounding.
[c]Capital cost estimate representative of an existing facility cost.

TABLE C-11. ANNUALIZED COSTS FOR FIBER-BED MIST ELIMINATORS FOR NEW HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	2,200	11,300	38,700
Operator and maintenance labor[b]	3,000	5,800	12,800
Maintenance materials	600	1,600	5,300
Fiber material replacement[c]	3,300	9,900	19,800
Indirect costs[d]	6,700	13,500	29,200
Capital recovery	13,400	26,700	53,500
Annualized cost[e]	29,200	68,800	159,300
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	28,900	66,200	149,200

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Fiber material replacement costs include the cost associated with purchasing new fiber material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.

TABLE C-12. ANNUALIZED COSTS FOR FIBER-BED MIST ELIMINATORS FOR EXISTING HARD CHROMIUM ELECTROPLATING MODEL PLANTS (NOVEMBER 1988 DOLLARS)

	Model plant size		
	Small	Medium	Large
Cost data[a]			
Utilities	2,200	11,300	38,700
Operator and maintenance labor[b]	3,000	5,800	12,800
Maintenance materials	600	1,600	5,300
Fiber material replacement[c]	3,300	9,900	19,800
Indirect costs[d]	7,200	14,400	31,000
Capital recovery	14,800	29,400	58,800
Annualized cost[e]	31,000	72,400	166,400
Chromic acid recovery[f]	(300)	(2,600)	(10,100)
Net annualized cost[e]	30,700	69,800	156,300

[a]All costs were rounded to nearest $100.
[b]Includes operator, supervisor, and maintenance labor.
[c]Fiber material replacement costs include the cost associated with purchasing new fiber material and transportation and disposal of the old material with 50% compaction.
[d]Includes overhead, property taxes, insurance, and administration.
[e]Numbers may not total exactly due to independent rounding.
[f]Chromic acid recovery credit is based on a control efficiency of 99.8 percent.