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# **ALTERNATE VOC CONTROL TECHNIQUE OPTIONS FOR SMALL ROTOGRAVURE AND FLEXOGRAPHY FACILITIES**

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16. ABSTRACT The report identifies Available Control Techniques (ACTs) for states to use as a reference when implementing Reasonable Available Control Technology (RACT) for graphic arts facilities that are covered by the Control Technologies Guidelines (CTGs), but emit less than 91 tonnes of volatile organic compounds (VOCs) per year. The CTGs for the graphic arts industry was published in December 1978. It defined RACT for VOCs emitted from publication and packaging rotogravure and from packaging flexography. Subsequent EPA guidance limited the applicability of RACT requirements to sources that emit 91 tonnes/yr or more of VOCs. The Clean Air Act Amendments of 1990 (CAAAAs) now require RACT for VOC sources that emit as little as 9 tonnes/yr in extreme ozone nonattainment areas. Therefore, states are now required to establish and implement RACT for these smaller sources as well.		
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## PREFACE

Environmental Protection Agency's (EPA) Control Technology Center (CTC) was established by EPA's Office of Research and Development and Office of Air Quality Planning and Standards to provide technical assistance to State and local air pollution control agencies. Three levels of assistance are available through the CTC. First, a CTC HOTLINE has been established to provide telephone assistance on matters relating to air pollution control technology. Second, more in-depth engineering assistance can be provided when appropriate. Third, the CTC can provide technical guidance through publication of technical guidance documents, development of personal computer software, and presentation of workshops on control technology matters.

Engineering assistance projects, such as this one, focus on topics of national and regional interest that are identified through contact with State and local agencies. The CTC has received numerous calls from State agencies concerning control technologies for graphic arts sources. This study was undertaken to describe control options for small rotogravure and flexographic printing facilities.

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## METRIC CONVERSIONS

Nonmetric	Times	Yields Metric
ft	0.3	m
ft <sup>2</sup>	0.093	m <sup>2</sup>
in	2.54	cm
in H <sub>2</sub> O	249	Pa
in <sup>2</sup>	6.45	cm <sup>2</sup>
lb	0.454	kg
scfm	0.00047	sm <sup>3</sup> /s
ton	0.907	tonne



## 1.0 SUMMARY

Emissions of volatile organic compounds (VOC) from rotogravure and flexographic printing facilities arise from the evaporation of solvents during ink drying. These emissions can be reduced by conversion of solvent-borne ink systems to water-borne ink systems, or by capture of the solvent vapors and use of a control device such as thermal or catalytic incineration systems or carbon adsorption systems. There are limitations associated with each approach and individual circumstances, including the type of product produced, the customer base, and the type of ink used, which will affect the applicability of different technologies.

Conversion to waterborne inks can reduce VOC emissions by approximately 80%. Uncertainties in retrofitting existing presses for water-borne inks exist; required modifications are site-specific. Drier systems and, in some cases, ink-supply systems must be modified. Gravure cylinders must be replaced. Water-borne inks can eliminate the problems of designing and testing capture systems. In some cases, it is difficult to achieve the same level of gloss with water-borne inks as with solvent-borne inks. In cases where water-borne inks are suitable, conversion to water-borne inks may be the most cost-effective solution. Due to the site-specific nature of conversion costs, no generalized cost estimates can be developed.

Properly operated carbon adsorption systems with total enclosures or efficient capture systems can reduce VOC emissions by 95 percent. Solvent can be recovered for reuse on site or sold to a reclaimer. Carbon adsorption systems are incompatible with certain inks and are most suitable for facilities with a predictable, long-term production schedule. Facilities using a wide variety of inks to print numerous small jobs are not likely to be able to use carbon adsorption systems. Activated carbon has a solvent capacity which varies for different organic components. Cost estimates have been developed on the basis of toluene as the design solvent. In some cases, other solvents which are present in some inks may require larger and, thus, more expensive systems.

Properly operated catalytic incinerator systems with total enclosures or efficient capture systems can reduce VOC emissions by up to 98 percent. Solvents are destroyed in these systems. Catalytic incinerators provide an energy savings over thermal incinerators, but they are not compatible with all inks. Incinerator specifications must be written with specific reference to the type of inks to be used. Small facilities may avoid catalytic incinerators because of higher initial capital costs than thermal incinerators, and the desire to maintain flexibility to print a wider variety of jobs.

Properly operated thermal incinerator systems, with total enclosures or efficient capture systems, can reduce VOC emissions by 98 percent. Thermal incinerators are compatible with most inks used in rotogravure and flexography, but these systems are relatively energy intensive. Cost-effectiveness data for these control devices are summarized in Table 1. The cost of total enclosures must be added to these costs.

**Table 1. Cost Effectiveness of Control Technologies for Small Rotogravure and Flexography Facilities<sup>a</sup>**

Plant Size <sup>b</sup> (ton/yr)	Cost Effectiveness (\$/Ton)		
	Thermal Incineration	Catalytic Incineration	Carbon Adsorption
10	\$3,500 to \$4,800	\$3,900	\$3,500
25	\$2,000 to \$3,000	\$2,500 to \$2,800	\$1,400
50	\$1,200 to \$2,400	\$960 to \$2,000	\$760 to \$780
100	\$850 to \$2,000	\$1,200 to \$1,600	\$450 to \$460
1000	\$170 to \$480	\$170 to \$350	\$120

<sup>a</sup>1991 dollars, exclusive of total enclosure or capture devices. Control efficiencies assumed to be 95 to 100 percent. Capture efficiencies are assumed to be 100 percent.

<sup>b</sup>Total solvent use including solvent present in purchased ink and solvent added by facility.

## 2.0 INTRODUCTION

In 1978, the U.S. Environmental Protection Agency (EPA) published Control Technology Guidelines (CTG) for the graphic arts industry applicable to emissions of VOC. This CTG document (1) defined reasonably available control technology (RACT) for publication and packaging rotogravure and packaging flexography. The applicability of these guidelines was subsequently limited to plants emitting 100 tons\* of VOC per year or more by EPA guidance (2).

The Clean Air Act Amendments (CAAA) of 1990 required RACT for sources that emit as little as 10 tons of VOC per year in extreme ozone nonattainment areas. To meet the ambient air quality standards for ozone, States with "extreme," "severe," or "serious" problems were required to establish and implement RACT for these smaller sources. This document identifies alternate control techniques (ACT) for States to use as a reference when establishing and implementing RACT for existing graphic arts facilities with potential uncontrolled VOC emissions of less than 100 tons per year.

## 3.0 GENERAL DESCRIPTION

In rotogravure and flexographic printing, ink is applied to a cylindrical image carrier. The ink is transferred to the print surface as it passes by the rotating cylinder. Different colors are printed on the print surface (paper, film, foil, etc.) as it passes successively through multiple print stations. Presses are available with as many as eight stations. In most cases, the stock to be printed is supplied from a roll or web. graphic arts facilities with potential uncontrolled VOC emissions of less than 100 tons per year. The printed stock can be rewound onto a roll, or cut, slit, and/or folded, depending on the type of press and application. In some cases, stock to be printed is fed sheet by sheet. Very fluid inks are required for these processes; drying involves the evaporation of the fluid part of the ink into heated air, which leaves behind the pigment and a binder. The evaporated material is typically an organic solvent, a mixture of organic solvents or a mixture of organic solvents and water. Evaporation of these solvents creates a potential source of VOC emissions.

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\*Readers more familiar with the metric system may use the conversion factors at the end of the front matter of this report (page vi).

Additional background information on printing technologies is presented in Vincent and Vataavuk (1), Strauss (3), National Association of Printing Ink Manufacturers (4), and Gravure Association of America (5).

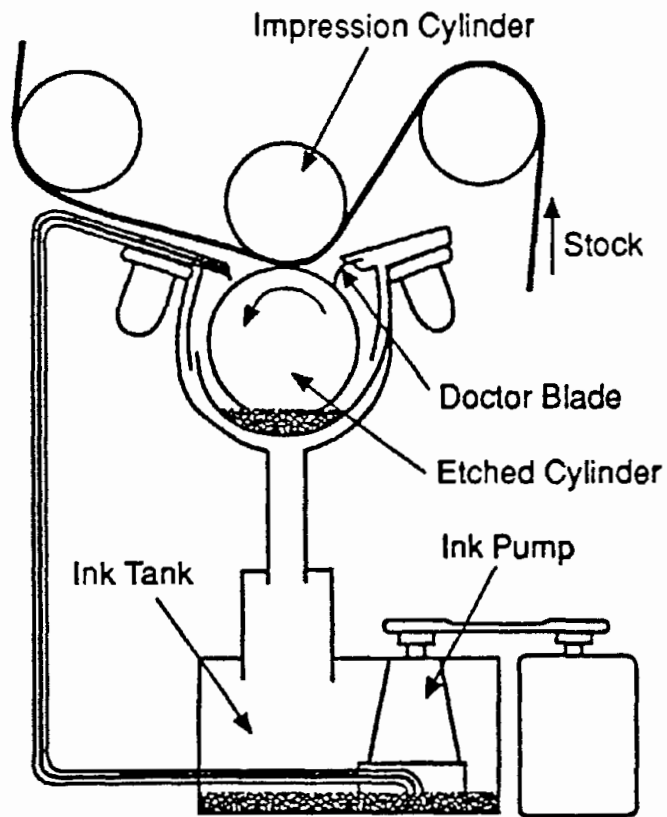
### 3.1 Description of the Rotogravure Process

Rotogravure is an intaglio printing process. This means that the image area is depressed relative to the surface of the printing cylinder. The printing cylinder typically is composed of chrome-plated copper or steel plated with copper then chrome. The image is formed by etching depressions (or cells) in the chrome or by etching the copper prior to chrome plating. The depth of the cells (typically about 0.035 mm) determines the amount of ink applied to the surface. The density of the cells varies between about 600 and 32,000 per square inch, with finer quality printing requiring more cells.

The printing cylinder rotates through a trough of ink (or ink fountain) where ink is applied to the cells. Excess ink is removed from the surface of the cylinder by a flexible doctor blade; leaving the cells full of ink. The ink is then transferred to the surface of the stock as it is pressed against the rotating cylinder. The printed stock, or web, then passes through one or more driers where the solvent in the ink is evaporated from the printed image. Solvent-laden air is captured from the driers and vented to the atmosphere or to a control system. In some cases, the hot air from the driers is cascaded from station to station. Figure 1 illustrates a typical rotogravure printing press.

The ink in the fountain is composed of ink supplied by the ink manufacturer (50 percent or more solvent) that has been mixed with additional solvent to maintain the proper viscosity. After mixing, inks used for rotogravure printing may contain 50 to 85 percent (or more) organic solvent (6). The solvents in rotogravure ink include esters, alcohols, ketones, and aromatic and aliphatic hydrocarbons (4).

Changing from one job to another involves changing the cylinders and, if different colors are to be printed, cleaning the ink residue in the fountains. In packaging rotogravure, the cylinders are stored to permit printing the same job at a later date.



Source: EPA/450/2-78-033.

**Figure 1. Rotogravure printing.**

### 3.2 Description of Flexography

Flexography is a relief printing process. This means that the image surface is raised relative to the surface of the cylinder. The image surface is a flexible rubber or polymeric plate that is wrapped around the plate cylinder. Ink is applied to the raised image surface by one of two different methods. In the older method, a rotating cylindrical "fountain roller" is partially submerged in the ink fountain. This ink is transferred to a "form roller," which rotates against the fountain roller. Excess ink is removed from the form roller with a doctor blade. The form roller then transfers the ink to the raised surfaces of the printing plate, which rotates against it. In the newer method, the form roller rotates through the ink trough and the fountain roller is omitted. The ink is applied to the stock as it is pushed against the printing plate by a rotating impression cylinder. Figure 2 illustrates a typical flexographic printing process.

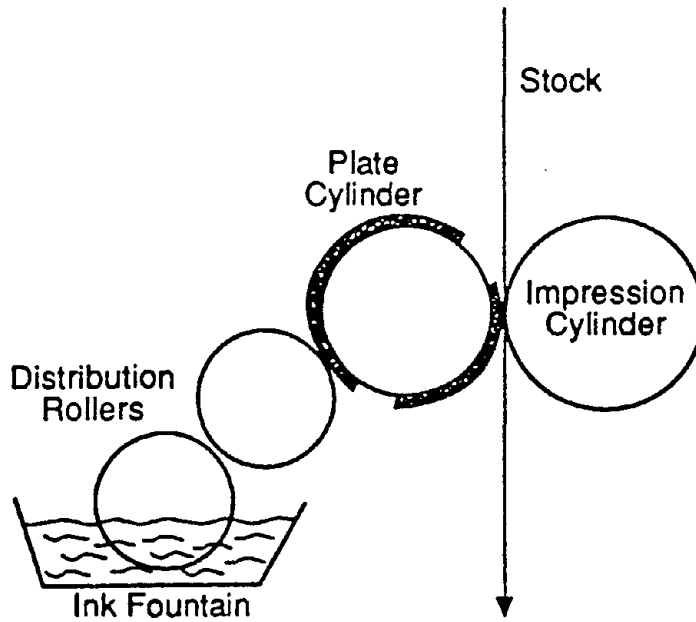
The ink used in flexographic printing is composed of one or more resins dissolved in one or more solvents. The solvents, which include alcohols, esters, glycol ethers, and aliphatic hydrocarbons, must be compatible with the rubber or polymeric printing plates. Dyes and pigments also are dissolved and dispersed in the ink. The inks contain approximately 75 percent solvent. Water-based inks are also available.

After printing, the inks are dried by evaporating the solvents into hot air driers. Solvent-laden air is captured from the driers and vented to the atmosphere or to a control system.

Changing from one job to another involves replacing the printing plates on the plate cylinders and if different colors are to be printed, cleaning the ink residue in the fountains and on the rollers.

## 4.0 CAPTURE TECHNOLOGIES

Capture technologies are methods, procedures, or facilities that can be used to collect and contain VOCs that are emitted from a particular process. The term capture efficiency is defined as the fraction of all organic vapors generated by a process that is directed to an abatement or recovery device. Two types of capture technologies are total enclosures and capture devices.



Source: EPA/450/2-78-033.

**Figure 2. Flexographic printing.**

#### 4.1 Total Enclosure

Permanent total enclosures are structures that completely surround emissions sources so that all air leaving the enclosure is exhausted through a control device. Existing rooms can be modified and tested to confirm compliance with the total enclosure criteria. New structures can be built around emissions sources to serve as total enclosures within existing rooms. EPA has specified five criteria that must be met for an enclosure to be considered a permanent total enclosure. These criteria have been published in New Source Performance Standards for the magnetic tape industry and for the coating of polymeric substrates, 40 CFR 60 (7). The criteria are as follows:

- 1) All VOC emissions must be captured and contained for discharge through a control device.
- 2) The total area of all natural draft openings (NDOs) must not exceed 5 percent of the surface area of the enclosure walls, floor, and ceiling. NDOs include makeup air vents, open doors and windows, cracks under doors, and other openings.
- 3) All doors and windows that are not to be considered NDO must be closed during routine operation of the process. (Doors can be equipped with automatic closures to establish that they are not NDO.)
- 4) The average facial velocity of air entering through all NDOs must be at least 200 ft/min. This is equivalent to a pressure drop of at least 0.004 inches of water across the NDO. (The pressure inside the enclosure must be negative relative to the outside of the enclosure. The direction of flow must be into the enclosure.)
- 5) Any NDO must be at least four equivalent diameters from a source of VOC. (A window with a 4-ft<sup>2</sup> opening could be located no less than 9 ft from the nearest source of emissions.)

Any enclosure meeting these criteria will be considered a total enclosure, and capture efficiency will be assumed to be 100 percent. An existing room might meet these criteria with some modifications. Alternatively, an enclosure could be constructed around a press or presses within an existing room.



## 4.2 Capture Devices

Capture devices may be enclosures or rooms that do not meet the criteria for permanent total enclosures. Alternatively, devices such as fume hoods, "floor sweeps," or open booths may be used to capture VOC. These devices collect air in the region where VOC is emitted and duct it to a control device. If a capture device is used as part of a VOC emissions control system, in other than a permanent total enclosure, the capture efficiency may be determined through testing. The overall efficiency of a system that uses a capture device is the product of the capture efficiency and the efficiency of the control device.

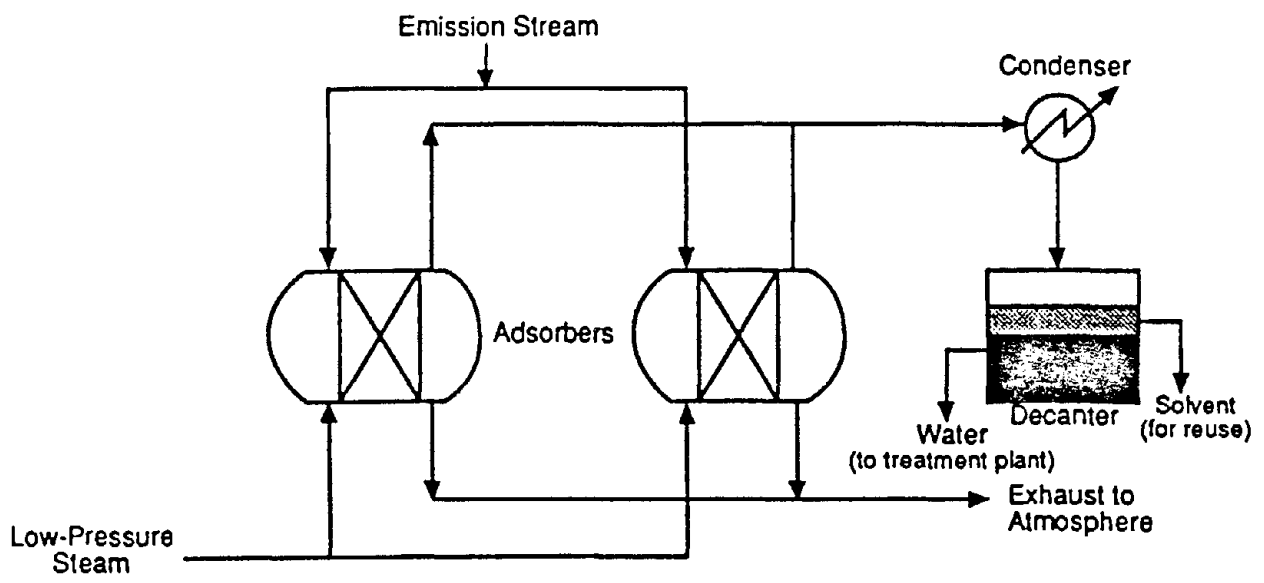
The efficiency of a capture device may be determined using a mass balance based on gaseous VOC concentrations measured around the partial enclosure. A temporary total enclosure may be constructed for the purpose of obtaining an accurate mass balance for use in determining the capture efficiency of a capture device.

## 5.0 CONTROL TECHNOLOGIES AND POLLUTION PREVENTION OPTIONS

### 5.1 Carbon Adsorption

Activated carbon is a material with a high surface area that adsorbs many organics from air streams. When used for gas phase emissions control, granular-activated carbon is used in fixed-bed adsorbers. Typically, contaminated air is collected using permanent total enclosures or capture devices and is passed through two or more beds of carbon. VOC in the air is adsorbed on active sites on the carbon. A schematic of a typical carbon adsorption system is given in Figure 3.

Carbon has an experimentally determined capacity for specific concentrations of specific organics. Over time, this capacity is exhausted (essentially all of the active adsorption sites are occupied) and the organics pass through unadsorbed. Adsorbers are operated in parallel so that when the capacity in one unit is exhausted, it can be removed from service and a second adsorber can be put into service. The exhausted carbon in the first adsorbent can then be replaced or regenerated. A wide variety of differently manufactured activated carbons are available. These materials have different capacities for different organic compounds. Where a variety of volatile organics are present in a contaminated gas stream, the control of the compound that breaks through first dictates the selection and operating procedure for the adsorbers.



Source: EPA/625/6-91/014.

Figure 3. Carbon adsorption system.

Ketones, which are present in many rotogravure inks, have caused problems in carbon adsorption systems in the past because they polymerize on the surface of the carbon granules, at times leading to bed fires. Very high recovery efficiencies are possible if the carbon adsorbers are properly maintained (9).

In contrast to incineration techniques, carbon adsorption does not destroy the VOC in the contaminated air but merely removes it. This may be an advantage or a disadvantage. To restore the capacity of the activated carbon for reuse, it must be regenerated. Activated carbon is regenerated by heating it with steam or hot air to drive off the adsorbed organics. These desorbed organics must be controlled eventually. Carbon regeneration can take place on site, or the carbon can be returned to the vendor for routine regeneration and replacement.

If the composition and flow rate of the gas stream to the carbon adsorption system are relatively well known, the required replacement schedule can be predicted from data provided by the carbon vendor. Where these parameters are uncertain, organic vapor monitors can be installed to detect breakthrough. At this point, the adsorber can be removed and regenerated. A new adsorber containing regenerated carbon can be installed at this time.

Rotogravure and flexographic printing facilities typically buy solvents for diluting the purchased ink to maintain the proper flow characteristics. At facilities where one solvent (or one solvent mixture) is used exclusively (or nearly exclusively), the use of activated carbon for emissions control offers the potential for recovery and reuse of solvent. Facilities that use a variety of inks, with different solvents and solvent mixtures, to meet the requirements of numerous small printing jobs will be less likely to take advantage of this option. A mixture, particularly an unknown mixture of solvents, is much less useful for blending purposes.

Design and cost estimation procedures for carbon adsorption systems are given in EPA (8) and Vataavuk (10). Carbon adsorption efficiencies vary depending on the specific VOC or VOC mixture. VOC removal efficiencies of at least 95 percent can be achieved, provided: (a) the adsorber is supplied with an adequate quantity of high-quality activated carbon, (b) the gas stream receives appropriate conditioning (e.g., cooling, filtering) before entering the carbon bed, and (c) the carbon beds are regenerated before breakthrough (11).

## 5.2 Thermal Incineration

Thermal incinerators are control devices in which the contaminated air streams collected with total enclosures or capture devices are burned. VOCs are converted to carbon dioxide and water with a high degree of efficiency. Gas streams of interest in the graphics arts industry will contain sufficient oxygen to support combustion. Dilute gas streams, which may be present during process shutdown and make-ready periods, may require the addition of supplemental fuel to sustain combustion. A schematic of a thermal incineration system is shown in Figure 4.

In thermal incineration, the contaminated air stream is preheated, ignited, and combusted. Various designs use different types of combustion devices. In general, combustion chamber designs must provide high turbulence to mix the VOC, fuel, and air to ensure essentially complete combustion. The other requirements are a high enough temperature and a long enough residence time to complete the combustion process. Temperatures are generally maintained at about 900 °C (1600°F) but will vary depending on the solvent mixture involved. Properly designed and adjusted incinerators operating at a maximum of 900 °C (1600°F) and 0.75 second residence time will achieve at least 98 percent VOC reduction.

Upon ignition, the VOCs in the gas stream are oxidized and destroyed. The rate of destruction at any given temperature varies depending on the composition of the contaminated air stream. Generally, heat released from the reaction is sufficient to heat the contaminated air stream to the ignition temperature. In some cases, heat exchangers are used to recover heat from the combustion reaction for use in preheating the contaminated air stream.

Because the incinerator must be in operation at times when VOC emissions are very low (i.e., when presses are on standby or during changeovers), supplemental fuel requirements will vary. During these time periods, supplemental fuel in the form of natural gas is used to sustain combustion at the necessary temperature to ensure destruction of the VOC in the gas stream.

Incineration systems are supplied with controls to start-up and bring the combustion chamber to the proper temperature. These controls can provide an interlock to prevent operation of the press until the incinerator temperature is adequate to ensure destruction of the VOC. Adjustments in supplementary fuel requirements

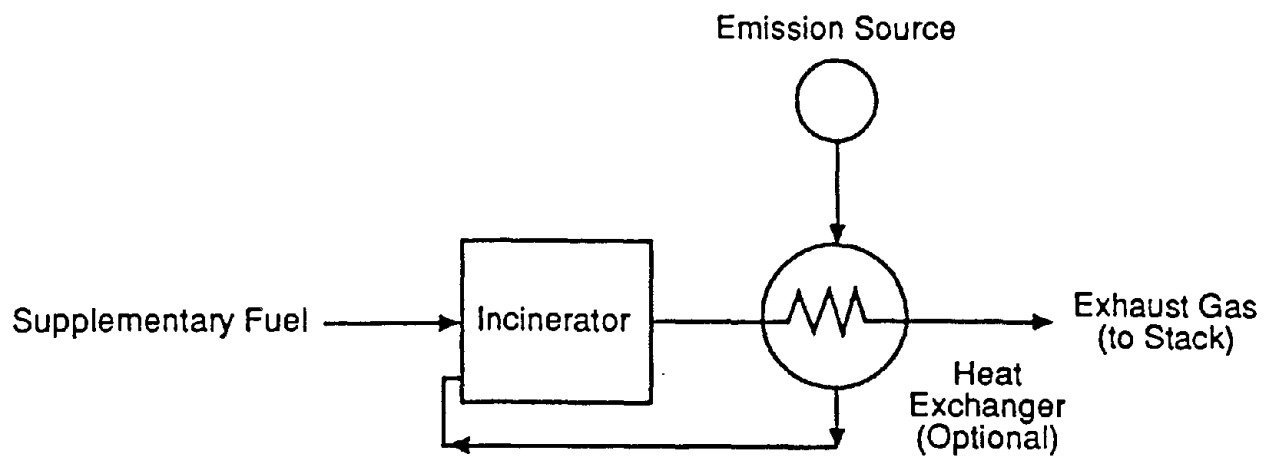


Figure 4. Thermal Incineration.

based on changes in emission rate, air flow rate, and ambient temperature can also be made automatically.

Design and cost estimation procedures for thermal incinerators are given in *Handbook: Control Technologies for Hazardous Air Pollutants* (8) and *OAQPS Cost Control Manual*, (10). Incinerators are assumed to be 98 percent effective for VOC destruction (1).

### 5.3 Catalytic Incineration

Catalytic incinerators are control devices in which the contaminated air streams collected with total enclosures or capture devices are burned. VOCs are converted to carbon dioxide and water with a high degree of efficiency. In the presence of a catalyst, this reaction will take place at lower temperatures than those required for thermal incineration. Temperatures between 350 and 500 °C (660 and 930 °F) are common. The catalysts are metal oxides or precious metals which are supported on ceramic or metallic substrates.

From an operational standpoint, the lower reaction temperature means that the requirement for supplemental fuel is reduced or eliminated during normal operation. Provision for supplemental fuel must still be made for start-up and standby periods. Gas streams of interest in the graphics arts industry will contain sufficient oxygen to support combustion. The lower operating temperatures also decrease the formation of oxides of nitrogen.

The use of a catalyst is inconsistent with certain ink formulations. Chlorinated solvents and some silicone ink additives are among some of the compounds that can poison or deactivate catalysts. The specification of a catalytic incinerator for a particular application must take into account the specific inks to be used. Facilities dedicated to long-term production for specific packaging applications will be able to commit to a specific type of ink chemistry more readily than facilities printing numerous small jobs.

Design of catalytic incinerators varies from manufacturer to manufacturer. The major differences involve the geometry of the combustion chamber, the type of catalyst and support material, and the type of contact between the gas and the catalyst. In fixed-bed designs, gas flows through beds of catalyst beads (or pellets) or through a monolithic support. In fluidized bed designs, gas flows through an

expanded fluidized bed of catalyst pellets. A summary of performance test data is given by Spivey (12). Selection and cost estimation procedures for catalytic incinerators are given in *Handbook: Control Technologies for Hazardous Air Pollutants* (8) and the *OAQPS Control Cost Manual* (10). Catalytic incinerators have an estimated VOC destruction efficiency of 98 percent. A schematic of catalytic incineration is shown in Figure 5.

#### 5.4 Water-Borne Inks

Problems associated with capture and control of VOC present in rotogravure and flexographic inks can be reduced substantially by substituting water-borne inks for the more commonly used solvent-borne inks. Water-borne inks contain a higher proportion of solids (pigments and resins) than solvent-borne inks. The VOC content of water-borne inks is approximately 5 to 30 percent as used (1) in contrast to 50 to 85 percent for solvent-borne inks. As a control option, the 1979 EPA Guidelines (2) specified a limit of 25 percent organic in the volatile fraction of water-borne ink. Conversion of an existing uncontrolled press to water-borne inks could eliminate the need for a capture and control system. However, extensive changes in equipment and operating procedures may be required to convert to water-borne inks.

In general, water-borne inks produce different printing results than organic solvent-based inks. These results may include lower gloss and lower resolution. Some types of stock, particularly high-gloss coated paper, may be incompatible with water-borne inks. For many applications, particularly in packaging, water-borne inks can produce jobs of adequate quality.

Conversion of a press from solvent-borne to water-borne inks requires changes in driers, materials, and operation. Rotogravure presses also require differently engraved cylinders for operation with water-borne inks. Drying involves evaporation of the liquid portion of the ink from the stock. Water has a higher boiling point, a higher heat of vaporization, and a lower vapor pressure than the organic solvents used in rotogravure and flexographic inks. As a result, it dries more slowly than solvent under any set of conditions. Driers used with water-borne inks require some combination of more air, warmer air, and more residence time than do driers used for a similar job printed with solvent-borne inks. More residence time is achieved with a longer drier and, in some cases, a lower press speed. Some presses do not have enough space for installation of longer driers without major rebuilding. In addition, lower press speeds result in reduced output from a given press.

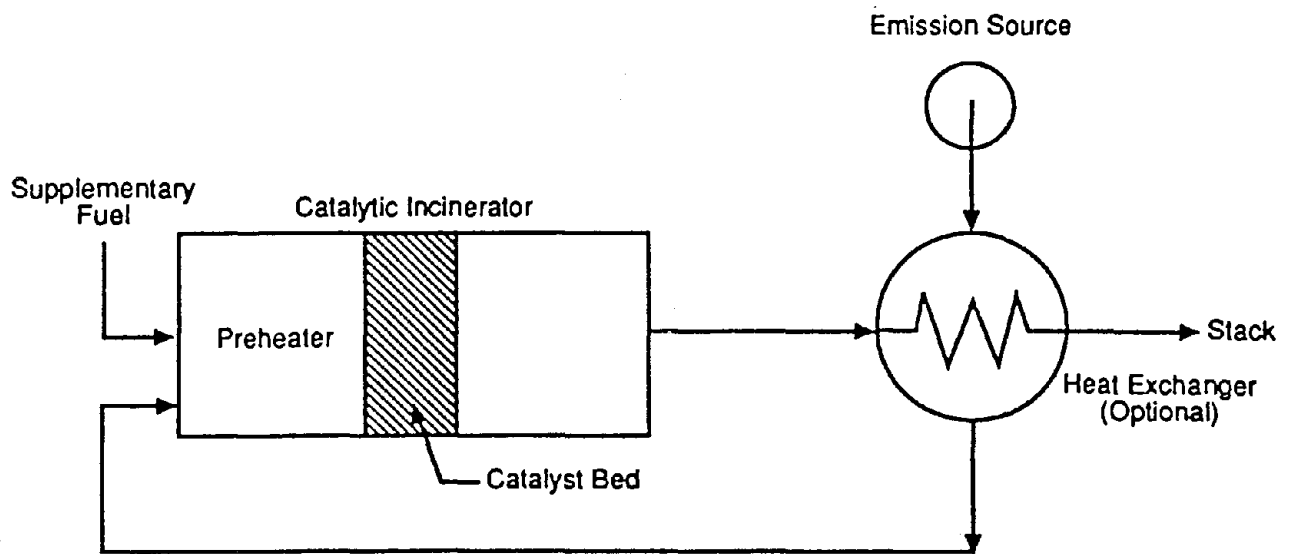


Figure 5. Catalytic Incineration.



Water is more corrosive to carbon steel components of the presses than are organic solvents, and driers fabricated from stainless steel are more expensive than the commonly used carbon steel driers. Increased corrosion of structural elements, driers, bearings, and gravure cylinders may require expensive modifications when existing presses are converted to water-borne inks. It is difficult to predict the extent of this problem.

Rotogravure cylinders have a particular cell geometry consistent with the flow characteristics of the ink being used. Conversion of a packaging gravure facility to water-borne inks would mean that stored cylinders, originally designed for use with organic solvent-borne inks, could no longer be used. This is less of a problem with publication rotogravure facilities, and not a problem with flexographic facilities.

Conversion to water-borne inks also necessitates modifications in certain operating procedures. Solvent-borne inks contain dissolved resins; these can be removed from ink fountains, rollers, cylinders and other components with solvent during setup and changeover periods. Water-borne inks contain dispersed resins, which harden upon drying. Cleanup operations are more difficult and less flexible with water-borne inks.

The actual cost of the ink required for a particular job is slightly higher for water-borne inks. The cost per pound of water-borne inks is considerably higher than solvent-borne inks; however, less water-borne ink than solvent-borne ink is required to print a particular job because of its higher solids content.

Direct cost comparisons between conversion to water-borne inks and installation of capture and control systems are not possible. If existing equipment can be adapted to water-borne inks and product quality is acceptable to the customer, VOC emission reductions of approximately 80 percent are possible. In addition, air quality in the work place will improve and the potential for fire hazards will decrease. A significant reduction in fire insurance premiums will result from conversion to water-borne ink.

Morris (13) describes the following case studies of conversion from solvent-borne to water-borne inks. Facility A extrudes polyethylene bags and prints them flexographically. An equivalent or better product was produced after altering the surface treatment of the polyethylene, replacing the anilox rolls on the press (changing from 150 to 360 line screen), and increasing the drier air velocity and air volume.

Facility C prints clay-coated cardboard by rotogravure. Conversion involved changing the type of stock printed, retrofitting the driers for a higher volume of lower temperature air, and changing the cell depth and line count of the cylinders (13).

Friedman and Vaught (14) described the conversion of a flexographic facility operated by Amko Plastics from solvent-borne to water-borne inks. The conversion involved redesign of air blowers, plenums, and drier hoods to improve drying. The anilox rollers, fountain rollers, and printing plates were also modified. As a result of the conversion, explosion-protected storage rooms were no longer required for the ink. Other advantages included the elimination of an underground solvent storage tank with a resulting decrease in liability insurance, more consistent color throughout press runs, a savings on ink costs (the ink is more expensive per pound but less is required), and an improvement in air quality in the press room. Disadvantages included lower gloss on some jobs and higher costs associated with wastewater and sludge produced during cleanup.

### 5.5 Other Types of Inks

The need to capture and control VOC emissions from graphic arts facilities would be reduced or eliminated if the VOC in the ink formulations could be reduced or eliminated. The potential for replacing VOC with water has been described. Other approaches involve using inks that have less liquid (organics or water) and more solids (pigments, binders and resins). Several types of high-solid inks are available for use in other printing processes (lithography and letter press in particular). At the current stage of development, however, these inks are unsuitable for rotogravure and flexographic presses. Improved high-solid inks are continuously under development. However, no high-solid inks are presently available with viscosities low enough to be suitable for rotogravure or flexography.

Radiation-curable inks are combinations of monomers that are applied to the substrate and polymerize in the presence of ultraviolet (UV) light or electron beams. At present, these inks are available for letter press, lithographic, and screen printing. Walata and Newman (15) found no current applications of these technologies in rotogravure or flexographic printing. The limitations of these ink systems result primarily from their high viscosity. Electron beam curing must take place in an oxygen-free environment. This is inconsistent with existing rotogravure and flexographic presses. UV-curable inks are less sensitive to the presence of oxygen but they require dilution with solvent or water to reduce the ink viscosity to a level

suitable for the existing presses. Modifications to existing presses could theoretically be made to allow these inks to be used, but drier modifications may also be needed to evaporate the solvent or water. UV systems suitable for retrofit to existing presses are not presently available.

## 6.0 DESCRIPTION OF MODEL PLANTS

Model plants have been specified to provide a consistent basis for comparison among control options. The potential uncontrolled emissions considered were 10, 25, 50, 100, and 1,000 tons per year of VOC. For the purposes of this report, potential uncontrolled emissions are equal to solvent use. This includes the solvent content of the purchased ink, solvent added to make the ink press-ready, and makeup solvent to correct for evaporation in the ink fountain.

There are, of course, an infinite number of scenarios that can result in any given annual ink usage. Model plants have been specified in Table 2 on the basis of total uncontrolled emissions. The important parameters are the yearly emissions, the VOC concentration in the drier exhaust, and the hours of operation. Rotogravure ink would be more fluid (i.e., less viscous as a result of greater solvent dilution) than flexographic ink. There is enough variation between individual presses and printing jobs that the distinction is unimportant. The EPA Guidelines Document (1) lumps rotogravure and flexography, and estimates solvent content at between 50 and 80 percent. These data are presumably on an as-used basis. If it is important to have a higher as-used solvent content, this parameter could be adjusted from 67 percent to as high as 80 percent by making corresponding changes in the other specifications.

The fraction of time presses used varies widely depending on the size of individual jobs. Setup time is not affected by length of the job. Small facilities, such as those considered in the model plants, may have much more downtime as a result of frequent changeovers between small jobs. Facilities that operate less than 24 hours per day have the flexibility to schedule additional shifts if needed. A utilization rate of 60 percent has been specified. This could be adjusted to a lower rate (much lower if downtime, due to lack of business, is considered) by adjusting other specifications (e.g., potential operating time).

**Table 2. Model Plant Specifications <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	No. of presses	Anticipated operating schedule (h/yr)
1	10	1	8 h/d, 5 d/wk (2,086 h/yr)
2	25	1	16 h/d, 5 d/wk (4,170 h/yr)
2A	25	2	8 h/d, 5 d/wk (2,086, h/yr)
3	50	1	16 h/d, 5 d/wk (4,170 h/yr)
3A	50	2	8 h/d, 5 d/wk (2,086, h/yr)
4	100	1	16 h/d, 5 d/wk (4,170 h/yr)
4A	100	2	8 h/d, 5 d/wk (2,086 h/yr)
5	1,000	5	16 h/d, 7 d/wk (5,840 h/yr)

<sup>a</sup>Specifications based on the following assumptions:

- Uncontrolled emissions are based on total VOC used.
- Press utilization: 60 percent.
- Setup, make-ready, etc.: 40 percent.
- Exhaust flows will be specified at 10 percent and 25 percent of the lower explosive limit (based on toluene).
- Capture efficiencies are assumed to be 100 percent.

The number of presses, web width, press speed, and coverage at these facilities can vary greatly. Within the expected precision of the estimates on emissions, the primary consideration is the total solvent use (i.e., the total potential uncontrolled emissions). Width, speed, and coverage, consistent with a particular ink consumption, will make little difference in emissions control costs.

## 7.0 COSTS

### 7.1 Costs of Converting to Water-Borne Inks

The costs of conversion to water-borne inks involve modifications to existing presses. At a minimum, this will involve installation of higher capacity driers or modification of existing driers to handle greater volumes of air. A variety of additional modifications to equipment and operating procedures (e.g., construction material modifications, operating speeds, and equipment cleaning procedures) will also be necessary. The costs of these modifications cannot be predicted accurately because they will depend on the particular jobs being printed. Required changes in operating procedures (reduced press speed, for example) may impose significant costs. Another important consideration is the downtime associated with installation and debugging of retrofit equipment. This downtime in production may make press modifications unreasonable for small facilities with a single printing press.

The primary costs associated with conversion result from the downtime necessary during the experimentation to develop satisfactory operating procedures. For rotogravure facilities, the largest item of capital equipment associated with conversion to water-based units is the dryer. A typical cost for a 5-foot dryer on a 36-inch web press is \$36,000  $\pm$  50 percent (16). An eight-station press might require eight such driers. Packaging rotogravure plants maintain an inventory of cylinders for reuse in subsequent press runs, which would be made obsolete by conversion to water-borne inks. Each cylinder can cost as much as \$2,000 to replace. Thus, replacement of 100 cylinders might cost approximately \$200,000.

The overall cost of water-borne inks to print a particular job may be slightly higher, or slightly lower, than solvent-borne inks. This takes into account both the higher cost per pound and the fact that water-borne inks have a higher solids content and, thus, less is required. The conversion of a solvent-borne ink facility to water-borne inks will result in a significant savings in fire insurance premiums. In addition, press room air quality will be greatly improved.

## 7.2 Total Enclosures for Existing Facilities

The cost of retrofitting an existing facility with a total enclosure capture system varies greatly depending on the layout of the facility. Many existing press rooms already function as total enclosures. Confirmation that an existing structure qualifies as a total enclosure may be as simple as measuring the dimensions, the face velocity, and direction of the air flow at all natural draft openings. This could be accomplished with a tape measure and an anemometer in a few hours.

In the worst case, construction of a total enclosure would necessitate construction of a new room within the existing structure. A more reasonable situation might involve using two existing walls and building two new walls (each containing a door) to create a permanent total enclosure within an existing facility. Sample retrofit specifications and estimated costs are given in Table 3 (17). It should be noted that the actual costs to construct a permanent total enclosure can vary from essentially zero to more than twice the costs listed.

## 7.3 Costs of Thermal Incinerators

Emissions stream characterization assumptions that are necessary to evaluate control technology costs are given in Table 4. Control systems are assumed to operate during downtime at the same flow rate at which they operate during printing operations. The capital costs of thermal incineration systems are given in Table 5, as estimated from the EPA Handbook (8). The scale of equipment required is primarily determined by the flow rate and is much less sensitive to the VOC concentration. For any given annual quantity of potential emissions, the cost of the equipment will be affected by the operating hours. Thus, a plant with uncontrolled emissions of 100 tons annually will need a larger incinerator if it operates 40 hours per week than if the same mass of VOC is created by a smaller press working three shifts per day. Similarly, a plant emitting 100 tons per year with a given operating schedule and 50 percent downtime will have higher control costs than a smaller plant printing 75 percent of the operating hours.

**Table 3. Permanent Total Enclosure Capital Cost Estimates <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	Enclosure specifications	Cost estimate (1991 \$)
1	10	Two walls -- 15 ft high/12 ft wide (each) Two doors -- 10 ft high/12 ft wide 8 ft high/ 3 ft wide	\$ 4,000
2	25	Two walls -- 15 ft high/12 ft wide (each) Two doors -- 10 ft high/ 4 ft wide 8 ft high/ 3 ft wide	4,000
3	50	Two walls -- 15 ft high/20 ft wide (each) Two doors -- 10 ft high/ 8 ft wide 10 ft high/ 4 ft wide	6,800
4	100	Two walls -- 15 ft high/25 ft wide (each) Two doors -- 10 ft high/ 8 ft wide 10 ft high/ 4 ft wide	6,800
5	1,000	Two walls -- 18 ft high/50 ft wide (each) Two doors -- 14 ft high/ 8 ft wide (each)	19,000

<sup>a</sup>These estimates include materials, labor, contractor's overhead, and contractor's profit for 6-inch thick concrete block construction. Labor rates are based on average costs in 30 major U.S. cities. Data from R.S. Means Company, *Building Construction Cost Data - 1990*, 48<sup>th</sup> Annual Edition. Costs have been adjusted to fourth quarter 1991 using Marshall and Swift cost index (18).

**Table 4. Assumptions for Model Plant Costing <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	Operating Time (h/yr)	25% LEL Concentration (ppmv)	Flow rate (std ft <sup>3</sup> /min)	10% LEL Concentration (ppmv)	Flow rate (std ft <sup>3</sup> /min)
1	10	2,086	3,250	500	1,300	965
2	25	4,170	3,250	500	1,300	1,207
2A	25	2,086	3,250	965	1,300	2,413
3	50	4,170	3,250	965	1,300	2,413
3A	50	2,086	3,250	1,930	1,300	4,826
4	100	4,170	3,250	1,930	1,300	4,826
4A	100	2,086	3,250	3,860	1,300	9,652
5	1,000	5,840	3,250	8,239	1,300	20,658

LEL = lower explosive limit (for toluene).

<sup>a</sup> The actual flow rates for model plants 1 and 2 are 385 and 483 std ft<sup>3</sup>/min respectively, but 500-std ft<sup>3</sup>/min thermal incinerator costs have been used because smaller sizes may not be available. A permanent total enclosure (100 percent capture) is assumed.



**Table 5. Thermal Incinerators -- Capital Costs <sup>a</sup>**

Model plant	Potential uncontrolled (ton/yr)	Total (\$)	25% LEL Annualized (\$/yr)	Total (\$)	10%LEL Annualized (\$/yr)
1	10	\$ 99,000	\$ 16,000	\$ 120,000	\$ 19,000
2	25	99,000	16,000	120,000	20,000
2A	25	115,000	19,000	140,000	23,000
3	50	120,000	19,000	140,000	23,000
3A	50	130,000	22,000	170,000	28,000
4	100	130,000	22,000	160,000	27,000
4A	100	160,000	26,000	200,000	33,000
5	1,000	360,000	59,000	450,000	74,000

<sup>a</sup> Costs are derived from U.S. EPA, *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25- ton/yr plants at 25 percent LEL are biased high due to unreliable cost data at flow rates below 500 std ft<sup>3</sup>/min. Estimates assume 50 percent heat recovery for the 1,000-ton/yr plants and no heat recovery for all other plants as energy savings do not justify increased capital costs. Costs have been escalated to the fourth quarter of 1991 using the Marshall and Swift Cost Index (18). Costs do not include construction of a permanent total enclosure.

Annual operating costs for thermal incinerators are given in Table 6. Total costs are very sensitive to the VOC concentration in the emissions stream for any given model plant size because of the importance of gas flow rate in the capital cost and because of the natural gas requirement (included under utilities) to heat the emission stream to approximately 900 °C (1600 °F). Cost effectiveness, or total cost/ton of VOC controlled, is given in Table 7.

#### 7.4 Costs of Catalytic Incinerators

The cost of catalytic incineration has been estimated based on flow and concentration assumptions given in Table 4. Catalytic incinerator systems are rarely used to control streams of less than 2,000 std ft<sup>3</sup>/min. No estimates are given for the 10- and 25-ton/yr model plants at 25 percent lower explosive limit (LEL). An upper bound on these costs would be the costs for facilities of the same size operating with exhaust streams at 10 percent LEL.

Catalytic incineration is not technically feasible for all ink formulations. The cost estimates are given for facilities using ink formulations consistent with the available catalysts. Under some circumstances, it may be possible to change to a different type of ink in order to produce emissions controllable with catalytic incineration. The capital cost of catalytic incinerator systems is given in Table 8. As with thermal incinerators, the flow rate is the most significant factor in sizing the equipment. A given mass of VOC is much more expensive to control in dilute form than in more concentrated form.

Total annual costs for catalytic incinerator systems have been estimated in Table 9. These costs are based on operation of the system during downtime between press runs. As with thermal incineration systems, the cost of natural gas to heat the exhaust stream to the operating temperature is the major operating expense. Catalytic incinerators operate at lower temperatures than thermal incinerators, which provides a cost advantage. Catalytic incinerators operating at 500° C (900° F) can achieve destruction efficiencies equivalent to thermal incinerators operating at 900 °C (1600° F). Cost effectiveness, or total cost per ton of VOC

**Table 6. Thermal Incinerators -- Annual Operating Costs <sup>a</sup>**

plant	Potential uncontrolled (ton/yr)	%LEL	Capital (annualized)	Operating Labor	Maintenance	Utilities	Overhead	TOTAL
1	10	25	\$16,000	\$ 2,100	\$4,000	\$ 5,000	\$ 7,700	\$ 35,000
1	10	10	19,000	2,100	4,000	13,000	9,500	48,000
2	25	25	16,000	4,300	8,100	10,000	11,000	49,000
2A	25	25	19,000	2,100	8,100	10,000	12,000	51,000
2	25	10	20,000	4,300	8,100	32,000	12,000	76,000
2A	25	10	23,000	2,100	8,100	32,000	10,000	75,000
3	50	25	19,000	4,300	8,100	19,000	12,000	62,000
3A	50	25	22,000	2,100	8,100	19,000	12,000	63,000
3	50	10	23,000	4,300	8,100	64,000	13,000	112,000
3A	50	10	28,000	2,100	8,100	64,000	14,000	120,000
4	100	25	22,000	4,300	8,100	38,000	13,000	85,000
4A	100	25	26,000	2,100	8,100	38,000	26,000	100,000
4	100	10	27,000	4,300	8,100	130,000	13,000	180,000
4A	100	10	33,000	2,100	8,100	130,000	30,000	200,000
5	1,000	25	59,000	5,900	11,000	74,000	25,000	170,000
5	1,000	10	74,000	5,900	11,000	370,000	28,000	490,000

<sup>a</sup> Costs are derived from U.S. EPA, *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25-ton/yr plants at 25 percent LEL are biased high due to unreliable cost data at flow rates below 500 std ft<sup>3</sup>/min. Estimates assume 50 percent heat recovery for the 1,000-ton/yr plants and no heat recovery for all other plants as energy savings do not justify increased capital costs. Natural gas cost estimated at \$0.0033/std ft<sup>3</sup>; electricity at \$0.059/kWh. Costs have been escalated to the fourth quarter of 1991 using the Marshall and Swift Cost Index (18). Annualized capital costs do not include costs of construction of a permanent total enclosure.

**Table 7. Thermal Incineration -- Cost Effectiveness<sup>a</sup>**

Model Plant	Potential Uncontrolled Emissions (ton/yr)	Concentration (% LEL)	Cost Effectiveness (\$/ton)
1	10	25	\$3,500
1	10	10	4,800
2	25	25	2,000
2A	25	25	2,000
2	25	10	3,000
2A	25	10	3,000
3	50	25	1,200
3A	50	25	1,300
3	50	10	2,200
3A	50	10	2,400
4	100	25	850
4A	100	25	1,000
4	100	10	1,800
4A	100	10	2,000
5	1000	25	170
5	1000	10	480

<sup>a</sup>Cost effectiveness is based on 100 percent capture. If less efficient capture devices are used, cost effectiveness should be adjusted by dividing listed cost effectiveness by fractional efficiency.

**Table 8. Catalytic Incinerators – Capital Costs <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	25% LEL		10% LEL	
		Total	Annualized	Total	Annualized
1	10	NA	NA	\$ 110,000	\$ 17,000
2	25	NA	NA	120,000	20,000
2A	25	NA	NA	170,000	28,000
3	50	\$ 110,000	\$17,000	180,000	29,000
3A	50	150,000	25,000	250,000	41,000
4	100	150,000	25,000	250,000	41,000
4A	100	220,000	37,000	370,000	61,000
5	1,000	340,000	55,000	690,000	110,000

NA = Not Applicable.

LEL = lower explosive limit (for toluene).

<sup>a</sup> Costs are derived from U.S. EPA, *Handbook: Control Technology for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25-ton/yr plants at 25 percent LEL are not given because equipment of this size may not be available. Costs for 10- and 25-ton/yr plants may be biased high because reliable cost data are not available in this size range. Costs assume 50 percent heat recovery for the 1,000-ton/yr plant operating at 10 percent LEL and no heat recovery for all other plants, as energy savings do not justify increased capital costs. Costs have been escalated to fourth quarter 1991 using the Marshall and Swift Cost Index (18). Capital costs do not include cost of construction of a permanent total enclosure.

**Table 9. Catalytic Incinerators—Annual Operating Costs <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	% LEL	Capital (annualized)	Operating labor	Maintenance	Utilities	Overhead	Total
1	10	10	\$17,000	\$2,100	\$ 5,400	\$ 5,800	\$ 8,900	\$ 39,000
2	25	10	20,000	4,300	9,900	15,000	13,000	62,000
2A	25	10	28,000	2,100	9,900	15,000	14,000	69,000
3	50	25	17,000	4,300	9,500	5,400	13,000	49,000
3A	50	25	25,000	2,100	9,500	5,400	13,000	55,000
3	50	10	29,000	4,300	11,000	29,000	16,000	89,000
3A	50	10	41,000	2,100	11,000	29,000	18,000	100,000
4	100	25	25,000	4,300	11,000	65,000	15,000	120,000
4A	100	25	37,000	2,100	11,000	65,000	17,000	130,000
4	100	10	39,000	4,300	16,000	58,000	22,000	140,000
4A	100	10	61,000	2,100	16,000	58,000	26,000	160,000
5	1000	25	51,000	5,900	23,000	65,000	31,000	180,000
5	1000	10	100,000	5,900	41,000	148,000	56,000	350,000

LEL = lower explosive limit for toluene.

<sup>a</sup> Costs are derived from U.S. EPA, *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25-ton/yr plants at 25 percent, LEL are not given because equipment of this size may not be available. Costs for 10- and 25-ton/yr plants may be biased high because reliable cost data are not available in this size range. Costs assume 50 percent heat recovery for the 1,000-ton/yr plant operating at 10 percent LEL and no heat recovery for all other plants as energy savings do not justify increased capital costs. Maintenance costs include a change of catalyst every 2 years. Overhead includes taxes, insurance, and administration. Costs have been escalated to fourth quarter 1991 using the Marshall and Swift Cost Index (18). Annualized capital costs do not include costs of construction of a permanent total enclosure.

controlled, is given in Table 10. Note that the decision to use catalytic incineration implies a commitment to use inks that are compatible with the catalyst.

### 7.5 Costs of Carbon Adsorption Systems

Carbon adsorption system costs have been estimated based on toluene as the VOC to be controlled. Working capacities of activated carbon applied to the model plants are assumed to be 0.67 lb toluene/lb carbon for the plants operating at 25 percent LEL and 0.61 lb toluene/lb carbon for the plants operating at 10 percent LEL. Different ink solvents and solvent mixtures may require more or less carbon.

Regenerable carbon adsorption systems are rarely used for control of flows less than 2,000 std ft<sup>3</sup>/min. Carbon canister systems for low flows are available at about \$4/lb. This is equivalent to \$13,000 per ton of VOC controlled. An oversized regenerable carbon system provides an upper bound on the cost of systems for small facilities. These systems are more economical than canister systems, even if sized several times larger than necessary.

Capital costs for regenerable carbon adsorption systems are given in Table 11. The cost of systems for the 50-ton/yr model plants can be applied to smaller plants. The carbon system costs are much less sensitive to the VOC concentration of the stream and are primarily influenced by the amount of carbon required and the size of the vessels required to house it. Costs have been estimated using the procedures described in *Handbook: Control Technologies for Hazardous Air Pollutants* (8); however, more conservative assumptions about cycle time have been used.

Annual operating costs are estimated in Table 12. Cost estimates for the 10- and 25-ton/yr model plants are extremely conservative but are included because oversized regenerable systems will still be much more economical than canister systems. No credits have been included for recovered solvents; if the solvents are suitable for reuse, a significant reduction in control costs can be achieved. Cost effectiveness, in terms of cost per ton of VOC controlled, is given in Table 13. Carbon systems will be more economical than incineration systems in many cases. Note that ink formulations used in specific plants may be inconsistent with adsorption systems or may require different, and perhaps more expensive designs.

**Table 10. Catalytic Incineration – Cost Effectiveness\***

Model plant	Potential uncontrolled emissions (ton/yr)	Concentration (% LEL)	Cost effectiveness (\$/ton)
1	10	10	\$3,900
2	25	10	2,500
2A	25	10	2,800
3	50	25	980
3A	50	25	1,100
3	50	10	1,800
3A	50	10	2,000
4	100	25	1,200
4A	100	25	1,300
4	100	10	1,400
4A	100	10	1,600
5	1000	25	180
5	1000	10	350

LEL = Lower explosive limit (for toluene).

\*Cost effectiveness assumes 100 percent capture. If capture efficiency is less than 100 percent, cost effectiveness should be adjusted by dividing by the fractional capture efficiency.



Table 11. Carbon Adsorption Systems--Capital Costs <sup>a</sup>

Model plant	Potential uncontrolled emissions (ton/yr)	25% LEL		10% LEL	
		Total	Annualized	Total	Annualized
3, 3A	50	\$ 77,000	\$13,000	\$ 77,000	\$13,000
4, 4A	100	\$110,000	\$17,000	\$110,000	\$17,000
5	1000	\$330,000	\$53,000	\$330,000	\$53,000

LEL = Lower explosive limit (for toluene).

<sup>a</sup>Costs are derived from, *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25-ton/yr plants are not given because equipment of this size may not be available. Costs for 50- and 100-ton/yr model plants are based on two adsorbers each with a working capacity equivalent to 24 hours of emissions. Costs for the 1,000-ton/yr model plant are based on three adsorbers each with a capacity equivalent to 12 hours of emissions. Smaller facilities could be controlled with systems suitable for the 50-ton/yr model plant. Costs for 100- and 1,000-ton/yr model plants may be biased high, as shorter cycle times (and smaller absorbers) may be adequate. Costs have been escalated to fourth quarter 1991 using the Marshall and Swift Cost Index (18). Capital costs do not include construction of a permanent total enclosure.

**Table 12. Carbon Adsorption Systems – Operating Costs <sup>a</sup>**

Model plant	Potential uncontrolled emissions (ton/yr)	% LEL	Capital (annualized)	Operating labor	Maintenance	Utilities	Overhead	Total
1	10	25	\$(13,000)	\$(2,100)	\$(9,000)	\$(200)	\$(11,000)	\$(35,000)
1	10	10	(13,000)	(2,100)	(9,000)	(200)	(11,000)	(35,000)
2, 2A	25	25	(13,000)	(2,100)	(9,000)	(500)	(11,000)	(36,000)
2, 2A	25	10	(13,000)	(2,100)	(9,000)	(650)	(11,000)	(36,000)
3, 3A	50	25	13,000	4,300	9,200	1000	(11,000)	38,000
3, 3A	50	10	13,000	4,300	9,000	1300	(11,000)	39,000
4, 4A	100	25	17,000	4,300	9,000	2000	13,000	45,000
4, 4A	100	10	17,000	4,300	9,000	2600	13,000	46,000
5	1000	25	53,000	5,900	14,000	20,000	25,000	120,000
5	1000	10	53,000	5,900	14,000	26,000	25,000	120,000

LEL - Lower explosive limit (for toluene).

<sup>a</sup>Costs are derived from *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991. Annualized costs are based on 10-year equipment life at 10 percent interest. Costs for 10- and 25-ton/yr plants have been estimated as equivalent to costs for 50-ton/yr plants because of the lack of reliable cost data for flows less than 2,000 std ft<sup>3</sup>/min and very high economies of scale in equipment costs. Estimates assume no credit for recovery of solvent. Recovered solvents may be worth up to \$200/ton, if the composition is suitable for reuse. Electricity cost is estimated at \$0.059/kWh. Carbon costs estimated at \$2/lb with a 5-year life. Overhead costs include taxes, insurance, and administration. Costs have been escalated to fourth quarter 1991 using the Marshall and Swift Cost Index (18). Annualized capital costs do not include costs of construction of a permanent total enclosure.

**Table 13. Carbon Adsorption – Cost Effectiveness <sup>a</sup>**

Model plant	Potential uncontrolled emissions (Ton/year)	Concentration (% LEL)	Cost effectiveness (\$/ton)
1	10	25	\$3,500 (13,000) <sup>b</sup>
1	10	10	3,500 (13,000) <sup>b</sup>
2, 2A	25	25	1,400 (13,000) <sup>b</sup>
2, 2A	25	10	1,400 (13,000) <sup>b</sup>
3, 3A	50	25	760
3, 3A	50	10	780
4, 4A	100	25	450
4, 4A	100	10	460
5	1000	25	120
5	1000	10	120

<sup>a</sup> Carbon capacity has been assumed at 0.6 lb carbon/lb toluene. Estimates for regenerable systems for 10- and 25-ton/yr model plants are based on capital costs for 50-ton/yr model plants. Actual cost for these plants will be lower. Costs were estimated using *Handbook: Control Technologies for Hazardous Air Pollutants*, EPA/625/6-91/014, 1991, and escalated to fourth quarter 1991 using the Marshall and Swift Cost Index (18). Cost effectiveness assumes 100 percent capture. If capture efficiency is less than 100 percent, cost effectiveness should be adjusted by dividing by the fractional capture efficiency.

<sup>b</sup> The cost of "throwaway" carbon canisters is estimated at \$4/lb total.

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