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Research Triangle Park NC 27711

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Control of Volatile Organic Emissions from Existing Stationary Sources -

Volume VIII: Graphic Arts - Rotogravure and Flexography

EPA-450/2-78-033
OAQPS No. 1.2-109

Control of Volatile Organic Emissions from Existing Stationary Sources - Volume VIII: Graphic Arts - Rotogravure and Flexography

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Emission Standards and Engineering Division
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U.S. ENVIRONMENTAL PROTECTION AGENCY
Office of Air and Waste Management
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OAQPS GUIDELINE SERIES

The guideline series of reports is being issued by the Office of Air Quality Planning and Standards (OAQPS) to provide information to state and local air pollution control agencies; for example, to provide guidance on the acquisition and processing of air quality data and on the planning and analysis requisite for the maintenance of air quality. Reports published in this series will be available - as supplies permit - from the Library Services Office (MD-35), U.S. Environmental Protection Agency, Research Triangle Park, North Carolina 27711, or, for a nominal fee, from the National Technical Information Service, 5285 Port Royal Road, Springfield, Virginia 22161.

Publication No. EPA-450/2-78-033
(OAQPS No. 1.2-109)

CONVERSION FACTORS FOR METRIC UNITS

Metric Unit	Metric Name	Equivalent English Unit
Kg	kilogram (10^3 grams)	2.2046 lb
liter	liter	0.0353 ft^3
m	meter	3.28 ft
m^3	cubic meter	35.31 ft^3
Mg	megagram (10^6 grams)	2,204.6 lb
metric ton	metric ton (10^6 grams)	2,204.6 lb

In keeping with U.S. Environmental Protection Agency policy, metric units are used in this report. These units may be converted to common English units by using the above conversion factors.

Temperature in degrees Celsius (C^o) can be converted to temperature in degrees Farenheit (^oF) by the following formula:

$$t^o{}_f = 1.8\ (t^o{}_c) + 32$$

$t^o{}_f$ = temperature in degrees Farenheit

$t^o{}_c$ = temperature in degrees Celsius or degrees Centigrade

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1.0 INTRODUCTION AND SUMMARY

1.1 GENERAL DISCUSSION

This report is one of a continuing series designed to assist State and local jurisdictions in the development of air pollution control regulations for volatile organic compounds. (VOC) which contribute to the formation of photochemical oxidants. The report deals with VOC emissions from the graphic arts operations which utilize inks containing volatile organic solvents.

The graphic arts industry encompasses printing operations which fall into four principal categories, namely: letterpress, offset lithography, rotogravure and flexography. This guideline is applicable to both the flexographic and rotogravure processes as applied to both publication and packaging printing. It does not apply to offset lithography or letterpress printing.

1.2 ACHIEVABLE CONTROL LEVELS

Rotogravure and flexography utilizes inks which contain large fractions (50 to 80 percent or higher) of volatile organic solvents. Certain applications are as high as 96 percent solvent.

Below are provided emission limitations that represent the presumptive norm that can be achieved through the application of reasonably available control technology (RACT). Reasonably available control technology is defined as the lowest emission limit that a particular source is capable of meeting by the application of control technology that is reasonably available considering technological and economic feasibility. It may require technology that has been applied to similar, but not necessarily identical source categories. It must be cautioned that the limits reported in this section are based on capabilities and problems which are general to the industry, but may not be applicable to every plant.

1.2.1 Available Add-On Control Devices

The vast majority of rotogravure and flexographic printing units use organic solvent-borne inks. Emission reduction can be achieved by use of carbon adsorption or incineration sytems. A reduction efficiency of 90 percent of the VOC delivered to these devices can and should be achieved. In addition, it is implicit the RACT requires installation of the best practicable capture system to assure that the VOC is directed to the control device. A number of carbon adsorption systems at publication and rotogravure plants have been reported to achieve overall recovery efficiencies of 75 percent or more, based on material balances. Assuming adsorber efficiencies of 90 to 95 percent, capture efficiencies of 75 to 85 percent were being realized. There is no available method of measuring capture efficiency directly.

Large packaging rotogravure presses could be expected to have capture efficiencies somewhat less than publication plants because of shorter runs and other factors. A capture efficiency of 75 percent would appear to be reasonable, with an overall VOC recovery/control efficiency of about 65 percent for either adsorption on incineration systems.

The capture problem for flexographic presses is more difficult than for rotogravure presses because of the manner of construction of flexographic presses. The printing units and dryers are mounted on a vertical circular axis such that effective hooding and ducting are difficult to construct. A capture efficiency of 70 percent appears to be reasonable for these presses for an overall VOC control efficiency of 60 percent.

1.2.2 Water-Borne and High Solids Inks

Water-borne inks are available which will meet some printing requirements of both rotogravure and flexography. Ink manufacturers are working to develop water-borne inks which will meet additional requirements. EPA desires to encourage such developments because of the material and energy saving potentials. It is recommended that printing systems in which all printing units utilize a water-borne ink whose volatile portion consists of 75 volume percent water and 25 volume percent organic solvent (or a lower VOC content) be considered equivalent to the exhaust treatment systems described in Section 1.2.1.

Some printing systems may be able to utilize water-borne inks for heaviest coverage, but still require some solvent-borne inks for light coverage.* For such systems, if a 70 volume percent overall reduction of solvent usage is achieved (compared to all solvent-borne ink usage), the complete operation can be considered equivalent to the exhaust treatment systems described in Section 1.2.1.

There are no high solids inks now in use in rotogravure or flexographic printing operations. However, ink manufacturers have stated that they will continue development work in this area. It is recommended that inks which contain 60 percent or more non-volatile material be exempt from emission limitations in order to encourage development of high solids inks.

*Heavy coverage means large areas of a given color. A thin strip of a given color is an example of light coverage.

1.2.3 Alternative Control Methods

Publication rotogravure uses inks with solvent mixtures of water-immiscible solvents. The vapor can be recovered with carbon adsorption systems and reused by ink manufacturers and printers. Some systems yield a net profit after amortization and operating expenses.

Printing of packaging materials by rotogravure and flexography requires inks with more complex solvent mixtures. Many of the solvents are water-soluble. Conventional carbon adsorption systems using steam for regeneration may not be a viable control method because the recovered solvents cannot be reused. Reformulation of the inks may, in some cases, make carbon adsorption a viable control technique. A new fluidized bed carbon adsorption system uses nitrogen for desorption and may provide a viable method for recovering solvents from packaging inks, as well as publication inks. Incineration systems with heat recovery may be a more practical solution for some packaging operations. Incineration has been shown to provide 90 percent and greater removal of VOC in many similar applications.

1.2.4 Differentiation of Coating and Printing Operations

The production of packaging materials involves two principal operations which emit volatile organic compounds: 1) coating and laminating of paper, film, and foil; 2) printing of words, designs, and pictures upon webs of paper, film, and foil. For the purposes of this document, coating is defined as the application of a uniform layer of material across the entire width of a web. Printing is the formation of words, designs and pictures, usually by a series of application rolls each with only partial coverage.

The recommended emission limits for coating and laminating operations in the production of packaging materials are given in Volume II of this series.* The emission limits in this document apply to printing operations in the production of packaging materials and to publication rotogravure printing operations. However, all units in a machine which has both coating and printing units will be considered as performing a printing operation. A typical operation is as follows: The first unit applies a uniform background color; subsequent units print addtiional colors; the final unit applies a varnish overcoat. Such a machine would be subject to the guideline for graphic arts.

1.3 COST EFFECTIVENESS

The cost effectiveness of carbon adsorption is influenced strongly by VOC concentration and tonnage and by the value of recovered solvent. Where VOC concentration is 1200 ppm, cost effectiveness range from \$51 to \$38/Mg (\$46 to \$34/ton) of VOC recovered over the range of 2000 Mg (2200 tons) to 4000 Mg (4400 tons) of VOC input per year. At a VOC concentration of 2400 ppm and 2000 Mg/yr input the recovery system pays for itself, and at 4000 Mg/yr input yields a \$15/Mg profit. These values are typical of a large operation where the solvent can be reused in the process or sold to an ink manufacturer. No data are available for smaller carbon systems.

The cost effectiveness of incineration systems are strongly influenced by annual tonnage of the VOC controlled and by the VOC concentration and degree of heat recovery. For a VOC input rate of about 90 Mg/yr (100 tons/yr) the cost of effectiveness ranges from \$600/Mg (\$600/ton) of VOC controlled at a concentration of 1500 ppm and 85 percent heat

*Control of Volatile Organic Emissions from Existing Stationary Sources - Volume II: Surface Coating of Cans, Coils, Paper, Fabrics, Automobiles, and Light-Duty Trucks. EPA-450/2-77-008, May 1977.

recovery to \$2000/Mg (\$1800/ton) at a VOC concentration of 500 ppm and no heat recovery. For a VOC input rate of about 1500 Mg/yr (1650 ton/yr) the cost effectiveness ranges from \$120 per ton of VOC at concentrations of 1500 ppm and 85 percent heat recovery to \$1500/Mg (\$1650/ton) for concentrations of 500 ppm and no heat recovery.

The greatest VOC control costs are associated with small flexographic printing operations having relatively low VOC levels and often operated intermittedly. In many cases, it may be possible to improve capture systems resulting in higher VOC levels and lower ventilation rates. Even with improved capture systems, it may not be reasonable to require exhaust gas treatment at many small printing installations.

2.0 SOURCES AND TYPES OF EMISSIONS

2.1 GENERAL DISCUSSION

Originally the term graphic arts meant only such fine arts as painting and drawing. In time the meaning expanded and shifted to various picture reproduction methods, such as engraving, etching, and lithographing. Finally, the graphic arts industry has become simply a different name for the printing industry.[1]

This diverse industry is characterized by a large number of small plants and a small number of large plants. Approximately 80 percent of commercial printing establishments employ fewer than 20 people.[2] The largest publication gravure plants employ hundreds of people and have a daily potential VOC emission rate of 20 Mg (22 tons).

Printing establishments are scattered throughout the country but the vast bulk of the printing has historically been done in the large metropolitan areas. Most periodicals are published in New York, Chicago, Philadelphia and Los Angeles.[2] However, in the last few years several new large plants have been built in non-urban areas. This appears to be a new trend.

2.2 PRINTING PROCESSES

Printing operations of any sizeable volume utilize presses in which the image carrier is curved and mounted on a cylinder which rotates, (rotary presses) or the image is engraved or etched directly on a cylinder.

In direct printing the image is transferred directly from the image to the print surface. In indirect printing the image is transferred to an intermediate roll (called a blanket) and thence to the print surface.

2.2.1 Flexography

In flexographic printing, the image areas are raised above the non-image surface. The distinguishing feature is that the image carrier is made of rubber and other elastomeric materials. A feed cylinder rotates in a trough of ink (called an ink fountain), and delivers ink to the plate (image), cylinder, through a distribution roll, as shown in Figure 2.1. Flexographic presses are usually of rotary web design, i.e., roll-fed. Presses printing upon corrugated paperboard are a major exception.

Flexography uses very fluid inks, (low viscosity) typically about 75 volume percent organic solvent. The inks dry by solvent absorption into the web and evaporation, usually in high velocity air dryers at temperatures below 120^{o}C. Solvents compatible with rubber or other plate materials must be used. Typical solvents are alcohols, glycols, esters, hydrocarbons and ethers.

2.2.2 Gravure

In the gravure method printing, image areas are recessed relative to non-image area. The image carrier is a copper-plated steel cylinder usually also chrome plated to enhance wear resistance. The image is in the form of cells or cups mechanically or chemically etched in the surface. Typically, a gravure cell is 35 μ (.0014 inches) deep by 125 μ (.005 inches) square, with 22,500 cells to the square inch.[3] The gravure cylinder rotates

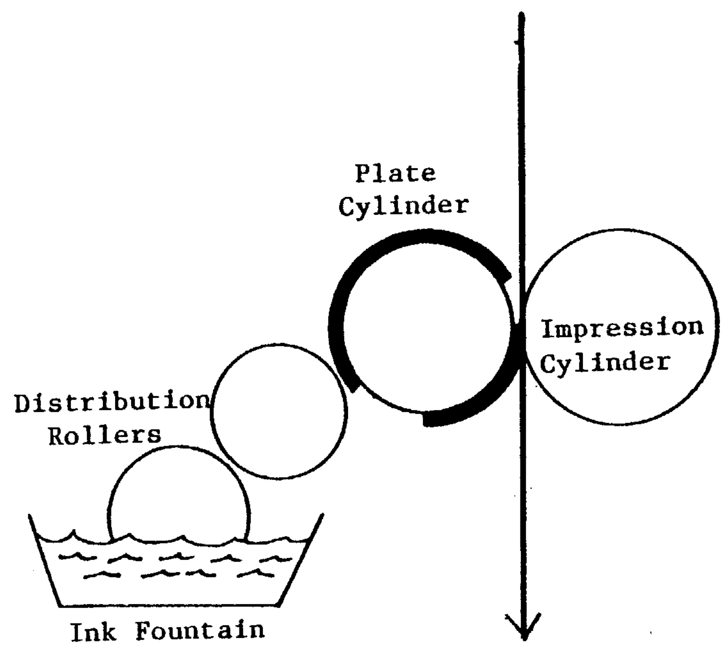

Figure 2-1. Ink Distribution System for Flexography

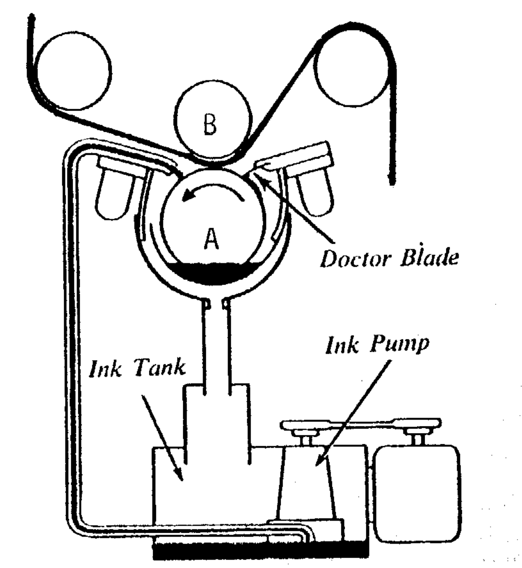

Figure2-2. Rotogravure Ink System
(A) Etched Cylinder
(B) Impression Cylinder

in an ink trough or fountain. Excess ink is removed by a steel doctor blade. The ink in the cells is then transferred to the web when it is pressed against the cylinder by a rubber-covered impression roll, as shown in Figure 2-2. Rotary gravure presses are called rotogravure presses.

Rotogravure also requires very fluid inks. Solvent content ranges from 50 to 85 percent or higher. Typical solvents, include alcohols, aliphatic napthas, aromatic hydrocarbons, esters, glycol ethers, ketones, nitroparaffins and water.[3] Solvent is evaporated in low temperature driers, 38^{0} to $93^{0}C$ (100^{0} to $200^{0}F$). The hot air imprringement dryers usually are indirectly heated by steam or hot air. Steam drum dryers are also used.

2.2.2.1 Uses for Flexographic and Rotogravure Printing and Coating

Flexographic and gravure printing and coating applications fall into three major cateogries: publication, packaging and specialties. In the publications field, magazines, mail order catalogues, brochures, newspaper supplements, comics and other commercial printing are printed by the gravure process. Packaging products predominantly printed by gravure, include cigarette cartons and labels, can labels, detergent cartons, and many other folding cartons. Flexography is typically used for bread bags, multi-wall bags, milk cartons, corrugated paper board, paper cups and plates, labels, tags, tapes and envelopes. Both printing processes are used for flexible film and foil to be used for overwraps or laminates, composite cans, carrier cartons, frozen food wraps, and gift wraps.

In the specialty field, both flexography and gravure are used for wall covering and decorating household paper products such as towels and tissue. Gravure is used for floor covering, cigarette filter tips, vinyl upholstery, woodgrains, and a variety of other products. Gravure is also used for applying accurately metered quantities of coatings to paper and other kinds of webs in various manufacturing operations where its fast-drying inks and the ability to print well on a wide variety of surfaces are advantageous.[3] Recommended emissions limitations from the coating uses of gravure are covered in other volumes of this guideline series, such as Volume II: Surface Coating of Cans, Coils, Paper, Fabric, Automobiles, and Light-Duty Trucks, and Volume VII: Factory Surface Coating of Flat Wood Paneling. The recommended emission limitations given in this volume do not apply to these operations.

2.2.2.2 Nature of the Flexographic and Gravure Printing Industries - Publication printing is done in large printing plants, numbering less than 50 in total.[3] Package and specialty printing by flexography and gravure is done by a considerably larger number of companies, ranging from large integrated packaging companies with many press units of small captive operations with only one or two press units.[3] It is estimated that there are from 13 to 14 thousand gravure printing units[4] and 30,000 flexographic printing units.[5]

2.3 STOCK FEEDING METHODS

Presses are divided into two classes by feeding methods: sheet-fed and roll-fed. Stock fed from a roll is referred to as a web. High volume roll presses are significant sources of VOC.

2.4 PRINTING INKS

Printing inks are composed of the same type of ingredients as surface coatings: pigments, vehicles and solvents. Of course, they are tailored to have different properties than coatings. In addition to regulatory limitations required by EPA, OSHA, FDA, and USDA, the specifications for an ink are governed by a number of considerations such as: (1) printing processes and methods; (2) kind of press; (3) paper or other substrate; (4) drying process; (5) desired finish, matte, gloss, etc., (6) end use of the printed product; (7) color; (8) fabrication method to which the printed stock will be subjected; (9) sequence of ink application, in multicolor printing.[1]

The solvent content of inks varies widely. Flexograph and gravure ink contain 50 to 85 percent solvent and dry by solvent evaporation. Water-borne inks are used for special applications; they contain 5 to 30 percent VOC solvent.

The following solvents are representative of those used in printing inks, usually in combinations:

Toluene	Ethanol
Xylene	Butanol
Heptane	Glycols
Isooctane	Glycol ether esters
Mineral Spirits	Glycol esters
Naphtha	Acetone
Hexane	Methyl ethyl ketone
Propanol	Isopropyl acetate
Isopropanol	Normal propyl acetate
Methanol	Ethyl acetate

2.5 EMISSION POINTS

Roll-fed printing presses require dryers to evaporate solvent in order to produce a product with immediate handleability. Solvent vapors are emitted from printing units and dryers. Some printing operations which utilize air pollution control equipment have the printing units hooded and vented to the control device.

2.5.1 Dryer Types

A variety of dryer types are used including steam-heated and other indirectly heated designs. Direct-fired dryers are mainly high velocity/ hot air dryers. Steam-heated dryers are the principal type of indirectly heated dryers.

Steam-heated dryers are of two types: drum and forced circulation dryers. Drum dryers are cylinders to which steam is applied. The printed web is brought around the drum with the printed surface on the outside. The web is heated by conduction. In forced circulation dryers, air is heated by passing over steam coils or tubes and is circulated through the drying chamber by a fan(s).

2.6 NATIONAL EMISSIONS

Data for a direct determination of the total national emissions from the printing industry are not available. However, a report by Gadomski[2] contained data on the ink and solvent usage for 1968 from plants estimated to have 32 percent of the national total. Total ink usage for these plants was 141 million pounds. Additional solvent for ink dilution and clean-up totaled 21 million gallons. Total solvent usage was 95,000 tons (87,000 Mg). From this the study suggested a 1968 national total usage of 300,000 tons (270,000 Mg). Assuming a three percent annual growth rate, the 1976 solvent usage rate would be 380,000 tons (340,000 Mg). The average degree of control is estimated to be 30 percent leaving uncontrolled emissions of 270,000 tons per year (240,000 Mg/yr).

The above report separated the ink consumption into a percentage for each printing process by the survey results and by a survey conducted by the National Association of Printing Ink Manufacturers. The additional solvent figures were also separated by printing process type. The three sets of figures were averaged to give the following breakdown:

Process	Percent of Emissions	Emissions Mg/yr
Gravure	41	100,000
Lithography	28	67,000
Letterpress	18	43,000
Flexography	13	30,000
		240,000

2.7 REFERENCES

1. Strauss, Victor, The Printing Industry. Printing Industries of America, Inc., Washington, D.C. 1967.

2. Gadomski, R. R., et. al. Evaluations of Emissions and Control Technologies in the Graphic Arts Industries, Phase I, Graphic Arts Technical Institute. August 1970.

3. George, H. F., Gravure Industry's Environmental Program. In conference on Environmental Aspects of Chemical Use in Printing Operations. EPA-5601/1-005. Office of Toxic Substances, Environmental Protection Agency, January 1976. pp 204-216

4. Long, R. P., and W. R. Daum, "Gravure Survey," Package Printing Diecutting, January 1975, pp 12-14. Cited in Reference 3.

5. Comment letter from the Flexographic Technical Association, November 27, 1978.

3.0 APPLICABLE SYSTEMS OF EMISSION REDUCTION

3.1 INTRODUCTION

Emissions of volatile organic compounds (VOC) can be reduced by add-on control devices and by the use of water-borne and low solvent inks. In this chapter the applicability of these methods to the various printing processes will be reviewed.

3.2 ADD-ON EQUIPMENT

Fume incinerators and carbon adsorbers are the only devices which have proven to have a high efficiency in controlling vapors from rotogravure and flexographic printing operations.

3.2.1 Carbon Adsorption

Recovery of solvents by use of carbon adsorption systems has been successful at a number of large publication rotogravure plants. The presses in question used a single, water immiscible solvent (toluene) or a mixture which is recovered in approximately the proportions used in the ink. Three such plants were reported to have systems which recover 6,000 to 7,000 gallons (20 to 23 Mg) per day of solvent each.[1,2,3] These recovery systems were installed for economic and regulatory reasons. Solvent is evaporated from the web in indirect steam heated dryers which precludes any solvent decomposition. Regeneration is accomplished by use of steam, followed by condensation and a simple decantation. Because the solvents are water-immiscible a relatively simple system for separating condensed water and solvent is possible.

Some rotogravure operations, such as printing and coating of packaging materials, utilize inks and coatings containing complex solvent mixtures. Many of the solvents are water soluble. The solvents required for a folding carton operation, for example, consists of toluene, heptane, ethyl acetate, methyl ethyl ketone, and isopropyl alcohol. The last three are soluble in water. If a carbon recovery system with steam regeneration were used, a distillation system would be required to recover and separate the water-soluble solvents. Since azeotropes (constant boiling mixtures) are formed, adequate separation would be very difficult. In addition, frequent product changes result in varying solvent combinations, making solvent recovery for reuse difficult and costly.

However, reformulation of inks offers a possible method of avoiding the above difficulties. Many of the present solvent mixtures were developed to comply with Rule 66 of Los Angeles County and similar legislation. Because of EPA's 1977 policy statement on reactivity, it is now possible to revert to the simpler solvent mixtures used in the past. Many printers will be able to revert to a mixture of immiscible hydrocarbons and a single ester or MEK, which could be reused as a mixture after dewatering. It will be practical for many packaging type printers to solve a large percentage of their emission control requirements by the use of carbon adsorption and relatively simple dewatering techniques.[4]

A new type of carbon adsorption system offers another method of avoiding trouble with water soluble solvents. A fluidized bed carbon system, developed in Japan, is being marketed in the United States. The carbon is in the form of highly abrasion resistant carbon beads. In the adsorbing section the beads cascade in the fluidized state down a tray tower. Solvent laden air enters the bottom of the tower and leaves at the top. The beads then flow through the desorbing section in a dense bed where they are heated indirectly in the presence of nitrogen which acts as a desorbing gas. The nitrogen is then cooled in indirect heat exchangers to condense the solvent. The nitrogen is then recycled to the desorber.

The following advantages are claimed for the fluidized bed system, relative to fix bed systems:

- Better thermal efficiency
- Lower blower power consumption
- No mixing with water at desorption
- No valves or cycling equipment
- less space required
- Less susceptible to blinding
- Can be regenerated at higher temperatures to remove high boiling materials

A disadvantage of this system is that relatively constant air volume must be maintained. Also the capital cost may be higher.

Additional information on theory, design and practices concerning carbon adsorption systems is given in Volume I (EPA-450/2-76-028) of this guideline series.[5]

3.2.2 Incineration

Incineration destroys organic emissions by oxidizing them to carbon dioxide and water vapor. Incineration is a technically feasible method of controlling emissions from all printing operations. Both direct flame (thermal) and catalytic incinerators are potential methods of controlling emissions from flexography and packaging gravure printing.

3.2.2.1 Heat Recovery

The cost of operating an incineration system can be substantially reduced by the use of heat recovery equipment. Primary heat recovery uses the hot incinerator exhaust gases to preheat the dryer exhaust gases prior to incineration. A secondary heat exchanger can sometimes supply the heated air required to operate the dryer. Cost data is given in Chapter 4 for incineration systems with and without heat recovery. Incineration and heat recovery systems are described in Volume I (EPA-450/2-76-028) of this series.[5]

In addition to direct-flame and catalytic incinerators, a third type is available. Pebble bed incinerators combine the functions of a heat exchanger and a combustion device. A diagram of such a system is shown in Figure 3-3. The solvent laden exhaust from the dryers and floor sweeps enter one of the pebble beds which has been heated by the combustion chamber exhaust in the previous cycle. Oxidation of the vapors starts in the preheat bed and is completed in the combustion chamber. The exhaust gases exit through a second pebble bed transferring heat to the pebbles. The dampers are reversed periodically, thereby alternating the functions of the two pebble beds.

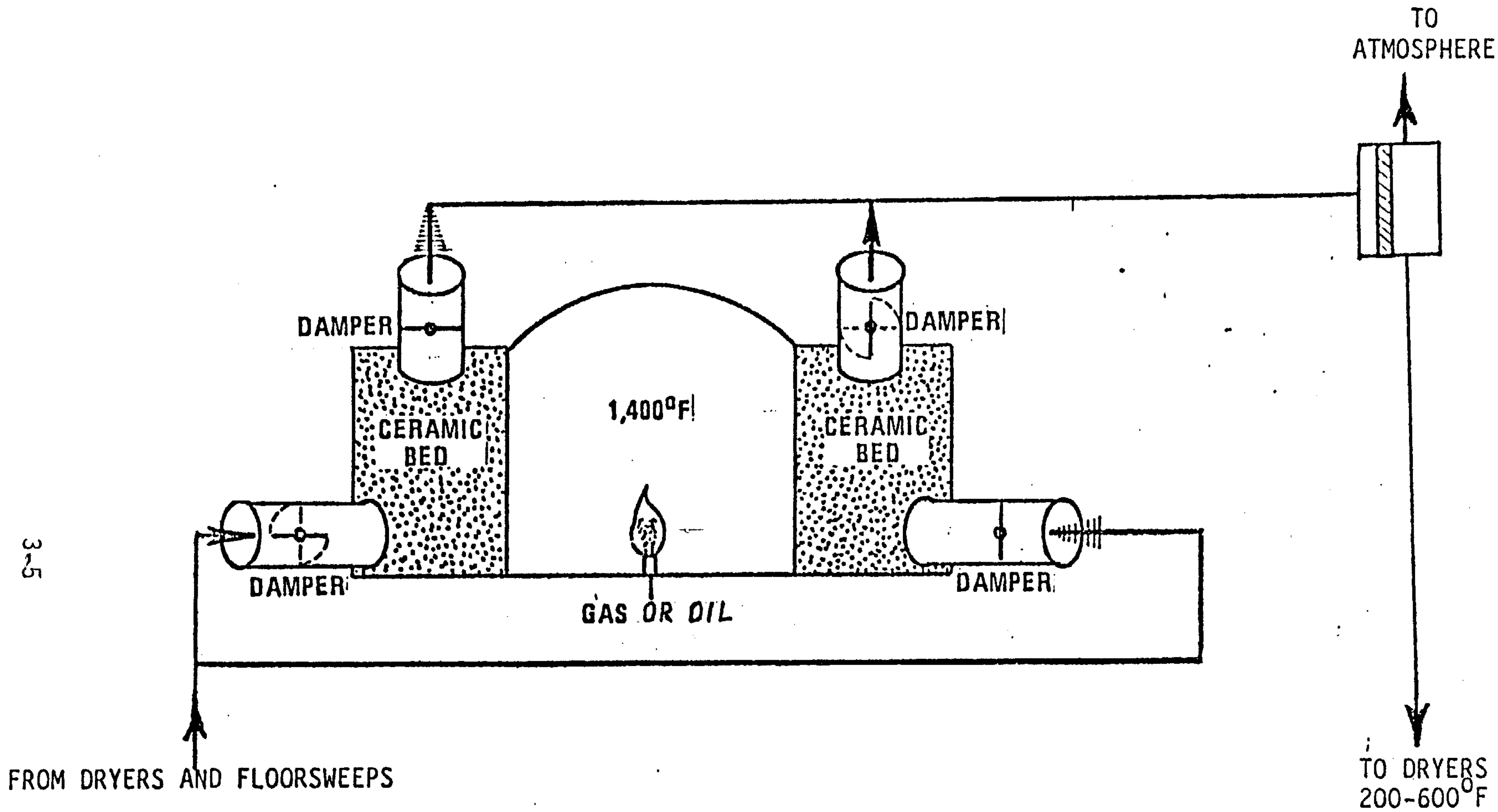

Figure 3.3 Ceramic bed regenerative type incineration and heat recovery system.

An incinerator having three or more pebble beds will allow one pebble bed to be removed from the process while the other two pebble beds are acting as both the energy recovery after incineration and as air preheat prior to incineration. The use of the third pebble bed will further allow the residual fumes in that chamber to be flushed to the combustion zone prior to flow reversal, thus providing the highest level of combustion efficiencies. Such flushing is not possible if there are only two pebble beds. A diagram of a five bed system is shown in Figure 3-4.

Pebble bed systems have been designed to achieve a heat recovery efficiency of 85 percent. When the vapor concentration is about 10 percent of the LEL, the burner throttles to a pilot light condition, the VOC fumes furnishing virtually all of the fuel requirement during periods of continuous operation.

Recovery of heat from incineration exhaust gases can also be accomplished by the use of liquid media heat exchangers. A system using hot oil to transfer heat from the incinerator exhaust to the dryers has been installed on a number of rotogravure presses at paperboard and bag printing plants. This system utilizes an organic vapor sensing device to control dampers in dryer exhaust so as to maintain a preset percentage of the Lower Explosive Limit (L.E.L.). Thus the exhaust rate is minimized, and the VOC furnishes the greater part of the heat to operate the incinerator. Also the incinerator furnishes the heat to operate the dryers. A sketch of such a system is shown in Figure 3-5.

3.3 USE OF LOW SOLVENT INKS FOR PACKAGING GRAVURE AND FLEXOGRAPHIC PRINTING

Low solvent inks are of three types: water-borne, high-solids and radiation curable inks. Only water-borne inks are widely used at the present time and are discussed in the following section.

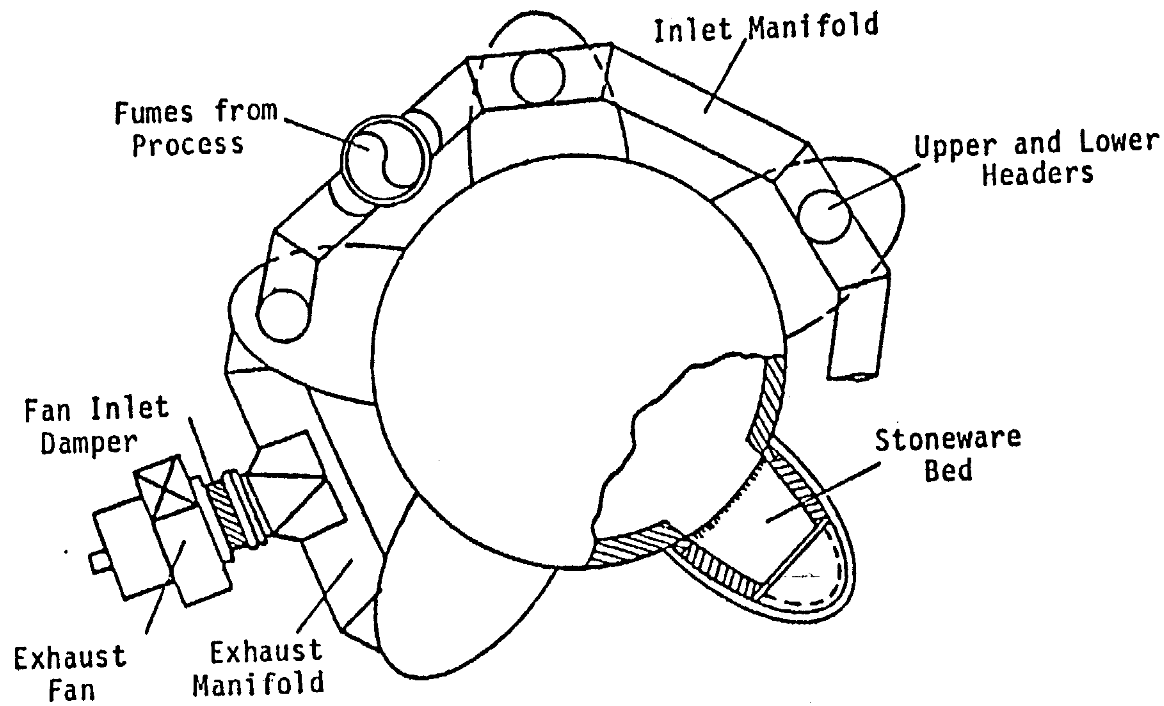

Figure 3.4 Top view of REECO RE-THERM system.

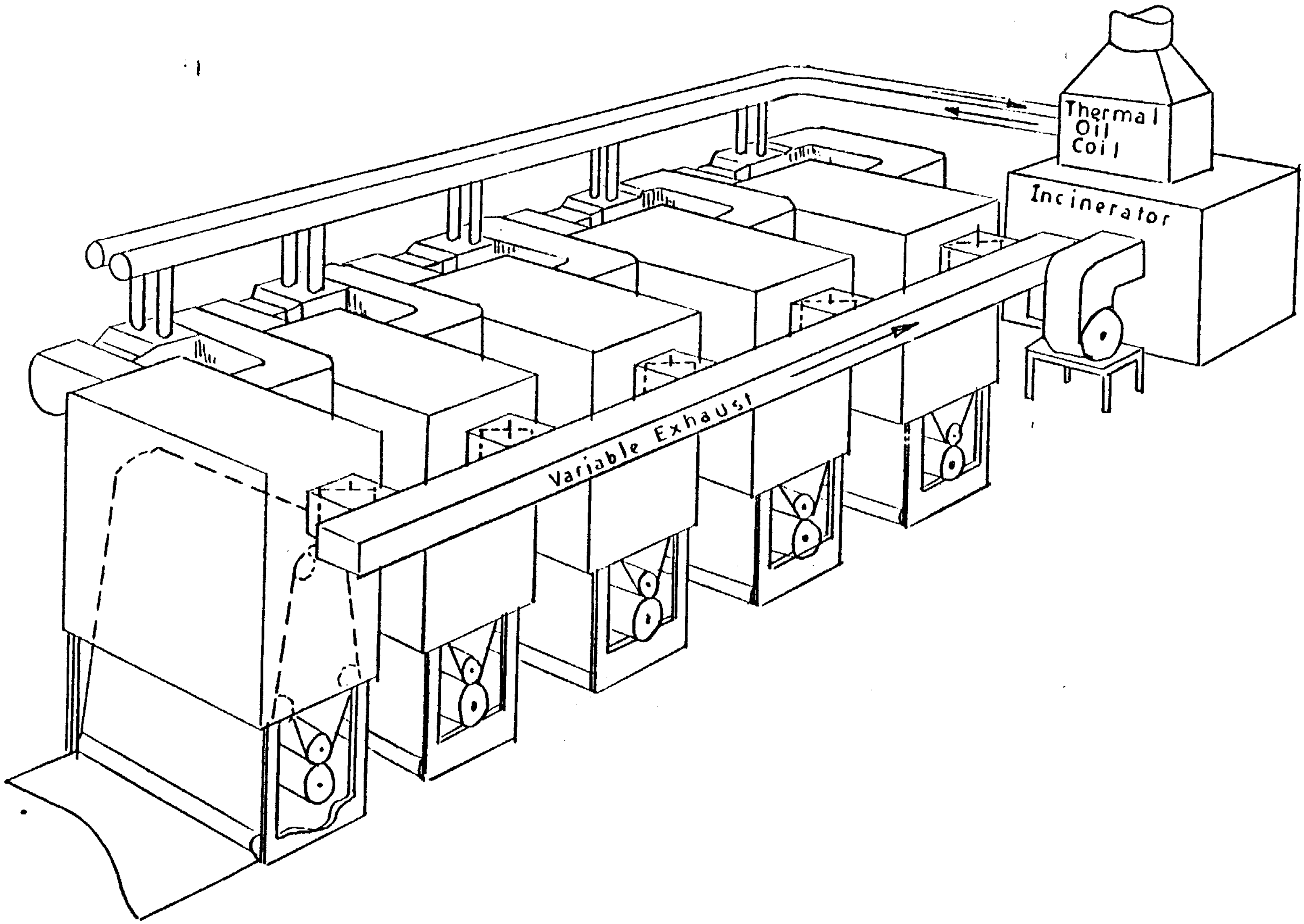

Figure 3.5 Incineration System with L.E.L. Sensors and a Hot Oil Heat Recovery System. Courtesy of AER Corporation.

3.3.1 Water-Borne Inks

These inks are not completely solvent-free, as the volatile portion contains up to 35 percent water soluble organic compounds. Water-borne inks are used extensively in printing of corrugated paperboard for containers, or multi-wall bags and other packaging materials made of paper and paper products. There is a limit upon the amount of water-borne ink that can be printed upon thin stock before paper will be seriously weakened. Thus, the expandeduse of water-borne inks faces this severe limitation.

3.4 SUMMARY OF APPLICABILITY OF CONTROL METHODS

The available control methods for each of the printing methods are summarized in the following sections.

3.4.1 Rotogravure

Publication rotogravure operations can be controlled by carbon adsorption systems with a capture efficiency of 75-85 percent of the VOC emitted from the printing units and the dryers. The carbon recovery system can be operated with a recovery efficiency of 90 percent of the VOC entering the carbon beds. An overall emission reduction efficiency of 75 percent can thus be achieved.

Packaging rotogravure printing operations can be controlled by incineration systems with an expected capture efficiency of 70-80 percent and a combustion efficiency of 90 percent. An overall emission reduction efficiency of 65 percent can thus be achieved.

Some rotogravure packaging printing operations with less demanding quality requirements can use water-borne inks. Most water-borne inks contain some VOC as a co-solvent. Emission limits comparable to carbon adsorption and incineration can be achieved if the solvent portion of the ink consists of 75 volume percent water and 25 volume percent organic solvent.

3.4.2 Flexography

Flexographic printing operations can be controlled by incineration systems with an expected capture efficiency of 65-70 percent and a combustion efficiency of 90 percent. Thus an overall emission reduction efficiency of 60 percent can be achieved.

Some flexographic packaging printing operations can utilize waterborne inks. Emission limits comparable to incineration can be achieved when the solvent portion of the ink consists of 75 volume percent water and 25 volume percent organic solvent.

3.5 REFERENCES

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4.0 COST ANALYSIS

4.1 INTRODUCTION

4.1.1 Purpose

This section presents estimated installed capital and annualized costs for control of volatile organic compounds (VOC) from that portion of the graphic arts industry involved in flexographic and rotogravure packaging printing and rotogravure publication printing. The section also includes an analysis of the cost-effectiveness of the control methods.

4.1.2 Scope

The analysis includes all the printing operations involved, i.e., the application and drying or curing of inks. Cost estimates have been developed on the basis of retrofitting VOC controls on existing plants. Two groups of printing processes are analyzed. The first uses flexographic and rotogravure processes on packaging. The second uses the rotogravure processes to print publications. Light hydrocarbon emissions are generated by both groups. Various typical plant sizes (based on annual ink use) are analyzed for both packaging and publication printing. Tables 4-1 and 4-2 present the process parameters of the model sizes selected for the packaging and publications groups, respectively. These parameters include exhaust gas volumetric flow rates and temperatures, control devices, and control efficiencies for each model plant. (Flow diagrams showing the plant configurations are presented in Chapter 2.)

4.1.3 Use of Model Plants

Cost estimates developed for this analysis are based solely on model plant configurations. Yearly ink usage of the model plant sizes selected for packaging printing are 7 Mg (7.7 tons), 40 Mg (44 tons), 150 Mg (165 tons),

TABLE 4-1. PROCESS PARAMETERS AND FLOW RATES FOR MODEL PLANT CONFIGURATIONS, FLEXOGRAPHIC AND ROTOGRAVURE PACKAGE PRINTING, WITH THERMAL INCINERATORS FOR VOC[a] CONTROL[b,c]

Incinerator system number	Plant size ink use, Mg/yr (tons/yr)	Press operating time, h/yr[d]	Primary heat recovery, %	Incinerator gas flow, Nm^3/min (scfm)	Gas temp., °C (°F)	VOC concentration, ppm	Uncontrolled VOC, Mg/yr (tons/yr)[e]	VOC capture rate, Mg/yr (tons/yr)
1	7 (7.7)	1000	0	28 (1000)	49 (120)	500	4.10 (4.50)	3.31 (3.65)
2	7 (7.7)	1000	0	9 (330)	49 (120)	1500	4.10 (4.50)	3.31 (3.65)
3	7 (7.7)	1000	40	28 (1000)	49 (120)	500	4.10 (4.50)	3.31 (3.65)
4	7 (7.7)	1000	40	9 (330)	49 (120)	1500	4.10 (4.50)	3.31 (3.65)
5	40 (44)	2000	0	85 (3000)	49 (120)	500	23.4 (26.0)	19.8 (22.0)
6	40 (44)	2000	0	28 (1000)	49 (120)	1500	23.4 (26.0)	19.8 (22.0)
7	40 (44)	2000	40	85 (3000)	49 (120)	500	23.4 (26.0)	19.8 (22.0)
8	40 (44)	2000	40	28 (1000)	49 (120)	1500	23.4 (26.0)	19.8 (22.0)
9	150 (165)	2000	0	282 (10,000)	49 (120)	500	87.3 (97.0)	65.7 (73.0)
10	150 (165)	2000	0	94 (3,330)	49 (120)	1500	87.3 (97.0)	65.7 (73.0)
11	150 (165)	2000	40	282 (10,000)	49 (120)	500	87.3 (97.0)	65.7 (73.0)
12	150 (165)	2000	40	94 (3,330)	49 (120)	1500	87.3 (97.0)	65.7 (73.0)
13	400 (440)	3000	0	563 (20,000)	49 (120)	500	232 (258)	197 (219.0)
14	400 (440)	3000	0	188 (6,700)	49 (120)	1500	232 (258)	197 (219.0)
15	400 (440)	3000	40	563 (20,000)	49 (120)	500	232 (258)	197 (219.0)
16	400 (440)	3000	40	188 (6,700)	49 (120)	1500	232 (258)	197 (219.0)
17	2500 (2750)	3000	0	3260 (115,000)	49 (120)	500	1400 (1600)	1120 (1250)
18	2500 (2750)	3000	0	1090 (38,000)	49 (120)	1500	1400 (1600)	1120 (1250)
19	2500 (2750)	3000	40	3260 (115,000)	49 (120)	500	1400 (1600)	1120 (1250)
20	2500 (2750)	3000	40	1090 (38.000)	49 (120)	1500	1400 (1600)	1120 (1250)

[a] Volatile Organic Compounds.

[b] Control efficiency is 90 percent across incinerator.

[c] These parameters also apply to pebble-bed incinerator.

[d] Each press is assumed to operate 50% of the plant operating time.

[e] Based on solvent content of the ink, 65 percent by volume and 58.5 percent by weight. Molecular weight of solvent, 92.

TABLE 4-2. PROCESS PARAMETERS AND FLOW RATES FOR MODEL PLANT CONFIGURATIONS, PUBLICATION ROTOGRAVURE, WITH CARBON ABSORPTION FOR VOC[a] CONTROL[b]

Adsorption system number	Plant size ink use, Mg/yr (tons/yr)	Press operating time, h/yr[c]	Gas flow, Nm^3/min (scfm)	Gas temp., °C (°F)	VOC concentration, ppm	Uncontrolled VOC, Mg/yr (tons/yr)[d]	VOC capture rate, Mg/yr (tons/yr)
1	3500 (3860)	4000	1420 (50,000)	49 (120)	1200	2040 (2250)	1590 (1750)
2	3500 (3860)	4000	710 (25,000)	49 (120)	2400	2040 (2250)	1590 (1750)
3	7000 (7720)	4000	2840 (100,000)	49 (120)	1200	4080 (4500)	3180 (3500)
4	7000 (7720)	4000	1420 (50,000)	49 (120)	2400	4080 (4500)	3180 (3500)

[a] Volatile Organic Compounds.

[b] Control efficiency is 90 percent across incinerator.

[c] Each press is assumed to operate 50 percent of the plant operating time.

[d] Based on solvent content of ink, 65 percent by volume and 58.5 percent by weight. Molecular weight of solvent, 92.

400 Mg (440 tons), and 2500 Mg (2750 tons). For publication printing, the yearly ink usages are 3500 Mg (3860 tons) and 7000 Mg (7720 tons). Because factors such as width and operating speed of the printing machinery influence control costs at actual facilities, actual costs for specific plant sizes will vary. Nevertheless, cost estimates based on model plants are useful for comparing control alternatives.

4.1.4 Bases for Capital Costs

Installed capital costs represent the total investment required for installing retrofit emission control systems on existing presses; they include the cost of equipment, material, labor for equipment erection, and other associated costs. These estimated costs reflect mid-1978 dollars and are based on equipment costs obtained from equipment vendors.[1-6, 8-10] The control equipment is assumed to be mounted on structural steel above grade or roof; the ducting requirement is based on equipment that is installed within 100 meters (350 ft) of the press.[7] The installation costs have been estimated on installed material requirements. No attempt has been made to include either production losses during installation and startup, or research and development costs. Table 4-3 presents the bases and assumptions used in estimating capital costs.

4.1.5 Bases for Annualized Costs

Annualized costs represent the cost of operating and maintaining control systems and the cost of recovering the capital investment required for these systems. They include direct costs such as utilities, materials, labor, and

TABLE 4-3. BASES FOR CAPITAL COST ESTIMATES

All costs are expressed in mid-1978 dollars.

The afterburners have a 0.5-second residence time and a 746°C (1375°F) incineration temperature.

Afterburners and carbon adsorption systems have a VOC emission reduction efficiency of 90 percent.

The initial carbon for bedding is included in capital costs.

Capital investment includes:

- Basic control equipment
- Auxiliary equipment (e.g., hoods, ducts)
- Fuel oil storage for 10 days operation
- Installation of basic and auxiliary equipment
- Removal of existing equipment, as required
- Contingencies
- Contractor's fee, taxes, and other indirect costs

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maintenance; indirect costs such as taxes, insurance, depreciation, interest rate, administration, and permits; and adjustments such as credits for recovered solvents. Table 4-4 presents bases and assumptions used to estimate annualized costs.

4.2 VOC CONTROL IN THE PRINTING INDUSTRY

4.2.1 Model Plant Parameters

Costs were developed for thermal incinerators with and without 40 percent primary heat recovery on flexographic and rotogravure packaging, and for carbon adsorption control on rotogravure publication printing processes. In addition, the costs for thermal incinerators with heat recovery were compared to costs for identically sized pebble bed incinerators.

4.2.2 Control Costs

The capital and annualized costs and cost-effectiveness ratios of thermal incinerators for VOC control on flexographic and rotogravure packaging model plants are presented in Tables 4-5 through 4-9; costs of carbon adsorption systems on rotogravure publication model plants are presented in Table 4-10. The respective cost data are plotted against model plant ink usage in Figures 4-1, 4-2, and 4-3. Finally, Table 4-11 displays these data for pebble bed incinerators.

In packaging printing, the incinerator with a primary heat recovery system requires a larger capital investment than one without primary heat recovery. Because primary heat recovery reduces fuel costs, the savings therefrom increase proportionately with volumetric flow rate and VOC concentration.

In packaging printing, incineration for each model plant size has been evaluated at two gas flow rates, the smaller rate being one third of the larger. These lower rates are considered attainable with minor modifications to press

TABLE 4-4. BASES FOR ANNUALIZED COST ESTIMATES

Description	Unit cost	Basis for costs and other comments
Annualized costs		One year period commencing mid-1978
Installation type		Retrofit
Press operating time		1000 h/yr or 250 days/yr at 4 h/day; 2000 h/yr or 250 days/yr at 8 h/day; 3000 h/yr or 250 days/yr at 12 h/day; 4000 h/yr or 250 days/yr at 16 h/day
Utilities		
No. 2 fuel oil[a]	0.105/liter ($0.396/gal)	$0.105/liter ($0.396/gal); based upon transport lots of 27,250 liters (7200 gal) delivered from Midwest terminal
Electricity	0.0266/kWh	EPA-230/3-77-015b report cost for iron and steel industry
Steam	$9.02/Mg ($4.10/10^3 lb)	Based on 80% efficiency; includes 16% for facilities, maintenance, depreciation, and others[b]
Operating labor	$8.66/h	Includes 20% for fringes
Maintenance		
Labor	$9.53/h	Hourly rate at 10% premium over operating labor $9.53/h
Material	$9.53	Average (over life of equipment) material costs equal to labor costs
Misc. maint., parts and material		Carbon beds: annual allowance for 5-year life, 10% of the equipment capital cost
Capital recovery factor	16.275% of capital cost	10% interest rate and 10 years equipment life
Taxes and insurance	2% of capital cost	
Administration and permits	2% of capital cost	
Adjustment credit[c]	$0.105/liter ($0.396/gal)	Reclaimed solvent for use of diesel or fuel oil

[a] Assumed to be the only fuel used by all systems.

[b] In other words: 1000 lb steam x 1000 Btu/lb x $0.396/gal ÷ (140,000 Btu/gal x 0.8 eff.) = $354/10^3 lb steam plus 16% = $4.10/10^3 lb steam.

[c] Where applicable.

TABLE 4-5. COST OF VOC CONTROL BY THERMAL INCINERATOR AT PLANT USING 7 Mg (7.7 tons) OF INK PER YEAR (Mid-1978 dollars)

	Without heat recovery		With 40% primary heat recovery	
	500 ppm[a]	1500 ppm[a]	500 ppm[a]	1500 ppm[a]
Equipment cost[b]	37,000	36,000	74,000	71,000
Installed capital cost[b]	94,000	85,000	162,000	152,000
Direct operating cost	5,800	2,900	4,600[c]	2,900[c]
Annualized capital charges	19,100	17,200	32,800	30,800
Total annualized cost	24,900	20,100	37,400	33,700
Pollutants controlled at 90% control device efficiency, Mg/yr (tons/yr)	2.98 (3.29)	2.98 (3.29)	2.98 (3.29)	2.98 (3.29)
Cost-effectiveness of of pollutant controlled, \$/Mg (\$/ton)	8,360 (7,570)	6,750 (6,110)	12,500 (11,370)	11,310 (10,240)

[a] VOC concentration by volume in emissions gas stream.

[b] References 1, 2, 5, 6, 7.

[c] Primary heat recovery reduces fuel consumption.

TABLE 4-6. COST OF VOC CONTROL BY THERMAL INCINERATOR AT PLANT USING 40 Mg (44 tons) OF INK PER YEAR (Mid-1978 dollars)

	Without heat recovery		With 40% primary heat recovery	
	500 ppm[a]	1500 ppm[a]	500 ppm[a]	1500 ppm[a]
Equipment cost[b]	43,000	37,000	73,000	74,000
Installed capital cost[b]	105,000	94,000	187,000	162,000
Direct operating cost	27,500	9,700	16,800[c]	6,800[c]
Annualized capital charges	21,300	19,000	37,900	32,800
Total annualized cost	48,800	28,700	54,700	39,600
Pollutants controlled at 90% control device efficiency, Mg/yr (tons/yr)	17.82 (19.80)	17.82 (19.80)	17.82 (19.80)	17.82 (19.80)
Cost-effectiveness of pollutant controlled, $/Mg ($/ton)	2,740 (2,460)	1,610 (1,450)	3,070 (2,760)	2,220 (2,000)

[a] VOC concentration by volume in emissions gas stream.

[b] References 1, 2, 5, 6, 7.

[c] Primary heat recovery reduces fuel consumption.

TABLE 4-7. COST OF VOC CONTROL BY THERMAL INCINERATOR AT PLANT USING 150 Mg (165 tons) OF INK PER YEAR (Mid-1978 dollars)

	Without heat recovery		With 40% primary heat recovery	
	500 ppm[a]	1500 ppm[a]	500 ppm[a]	1500 ppm[a]
Equipment cost[b]	63,000	43,000	120,000	73,000
Installed capital cost[b]	177,000	105,000	244,000	187,000
Direct operating cost	84,000	24,900	47,400	13,200[c]
Annualized capital charges	35,900	21,300	49,500	37,900
Total annualized cost	119,900	46,200	96,900	51,100
Pollutants controlled at 90% controll device efficiency, Mg/yr (tons/yr)	59.13 (65.70)	59.13 (65.70)	59.13 (65.70)	59.13 (65.70)
Cost-effectiveness of pollutant controlled, $/Mg ($/ton)	2,030 (1,830)	780 (700)	1,640 1,480	860 (780)

[a] VOC concentration by volume in emissions gas stream.

[b] References 1, 2, 5, 6, 7.

[c] Primary heat recovery reduces fuel consumption.

TABLE 4-8. COST OF VOC CONTROL BY THERMAL INCINERATOR AT PLANT USING 400 Mg (440 tons) OF INK PER YEAR (Mid-1978 dollars)

	Without heat recovery		With 40% primary heat recovery	
	500 ppm[a]	1500 ppm[a]	500 ppm[a]	1500 ppm[a]
Equipment cost[b]	77,000	52,000	133,000	95,000
Installed capital cost[b]	228,000	145,000	325,000	224,000
Direct operating cost	247,300	69,700	136,500[c]	33,600[c]
Annualized capital charges	46,200	29,400	65,900	45,400
Total annualized cost	293,500	99,100	202,400	79,000
Pollutants controlled at 90% control device efficiency, Mg/yr (tons/yr)	177.3 (197.1)	177.3 (197.1)	177.3 (197.1)	177.3 (197.1)
Cost-effectiveness of pollutant controlled, $/Mg ($/ton)	1,660 (1,490)	560 (500)	1,140 (1,030)	450 (400)

[a] VOC concentration by volume in emissions gas stream.

[b] References 1, 2, 5, 6, 7.

[c] Primary heat recovery reduces fuel consumption.

TABLE 4-9. COST OF VOC CONTROL BY THERMAL INCINERATOR AT PLANT USING 2500 Mg (2750 tons) OF INK PER YEAR (Mid-1978 dollars)

	Without heat recovery		With 40% primary heat recovery	
	500 ppm[a]	1500 ppm[a]	500 ppm[a]	1500 ppm[a]
Equipment cost[b]	351,000	117,000	720,000	240,000
Installed capital cost[b]	1,110,000	370,000	1,704,000	568,000
Direct operating cost	1,440,500	375,900	771,600[c]	168,300[c]
Annualized capital charges	225,000	75,000	345,500	115,200
Total annualized cost	1,665,500	450,900	1,117,100	283,500
Pollutants controlled at 90% control device efficiency, Mg/yr (tons/yr)	1,008 (1,125)	1,008 (1,125)	1,008 (1,125)	1,008 (1,125)
Cost-effectiveness of pollutant controlled, $/Mg ($ton)	1,650 (1,480)	450 (400)	1,110 (990)	280 (250)

[a] VOC concentration by volume in emissions gas stream.

[b] References 1, 2, 5, 6, 7.

[c] Primary heat recovery reduces fuel consumption.

TABLE 4-10. COST OF VOC CONTROL BY CARBON ADSORBER FOR PUBLICATIONS ROTAGRAVURE PRINTING (Mid-1978 dollars)

	Plant using 3500 Mg (3860 tons) of ink per yr		Plant using 7000 Mg (7720 tons) of ink per yr	
	1,200 ppm[a]	2,400 ppm[a]	1,200 ppm[a]	2,400 ppm[a]
Equipment cost[b]	338,000	185,000	608,000	338,000
Installed capital cost[b]	701,000	435,000	1,262,000	701,000
Direct operating cost	100,800	82,900	192,100	156,400
Recovered solvent (credit)	-170,100	-170,100	-340,200	-340,200
Annualized capital charges	142,100	88,200	255,900	142,100
Total annualized cost	72,800	1,000	107,800	-41,700
Pollutants controlled at 90% control device efficiency, Mg/yr (tons/yr)	1,431 (1,575)	1,431 (1,575)	2,862 (3,150)	2,862 (3,150)
Cost-effectiveness of pollutant controlled, $/Mg ($/ton)	51 (46)	0.70 (0.63)	38 (34)	-15 (-13)

[a] VOC concentration by volume in emissions gas stream.

[b] References 3, 4.

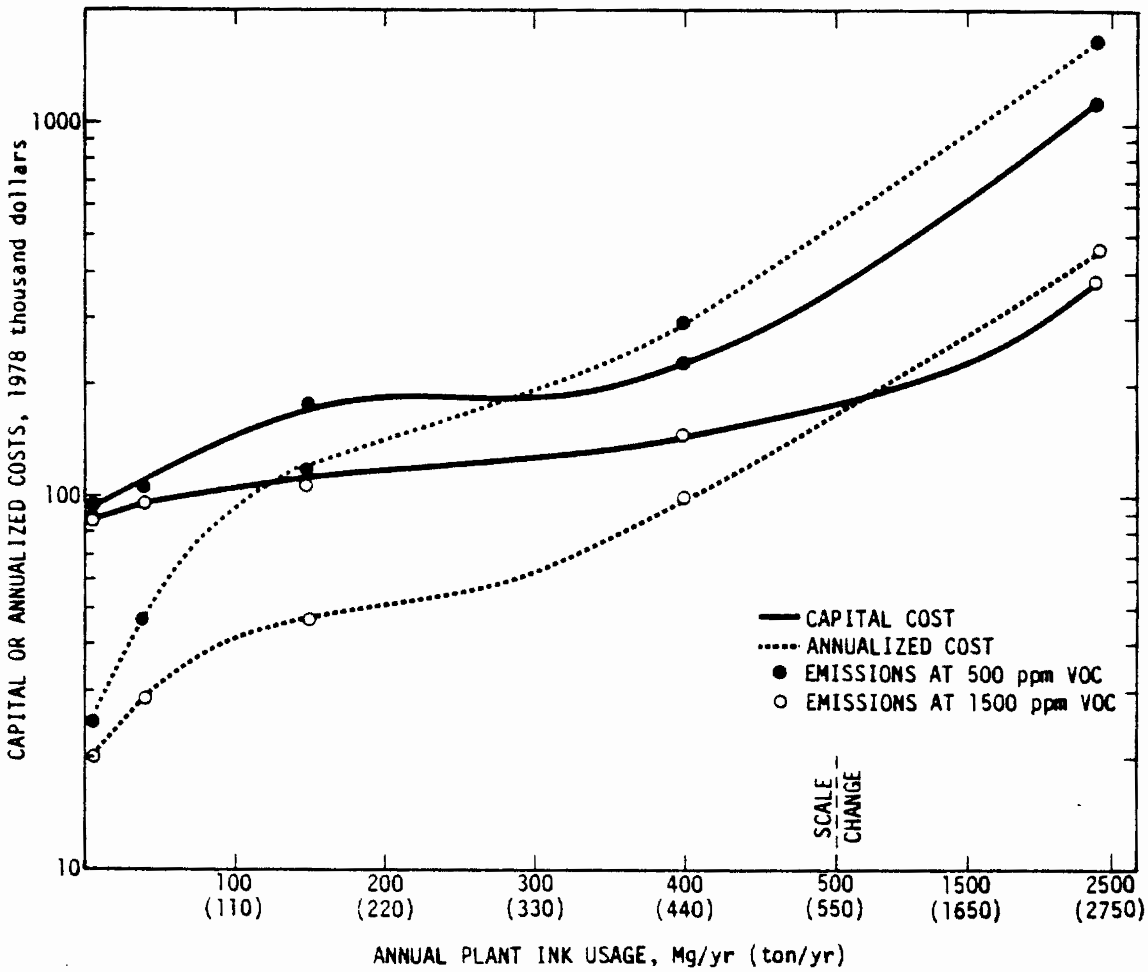

Figure 4-1. Capital and annualized costs of thermal incinerator without heat recovery for VOC control at existing graphic arts plant using flexographic and rotogravure printing process for packaging.

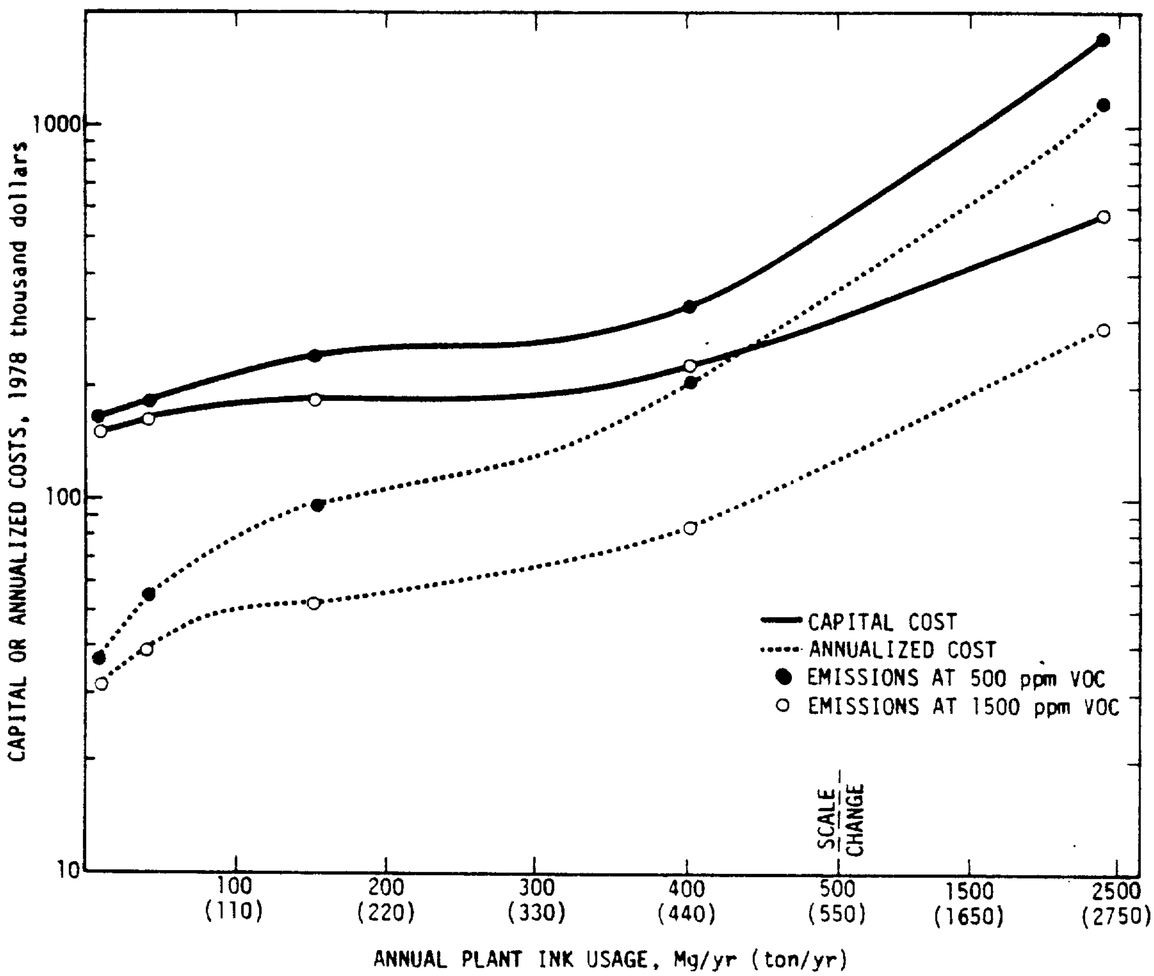

Figure 4-2. Capital and annualized costs of thermal incinerator with 50% primary heat recovery for VOC control at existing graphic arts plant using flexographic and rotogravure printing process for packaging.

enclosures. Significant modifications to enclosures or the addition of high-velocity air jets could reduce ventilation rates to one-sixth that of the unimproved, and could increase VOC concentration proportionately. This reduction in flow rates significantly reduces the control system capital cost for all plants. The capital cost reductions for the model plant sizes of 7 Mg/yr (7.7 tons/yr), 40 Mg/yr (44 tons/yr), 150 Mg/yr (165 tons/yr), 400 Mg/yr (440 tons/yr), and 2500 Mg/yr (2750 tons/yr) are, respectively: 10%, 10%, 41%, 36%, and 67% for incinerators without heat recovery; and 6%, 13%, 23%, 31%, and 67% for incinerators with 40% primary heat recovery.

For all model plants, these lower capital costs effect proportional reductions in annualized capital charges. This 66% reduction in the volumetric flow rate (with an accompanying trebling of VOC concentration) causes reductions in the direct annual operating costs (fuel, electricity, etc.) for the respective model plant sizes of: 50%, 65%, 70%, 72%, and 74% for incinerators without heat recovery; and 37%, 60%, 78%, 75%, and 78% for incinerators with 40% primary heat recovery. In other words, for a given model plant size, smaller incinerators are less expensive than larger ones to buy and operate.

The addition of primary heat recovery equipment to incinerators increases the capital cost, but reduces annual fuel consumption proportionately with the operating hours. Neither the 7 Mg/yr (7.7 tons/yr) plant nor the 40 Mg/yr (44 tons/yr) plant operates enough hours per year to realize an annualized cost savings from heat recovery, relative to the corresponding thermal incinerator without heat recovery. For the larger plants operating more hours per year, however, the incinerators with heat recovery have lower annualized costs than those without heat recovery.

The effect of heat recovery on total annualized cost is also illustrated by Figures 4-1 and 4-2. As these figures show, the annualized costs are less than 25% of the capital costs of incinerators with or without heat recovery for the smallest model plant. As the plant size increases to the largest model plant size, however, the annualized costs exceed capital costs for those without heat recovery, but the addition of heat recovery reduces the annualized costs to less than the corresponding capital costs.

Table 4-10 lists capital and annualized costs for carbon adsorption systems. Although the capital cost increases with plant size, smaller volumetric flow rates may effect reductions in both capital and operating costs for a given model plant size. For example, a 50 percent reduction in volumetric flow rate for the 3500 Mg/yr (3860 tons/yr) plant reduces the capital cost from $701,000 to $435,000, and reduces the annualized capital charges from $142,100 to $88,200. The solvent recovery credits are $170,100 for both volumetric flow rates, since the VOC emissions from the presses are based on the same hourly emission rate and the same annual operating hours. The direct operating costs are reduced from $100,800 and $82,900 solely because less electric power is required for the lower volumetric flow rate. It is important to note that neither the steam requirements for desorbing nor the cooling water required for condensing the steam and desorbed VOC is reduced, because both are related to the VOC collected and not the volumetric flow rate. In all, the total annualized cost is reduced from $72,800 to $1000 for a 3500 Mg/yr (3860 tons/yr) model plant. If this model plant were operated more hours per year, or at a faster line speed, the recovery credits could result in negative total annualized costs. For example, the 7000 Mg/hr (7720 tons/yr) plant, operating 4000 hours per year and emitting VOC at a concentration of 2400 ppm, has a negative annualized cost of $41,700. (See Figure 4-3.)

Installed and annualized costs for pebble bed units are shown in Table 4-11. Installed and operating costs for these units were obtained from a vendor.[8-10] However, because the vendor's estimates did not include ductwork, foundations, or fuel oil storage, his figures were adjusted to include costs for these auxiliaries.[11]

Costs for labor, fuel, power, and maintenance were computed using parameters supplied by the vendor and unit costs from Table 4-4. As with thermal incinerators, a ten-year operating life was assumed.

As Table 4-11 shows, the installed costs for pebble bed units range from $118,000 to $1,500,000 for the 7.0 Mg/yr (1500 ppm stream) and 2500 Mg/yr (500 ppm stream) model plants, rexpectively. For most plant sizes, these costs are 10 to 34 percent lower than those for incinerators with primary heat recovery (see Tables 4-5 to 4-9). The cost differences, however, are not significant relative to the precision of these study estimates.

The annualized costs, which vary widely, depend, in general, on the plant size, but on the gas flowrate and VOC emission rate in particular. As with thermal incinerators, the annualized capital charges accounts for more than one-half of the total annualized cost. Nonetheless, it must

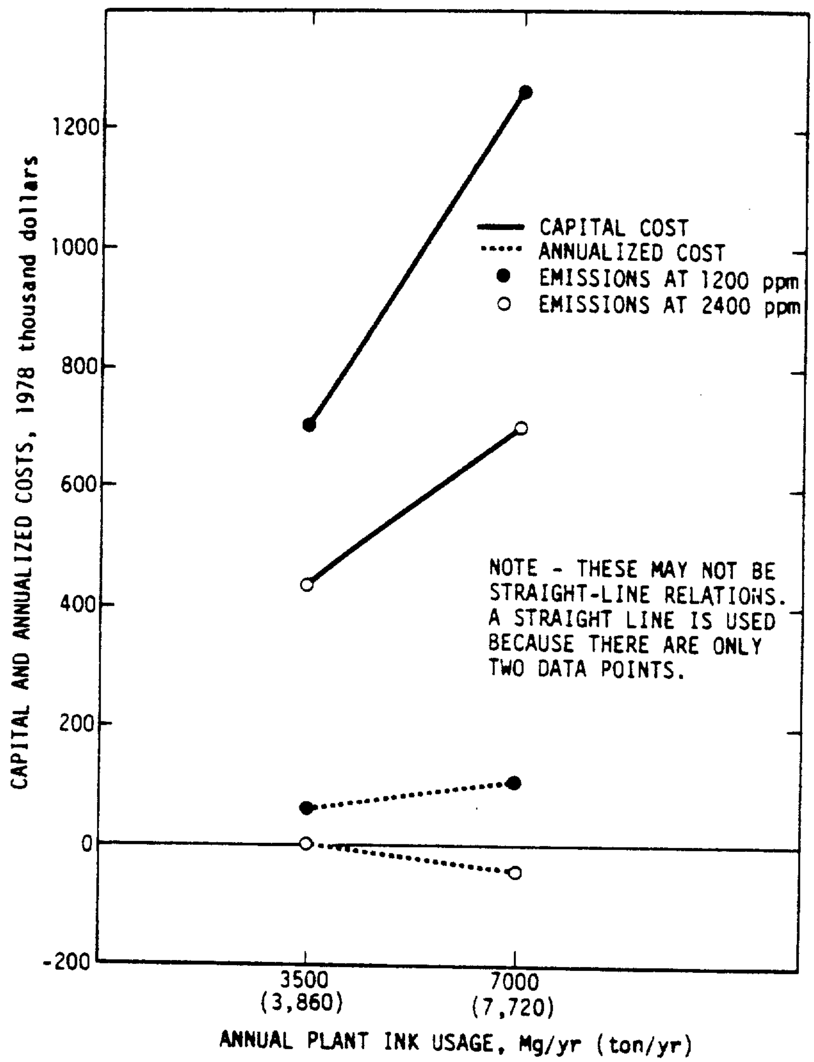

Figure 4-3. Capital and annualized costs of carbon adsorption VOC control at existing graphic arts plant using rotogravure printing process for publications.

TABLE 4-11. COST OF VOC CONTROL BY PEBBLE BED INCINERATOR[a,b,c]
(Mid-1978 dollars)

Plant size ink use, Mg/yr (tons/yr)	VOC concentration, ppm	Installed capital cost, $	Direct operating cost, $/yr	Annualized capital charges, $/yr	Total annualized cost, $/yr	VOC controlled, Mg/yr (tons/yr)	Cost-effectiveness, $/Mg ($/ton) VOC controlled
7.0 (7.7)	500	121,000	3,100	24,500	27,600	2.98 (3.29)	9,260 (8,400)
	1,500	118,000	2,700	23,900	26,600	2.98 (3.29)	8,930 (8,100)
40 (44)	500	146,000	7,200	29,600	36,800	17.82 (19.64)	2,070 (1,880)
	1,500	135,000	4,400	27,400	31,800	17.82 (19.64)	1,790 (1,620)
150 (165)	500	268,000	13,900	54,400	68,300	59.13 (65.18)	1,160 (1,050)
	1,500	167,000	4,600	33,900	38,500	59.13 (65.18)	650 (590)
400 (440)	500	391,000	34,900	79,300	114,000	177.3 (195.4)	640 (580)
	1,500	202,000	6,900	41,000	47,900	177.3 (195.4)	270 (250)
2500 (2750)	500	1,500,000	173,500	304,200	478,000	1,008 (1,111)	470 (430)
	1,500	585,000	11,600	118,600	130,000	1,008 (1,111)	130 (120)

[a] References 8 to 11.

[b] Designed for 85% primary heat recovery.

[c] Costs based on 90% device control efficiency; however, according to a vendor, a pebble bed incinerator can remove as much as 98 to 99% of the VOC.

be emphasized that the pebble bed incinerator vendor claims a very high primary heat recovery (85 to 90%), versus 40% for the thermal incinerator. Thus, the pebble bed's fuel cost constitutes an even lower percentage of its total annualized cost. Indeed, in some cases, the fuel requirements--and costs--are negligible.

Shown in Table 4-11, the annualized cost ranges from $26,600 to $478,000 per year for the smallest and largest plant sizes. These costs are significantly lower than those for the thermal incinerator with primary heat recovery. The incinerator costs range from $33,700 to $1,117,000 per year. Now, the costs in Table 4-11 correspond to an 85% heat recovery, a fairly typical value. If the recovery were boosted to 90%, the annualized costs would decrease modestly in most cases. However, in some instances the annualized costs would increase, because the higher heat recovery units would require larger pebble beds which would, in turn, drive up their installed costs.

4.2.3 Cost-effectiveness

The cost-effectiveness ratio (in this report) is defined as the total annualized cost per annual unit of pollutant controlled. The annual amount of pollutant controlled depends on control device efficiency and total operating hours. By definition, the lower the ratio, the better the cost-effectiveness.

The cost-effectiveness ratios and efficiencies of the control systems and the quantities of pollutant controlled are shown in Tables 4-5 through 4-10 for thermal incinerators and carbon adsorbers, and in Table 4-11 for pebble bed incinerators. Figures 4-4, 4-5, and 4-6 present cost-effectiveness curves for thermal incinerators on packaging printing processes and carbon adsorbers on publication printing processes.

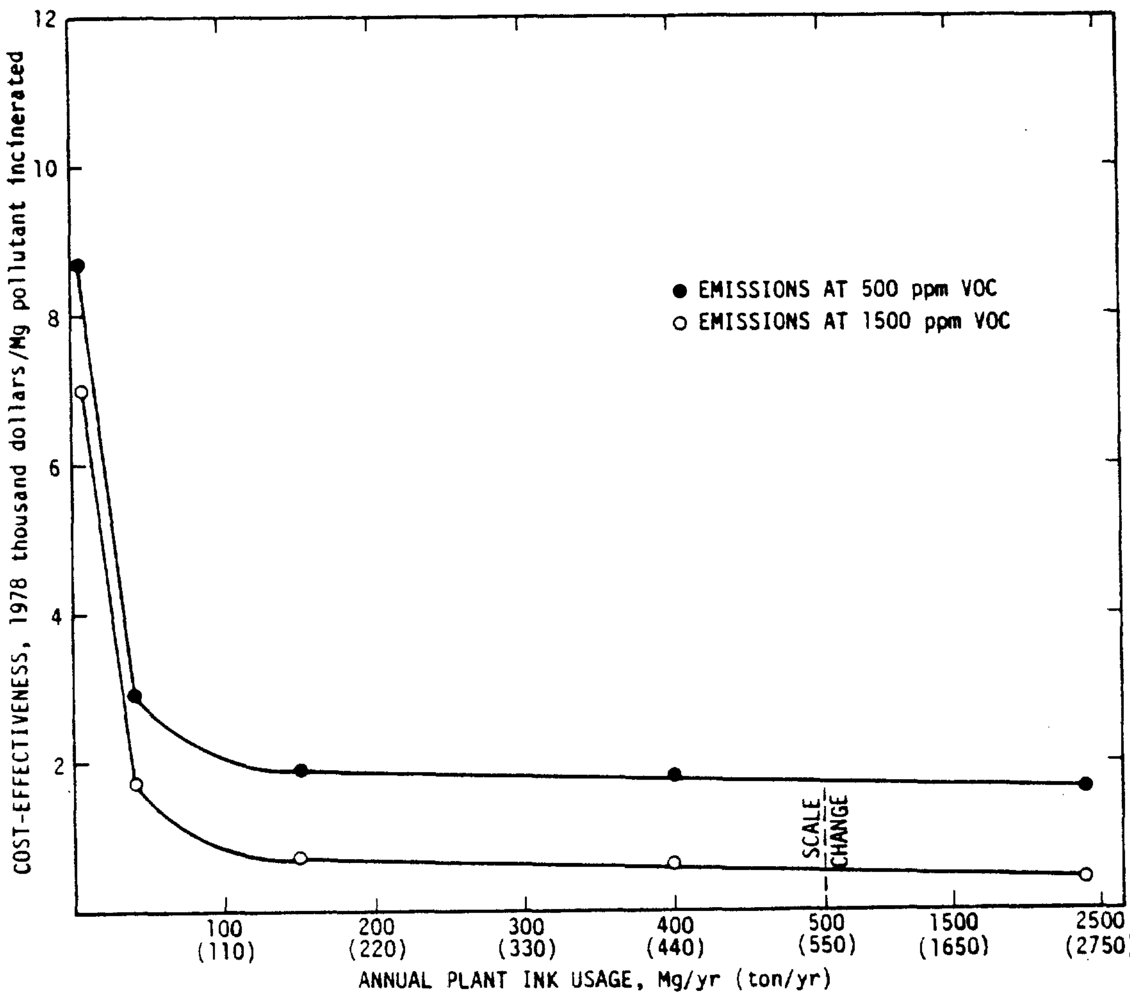

Figure 4-4. Cost-effectiveness of thermal incineration without heat recovery for VOC control of rotogravure printing process at graphic arts plant.

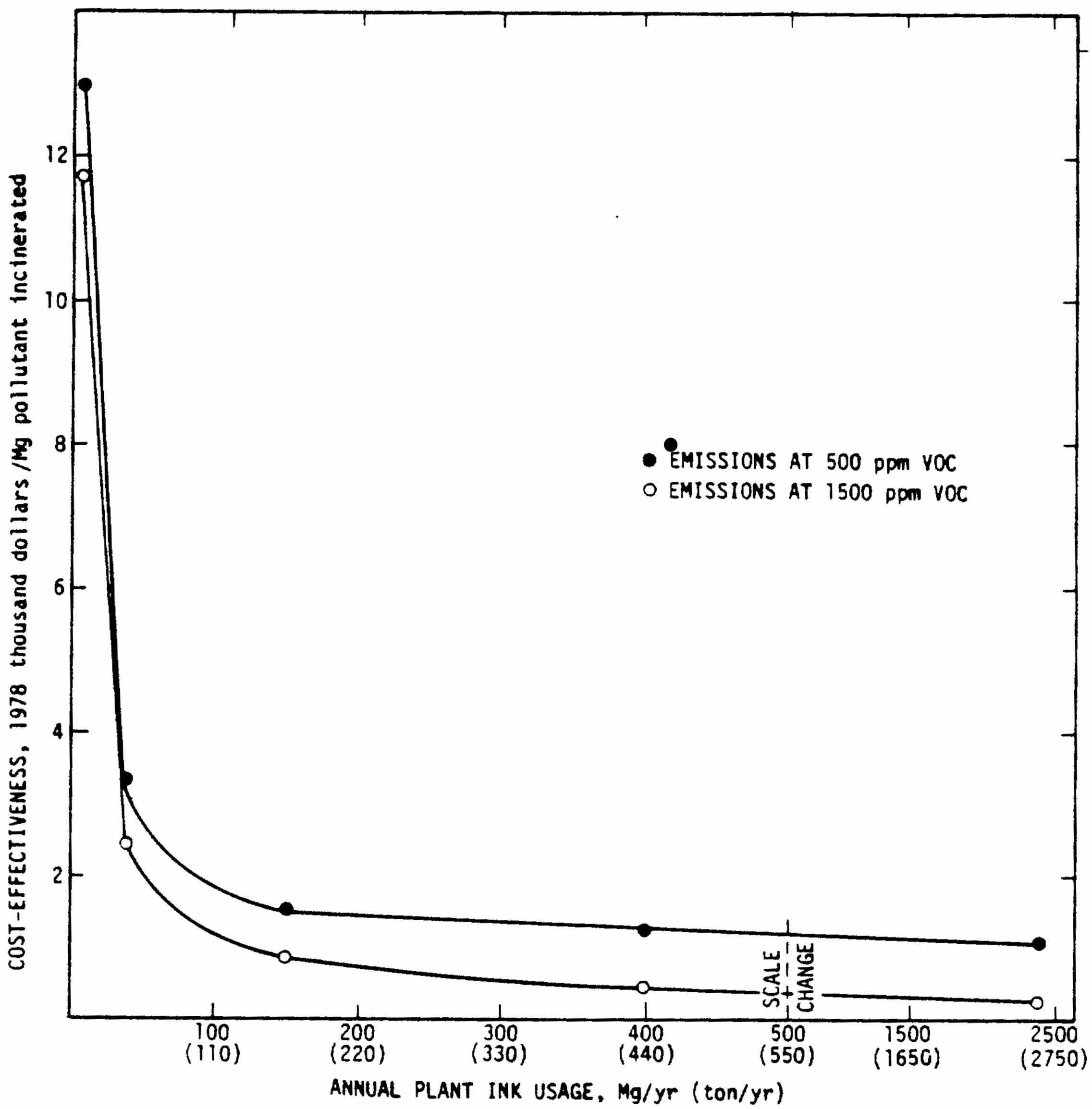

Figure 4-5. Cost-effectiveness of thermal incineration control with 40 percent heat recovery for VOC of rotogravure printing process at graphic arts plant.

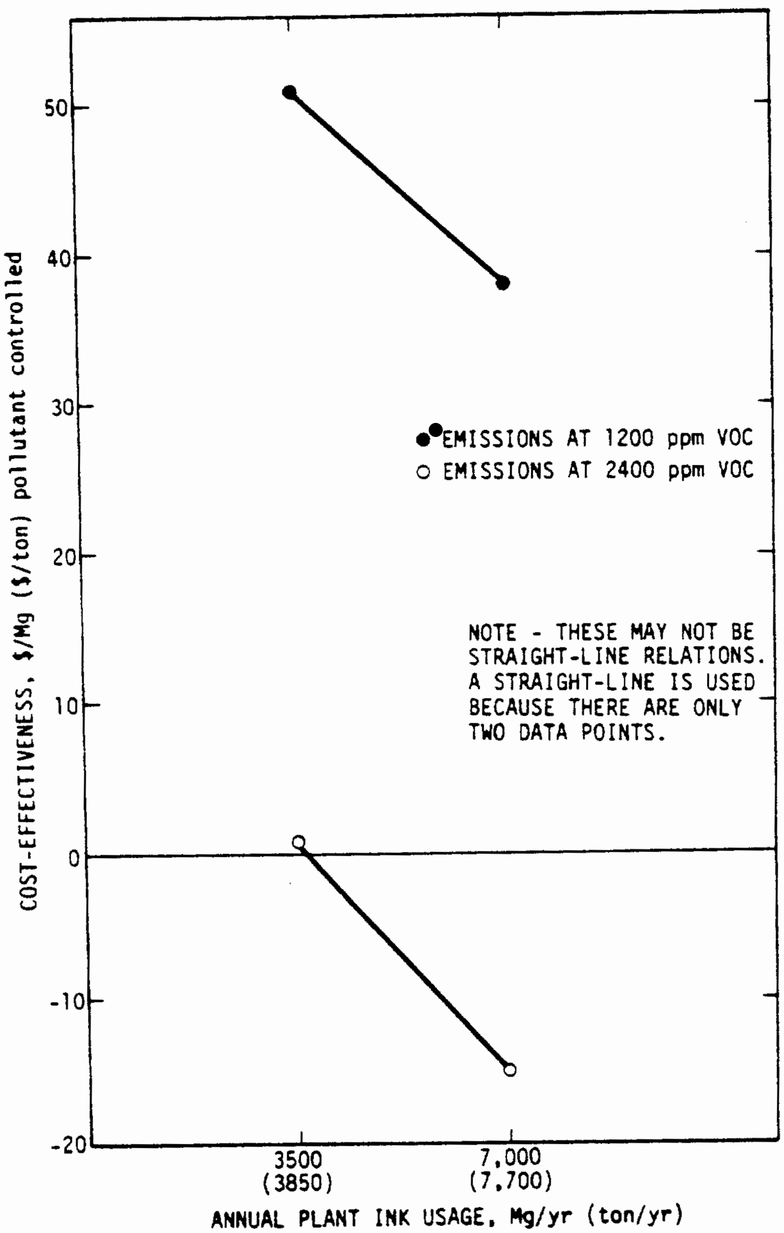

Figure 4-6. Cost-effectiveness of carbon adsorption control for rotogravure printing process at graphic arts plant.

Data show that the cost-effectiveness of control systems improves with plant size. Because thermal incinerator costs are based on the same efficiency for all plant sizes, their cost-effectiveness is enhanced by increased plant operation and control utilization. As shown in Figure 4-5 and discussed in Section 4.2.2, the incinerator with heat recovery is less cost-effective than a system without heat recovery for the two smaller packaging printing plants analyzed, and is more cost-effective for the three larger plants. The cost-effectiveness ratio for thermal incinerators with heat recovery decreases from $12,500/Mg ($11,370/ton) at the smallest plant to $280/Mg ($250/ton) at the largest plant, based on the 90% control device efficiency.

The cost-effectiveness of controlling the publication printing process also improves as the plant size increases. Specifically, the cost-effectiveness ratio decreases from $51/Mg ($46/ton) at the smallest plant to a negative $15/Mg ($13/ton) at the largest plant, based on this same 90% control device efficiency.

Lastly, because its annualized costs are consistently lower than those for identically-sized thermal incinerators with heat recovery, the cost-effectiveness of pebble bed incinerators is also better. Its cost-effectiveness ratio decreases from $9,260/Mg ($8,400/ton) to $130/Mg ($120/ton) as the plant size goes from smallest to largest.

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10. Ibid. November 20, 1978.

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5.0 ADVERSE AND BENEFICIAL EFFECTS OF APPLYING CONTROL TECHNOLOGY

5.1 INCINERATION

Incineration is applicable to packaging gravure and flexographic printing operations which use conventional solvent-borne inks. The principal disadvantage is the use of scarce and increasingly expensive fuel. Fuel consumption can be minimized by the inclusion of heat recovery equipment in the design. Primary heat exchangers can reduce fuel usage to some extent. Hypothetically, the use of pebble bed incinerators with their inherently effective heat recovery systems can reduce fuel usage substantially. At current fuel prices the annualized cost of the heat recovery system will be greater than the fuel saving and there will be a net increase in operating cost.

5.2 CARBON ADSORPTION

Carbon adsorption systems can recover solvent for reuse in ink manufacture. Thus, a valuable and increasingly scarce material can be conserved. Steam stripping is the usual method for removing adsorbed solvent from the carbon beds. If water soluble solvents are used in the inks, the condensed steam will contain organics which will require the additional expense of pretreatment facilities. This disadvantage is not present in the recently developed fluidized bed carbon adsorption system in which desorption is achieved by indirect heat and nitrogen gas.

6.0 MONITORING TECHNIQUES AND ENFORCEMENT ASPECTS

In the majority of cases the suggested emission limits will probably be met by incineration and carbon adsorption systems. The basic problem of the control official is determining that the control device is operating correctly. A measurement of efficiency across the device could be required when the unit is installed. (One test may be adequate when several identical units are installed).

A thermal incinerator which initially shows a high combustion efficiency will probably continue to perform well if operated at the same or greater temperature. All incinerators should be equipped with temperature indicators; recorders should be required for larger installations. The range instrument of 1200^{o} to $1800^{o}F$ will cover thermal incinerators; catalytic units seldom operate at less than 600^{o} or more than $1200^{o}F$. The sensing elements should be shielded from direct flame radiation. Other incinerator parameters are fixed by the design, e.g., there is no need to monitor residence time or mixing velocity.

For catalytic incinerators, the temperature rise across the catalyst bed should be measured during the initial test for combustion efficiency. This temperature rise reflects the activity of the catalyst (but may also vary with process variables and material input changes in the process). Temperature sensors should be installed on both the inlet and outlet of the catalyst bed to provide a continuous indication of catalyst activity.

To assure satisfactory operation of carbon adsorbers, it is necessary to regenerate the carbon beds at intervals sufficient to prevent "breakthrough". Breakthrough is the point at which VOC starts to appear in the exit gases in significant concentrations. The regeneration cycle is controlled by three methods: 1) a sequence timer, 2) a vapor detector, 3) both a sequence timer and a vapor detector.

A sequence timer is the simplest control method. The length of the adsorption period is determined by trial at the highest VOC concentrations likely to occur. This method can be wasteful of steam, as regeneration will often be performed before the bed is fully loaded. On the other hand, if the cycle is made too long , breakthrough will often occur.

A vapor detector sensitive to 50 to 100 ppm is sufficient for most applications. The detector may actuate an audible or visible alarm only, with the regeneration operations being performed manually. Or the detector may actuate an automatic control mechanism for performing the regeneration operation. This method is the more economical of steam, as regeneration is done only when the bed is loaded to the maximum allowable level. However, if the detector malfunctions extended breakthroughs could occur.

The combination system is always fully automatic. The sequence timer is set for a period of average VOC concentration. During periods of higher than average VOC concentration the vapor detector will initiate the regeneration. The timer will act as a back-up device in case of a malfunction of the vapor detector. Most system at publication rotogravure plants are of this type.

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15. SUPPLEMENTARY NOTES

16. ABSTRACT

This document provides guidance for development of regulations to limit emissions of volatile organic compounds from rotogravure and flexographic printing operations. This guidance includes recommended control requirements for carbon adsorption and incineration systems which represent Reasonably Available Control Technology for these operations. Provisions for the potential compliance by use of water-borne and high-solids inks are recommended. The industry is described, methods for reducing organic emissions are reviewed, and monitoring and enforcement aspects are discussed.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS	b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group
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