



National Emission Standards for Hazardous Air Pollutants for Source Categories: Paper and Other Web Coating Operations --- Background Information for Proposed Standards



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National Emission Standards for
Hazardous Air Pollutants for Source Categories:
Paper and Other Web Coating Operations -
Background Information for Proposed Standards

Emission Standards Division

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

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1.0 INTRODUCTION

1.1 OVERVIEW

Section 112 of the Clean Air Act (Act) requires that the U.S. Environmental Protection Agency (EPA) establish emission standards for all categories of sources of hazardous air pollutants (HAP). These national emission standards for hazardous air pollutants (NESHAP) must represent the maximum achievable control technology (MACT) for all major sources. The Act defines a major source as:

...any stationary source or group of stationary sources located within a contiguous area and under common control that emits or has the potential to emit, in the aggregate, 10 tons per year or more of any hazardous air pollutant or 25 tons per year or more of any combination of hazardous air pollutants.

In July 1992, the initial list of source categories for regulation under section 112 of the Act was published. "Paper and Other Webs (Surface Coating)" was included as a source category. To more clearly define the source category, the EPA subsequently decided to call the source category "Paper and Other Web Coating Operations." The NESHAP for the paper and other web coating (POWC) industry will establish standards for major sources in this source category.

The POWC source category can be described as processes that apply a uniform layer of material (coating) across essentially the entire length and/or width of a continuous substrate (web) to provide

a covering, finish, or functional or protective layer to a substrate, to saturate a substrate or to provide adhesion between two substrates for lamination. This definition serves to distinguish the POWC source category from the printing and publishing source category, which can be described as processes that apply words, designs, or pictures to a substrate. Web coating is done in the manufacture of some major product types such as: pressure-sensitive tapes and labels; photographic film; industrial and decorative laminates; flexible vinyl products; flexible packaging; abrasive products; and folding paperboard boxes. Because this source category is defined by the broad web coating operation, other product types may be included under the POWC source category.

The purpose of this document is to summarize the background information gathered during the development of the POWC NESHAP.

1.2 PROJECT HISTORY

1.2.1 Background

The POWC industry can be divided by technology, substrate, or type of product. Further divisions and industry segments can be identified in each of the major industry divisions. Many manufacturing processes include web coating operations as one step in the production process. It is estimated that more than 400 establishments in the U.S. have web coating operations.

Surface coatings usually provide a covering, a finish, or decorative, functional, or protective layer to a substrate. Coatings for lamination purposes provide adhesion for the case where two substrates are pressed together. For example, polyvinyl chloride film may be coated with an adhesive and then laminated to (pressed onto) fabric to manufacture wall coverings. In some processes, the web is formed on the coating line where it is then coated and wound.

The coating industry can be divided by technology into segments, such as gravure coaters, roll coaters, dip coaters, extrusion coaters, etc. While the industry manufactures a wide range of products, the manufacturing process varies little by product. The coating industry can also be divided by the type of substrate coated. The primary substrates coated by the industry are paper, film, and foil. The industry uses a range of films including polyester, polyethylene, polypropylene, polyvinyl chloride, and cellulose acetate. Other substrates coated by the industry include foam and fabric.

The coating industry can additionally be divided by the type of product. The types of products manufactured by the industry include but are not limited to: pressure-sensitive tapes and labels; photographic film; coated vinyl; wall coverings; sandpaper and other abrasives; paperboard boxes; vinyl flooring; industrial and decorative laminates; carbon paper and carbonless paper; circuit boards; and business forms.

The development of NESHAP for the POWC industry must take into account areas of overlap with other industries and NESHAP for other source categories. Potential areas of overlap are printing, fabric coating, and coil coating.

Many products manufactured by the POWC industry are printed and coated, often on the same production line. The printing and publishing NESHAP,¹ promulgated in May 1996, allows facilities that print and coat different materials on the same line, or print and coat the same substrate on different lines, to cover their coating operations under the printing and publishing NESHAP. Stand-alone coating equipment can be included as part of the affected source under the printing and publishing NESHAP if it is similar to the printing presses in any of the following ways: it applies solids-

containing materials to the same web or substrate; it applies a common solids-containing material; or it uses a common control device for control of organic HAP emissions. Therefore, many facilities whose coating operations could be covered under the POWC NESHAP may instead opt to cover their coating operations under the printing and publishing NESHAP. Also, although facilities coating fabric will be primarily covered under fabric coating, printing and dyeing NESHAP, facilities will likely be given the option of covering their fabric coating operations under the POWC operations NESHAP.

Some segments of the POWC industry are already subject to regulations limiting their volatile organic compound (VOC) emissions. In 1978, the EPA developed a control technique guidelines (CTG) document for surface coating of paper and fabric.² The EPA promulgated new source performance standards (NSPS) for pressure-sensitive tape manufacturers, flexible vinyl coating and printing operations, and polymeric coating of supporting substrates.^{3,4,5} While none of these regulations were specifically directed at reducing HAP emissions, many HAP used by the POWC industry are also VOC. Examples of HAP that are frequently used by this industry and are also volatile organic compounds (VOC) are formaldehyde, methyl ethyl ketone, methanol, toluene, and xylene. Therefore, many control devices installed by the industry to reduce VOC emissions also reduce HAP emissions.

1.2.2 Data Gathering

The POWC NESHAP project began in March 1996. In late 1996, a questionnaire was developed and distributed by the EPA, with the help of the Pressure Sensitive Tape Council (PSTC), to determine HAP use and control in the pressure-sensitive tape and label segment of the POWC industry. In 1997, the EPA developed and distributed a questionnaire, with the help of the Chemical Fabrics & Film

Association (CFFA) and the National Association of Photographic Manufacturers (NAPM), to determine HAP use and control by film formation and coating operations. Also in 1997, the EPA developed and distributed a questionnaire to determine HAP use and control in the manufacture of industrial and decorative laminates, with the help of the Laminating Materials Association (LMA), the National Electrical Manufacturers Association (NEMA), and the Association of Industrial Metallizers, Coaters, and Laminators (AIMCAL).

The EPA questionnaires were designed to evaluate HAP emissions from the industry and the current level of control of HAP emissions by the industry. The questionnaires were included with information collection requests (ICR) sent out under the authority of section 114 of the Act. Questionnaire responses were solicited from 104 companies that manufacture pressure-sensitive tapes and labels, 40 companies that operate film formation and coating equipment, and 49 companies that manufacture industrial or decorative laminates.

Besides information obtained from these questionnaires, the EPA made several site visits to POWC facilities. Also, the EPA met and/or conversed with many trade associations and industry representatives. Other sources of information obtained for the project include emission data from the 1996 Toxic Release Inventory⁶ (TRI) database, trade organization surveys, the Aerometric Information Retrieval System⁷ (AIRS) database, and the literature.

1.2.3 Emissions and Control Data

The available emissions and control information for the POWC industry are summarized in Chapters 2 and 3. Most of the information collected from POWC surveys is based on calendar year 1996, but represents current practices in the industry. Control efficiency data are also representative of current conditions. In some segments

of the industry, there has been a shift away from HAP use to either nonHAP VOC or waterborne materials.

1.3 DOCUMENT ORGANIZATION

This document is organized into six chapters designed to explain the background information collected for the paper and other web coating NESHAP. Following this introduction, Chapter 2 presents a profile of the paper and other web coating processes and industry. Chapter 3 describes the emission control techniques used by the POWC industry. Model plants developed to represent major sources in the POWC industry are presented in Chapter 4, along with control options and enhanced monitoring for the industry. In Chapter 5, the environmental and energy impacts of the control options for the POWC industry are presented. The cost impacts of these control options developed for the model plants are presented in Chapter 6.

1.4 REFERENCES

1. U.S. Environmental Protection Agency. National Emission Standards for the Printing and Publishing Industry. 40 CFR 63, Subpart KK, May 1996.
2. U.S. Environmental Protection Agency. 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. Research Triangle Park, North Carolina. May 1977.
3. U.S. Environmental Protection Agency. Standards of Performance for Pressure Sensitive Tape and Label Surface Coating Operations. 40 CFR 60, Subpart RR (48 FR 48375), October 18, 1983.
4. U.S. Environmental Protection Agency. Standards of Performance for Flexible Vinyl and Urethane Coating and Printing. 40 CFR 60, Subpart FFF (49 FR 26892), June 29, 1984.
5. U.S. Environmental Protection Agency. Standards of Performance for Polymeric Coating of Supporting Substrates. 40 CFR 60, Subpart VVV (54 FR 37551). September 11, 1989.
6. U.S. Environmental Protection Agency. Toxic Release Inventory System (TRI) Database. Office of Pollution Prevention and Toxics, Washington, DC. 1996.
7. U.S. Environmental Protection Agency. Aerometric Information Retrieval System (AIRS) Database. Office of Air Quality Planning and Standards, Research Triangle Park, North Carolina. 1997.

2.0 THE PAPER AND OTHER WEB COATING INDUSTRY

2.1 INTRODUCTION

The paper and other web coating (POWC) industry consists of the application of various coatings onto web substrates to manufacture a wide range of products, including, but not limited to, pressure-sensitive tapes and labels, vinyl film, photographic paper and film, flexible packaging, industrial and decorative laminates, sandpaper and other abrasives, and wall coverings.

Although the industry manufactures an extensive list of products, the coating processes used by the different segments of the industry are very similar. Typically, the substrate (web) is unwound, coated, rewound and/or cut to size, and packaged. Alternatively, a web may be unwound, coated, and then combined with another material by lamination (either before or instead of being rewound).

Emission sources are also similar throughout the different industry segments. Coating application and drying/curing are the largest emission sources for all segments of the industry, with minimal HAP emissions from cleaning, coating mixing, coating and solvent storage, and wastewater. Coating line emissions can represent up to 96 percent of the total HAP emissions from coating operations.¹ Some segments of the industry also manufacture substrates onsite. In the flexible vinyl industry segment of the POWC industry, 38 percent of the facilities responding to an EPA

survey stated that flexible vinyl substrates were formed onsite.² In the photographic film industry segment, 20 percent of the respondents indicated that they formed flexible vinyl substrates onsite.³

Many industrial facilities perform both coating and printing operations. Within the printing industry, the rotogravure and wide-web flexography product and packaging printing industry segment (that includes the flexible packaging industry as a major subsector) does the most coating, with material use distributed almost equally between inks and coatings.^{4,5} Printing operations are covered under EPA's promulgated National emission standards for hazardous air pollutants (NESHAP) for the printing and publishing industry.⁶ The printing and publishing NESHAP covers all types of printing operations and includes an option for facilities that perform both printing and coating to cover certain coating operations under the printing and publishing NESHAP. Therefore, many of the facilities whose coating operations could be covered under the NESHAP for the POWC industry may opt to cover these operations under the printing and publishing NESHAP. A detailed discussion of the printing and publishing industry is included in the background information document for that industry.⁷

In the responses from the POWC survey of the pressure sensitive tape and label, flexible vinyl, photographic film, and decorative and industrial laminates industry segments, 8 percent of all (824) coating application stations were printing stations. In the individual segments, the flexible vinyl industry segment had the highest percentage of printing stations at 30 percent. The other industry segments had much lower percentages of printing stations: decorative and industrial laminates and photographic film both had 2 percent, and pressure-sensitive tapes and labels had 0.7 percent.⁸

Section 2.2 includes a discussion of the typical coating processes used by the POWC industry. Section 2.3 contains a POWC industry profile that includes a discussion of the major segments of the POWC industry, and the types of coatings and operations that are specific to those segments of the industry. References may be found in Section 2.4. Appendix A lists the facilities that responded to the EPA survey of the POWC industry.

2.2 OVERVIEW OF THE COATING PROCESS

Section 2.2.1 provides a definition of a "web coating operation." In Section 2.2.2, the typical components of the coating process are explained with detailed descriptions of coating applicators and ovens. The types of coatings used in the POWC industry are described in Section 2.2.3.

2.2.1 Coating Operations

A web coating operation may be defined as a process that applies a uniform layer of material (coating) across essentially the entire length and/or width of a continuous (web) substrate to provide a covering, finish, or functional or protective layer to a substrate, to saturate a substrate or to provide adhesion between two substrates for lamination. Some coatings actually form part of all of the substrate, such as photographic, x-ray, and microfiche film; vinyl for wall and window coverings; the back side of carbonless paper; and reactive resins used in the manufacture of decorative and industrial laminates.⁹ These materials may or may not be further coated, printed, or processed. Coatings for lamination can also provide adhesion between two substrates.¹⁰

The distinction between a printing operation and a coating operation may not always be obvious. Printing may be described as a process that applies words, designs, or pictures to a substrate.

Although printing and coating are distinct operations for regulatory purposes, they have many similarities.

2.2.2 Coating Process

Components of a typical coating line in the POWC industry include an unwind roll, one or more coating applicators and drying ovens, a rewind roll or cutting/slitting operation, and flash-off area. Each coating application station may use the same type of coating applicator or different types of applicators. Typically, an oven immediately follows each application station. The coating applicator and the oven are the main emission sources on the coating line.

2.2.2.1 Coating Applicators. Several different types of applicators may be used to apply the coatings. The most common types of applicators used by the industry include (roto)gravure, reverse roll, slot die, knife, flexography, Mayer rod, dip and squeeze, and extrusion/calendering. Other types of applicators may be used for selected coating operations, but these are the primary types of applicators used by the POWC industry.

Table 2-1 shows the breakdown of coating applicators used by respondents of the POWC survey.¹¹ From these data it can be seen that gravure coating applicators were used the most (at 32 percent of the coating stations), with roll and/or reverse roll coaters used second most (at 20 percent), and slot die used third most (at 10 percent), together accounting for almost two-thirds of the coating application stations. The eight remaining coating applicator types together account for approximately one-third of the coating applicators in the surveys.

2.2.2.1.1 Rotogravure. Rotogravure (web-fed gravure) coaters are used extensively by the printing industry, but they are also used

Table 2-1. Types of Coating Applicators Used by Respondents of the POWC Survey

Application Method	Percentage of Application Stations
Gravure	32
Roll, Reverse Roll	20
Slot Die	10
Knife	9
Flexography	8
Mayer Rod	7
Dip	5
Extrusion/calendering	3
Rotary Screen	3
Printing	2
Flow	1
Total	100

for coating. The coating materials (or inks) are picked up in the recessed areas of the roll and transferred directly to the substrate. The gravure coater can print patterns on the substrate or coat some or all of the substrate. Figure 2-1 shows a diagram of a gravure coating unit; several of these may be combined on one coating line. In gravure coating, the coatings include both solvent and waterbased systems, with the solvents including aromatic, aliphatic, and oxygenated hydrocarbons. About 60 percent of the coatings are petroleum-based waxes and hot melts, 35 percent are extrusion coatings, and 5 percent water-based.¹²

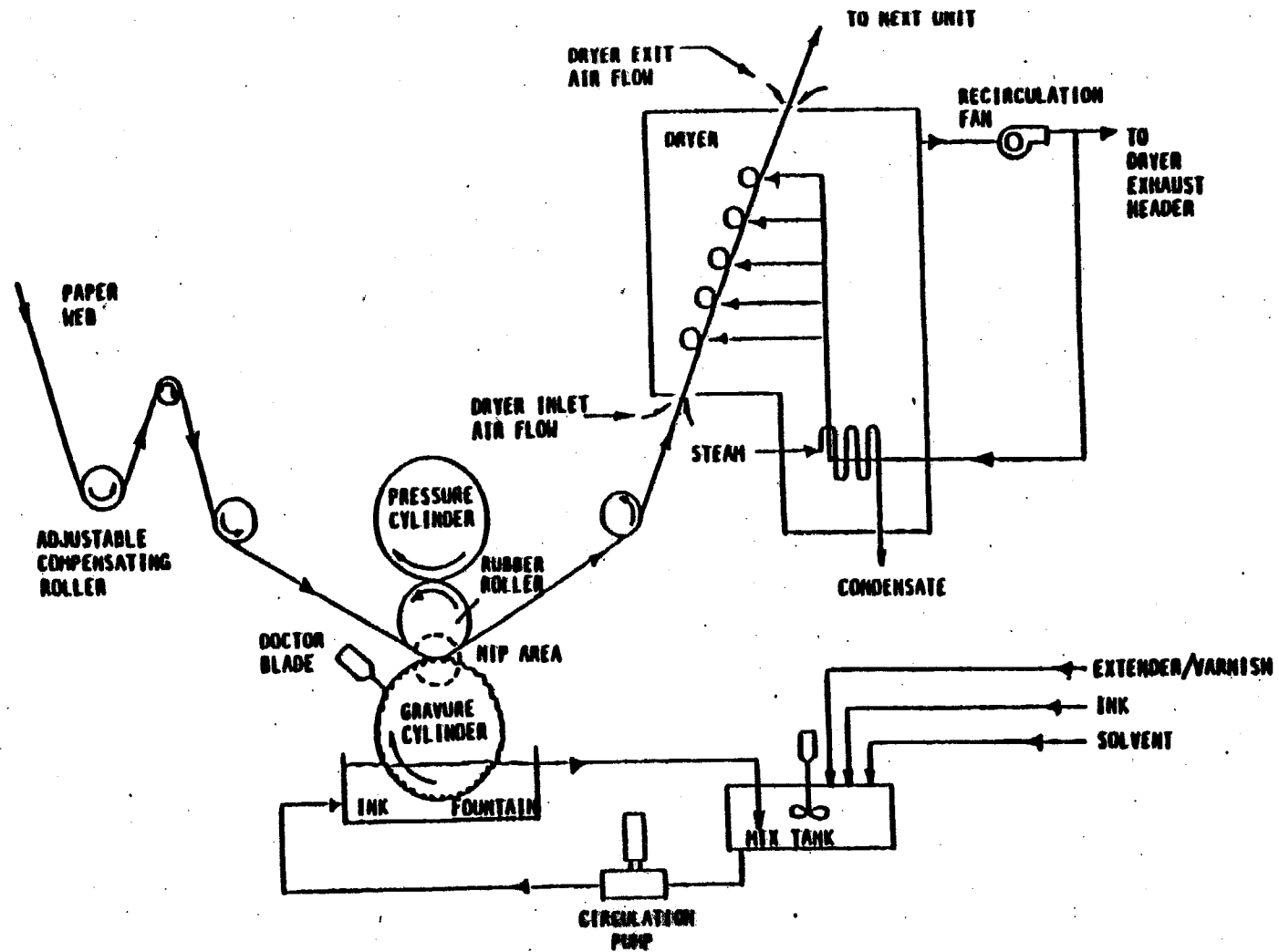


Figure 2-1. Gravure coating unit.¹³

Among the POWC survey respondents, gravure was the most common type of coating application station, at 32 percent of all coating stations, and also the most common coating technique in the pressure-sensitive tapes and labels industry segment (at 33 percent) and flexible vinyl industry segment (at 40 percent). In the decorative and industrial laminates industry segment, gravure coating was the second-most common (after dip), at 34 percent of the coating stations.

2.2.2.1.2 Reverse Roll. The reverse roll coater applies a constant thickness of coating to the substrate, usually by means of three rollers--a metering roller, a backing roller, and an applicator (transfer) roller. A metering roller picks up the coating solution from a trough and transfers it to an applicator roller. (Sometimes there is no metering roller and the coating is pumped directly onto an applicator roller.) The web is supported by a backing roller where the applicator roller contacts the paper. The applicator roller then transfers the coating to the substrate, as the web passes between the backing roller and the applicator roller. The applicator roller turns in a direction opposite to that of the paper, hence the name reverse roll coater. This reverse direction of the applicator roller reduces striations in the coating that can form if the applicator roller is turned in the same direction as the paper web. Figure 2-2 depicts a three-roll reverse roll coater.

Among the POWC survey respondents, roll and/or reverse roll was the second-most common type of coating application station, at 20 percent of all coating stations, with 28 percent of the photographic film stations, 26 percent of the pressure-sensitive tapes and labels coating stations, and 20 percent of stations in the

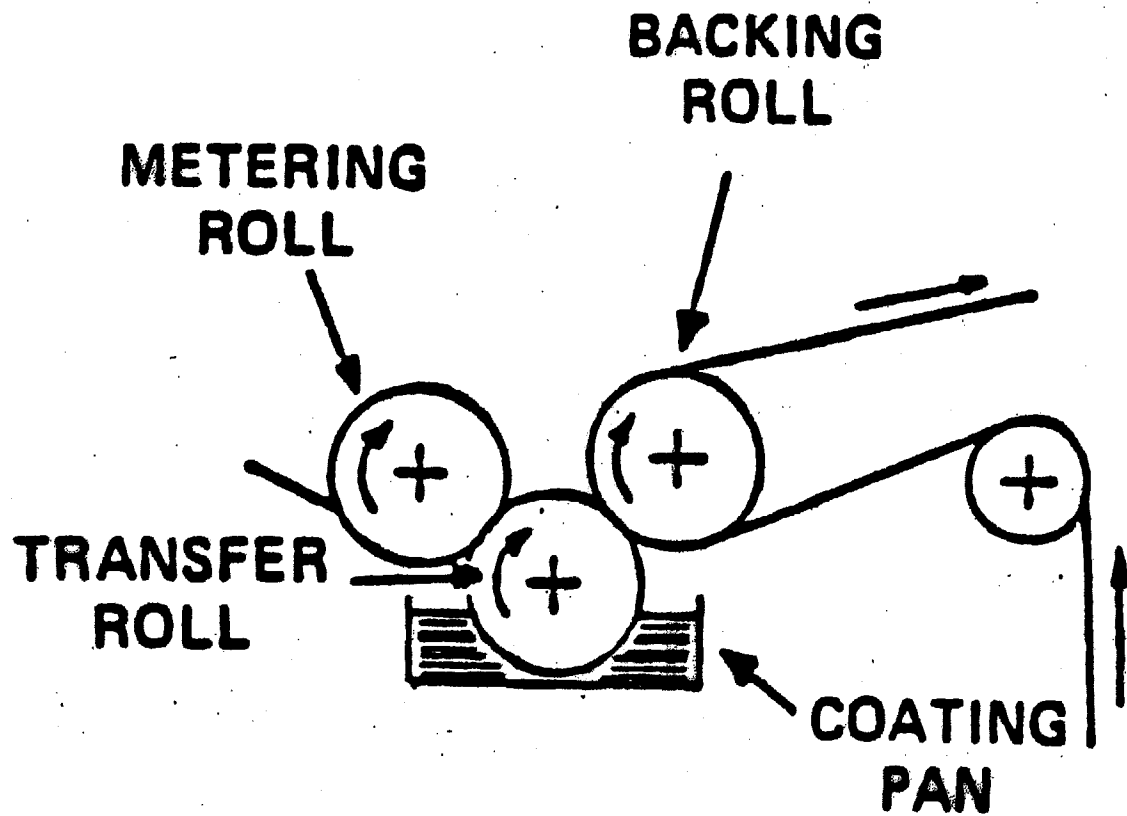


Figure 2-2. Three-roll reverse-roll coater.¹⁵

decorative and industrial laminates industry segment using roll and/or reverse roll coater coaters.

2.2.2.1.3 Slot Die. The slot die coater is similar to an extruder but is less heavy-duty than an extruder since less viscous materials are used with a slot die coater (see Section 2.2.2.1.8 for a discussion of extruders). In a slot die coater, the coating is extruded through an adjustable-width orifice onto the substrate and is sometimes followed by a smoothing roller. Slot die coaters are typically used for application of hot-melt coatings and adhesives, but may also be used to apply aqueous coatings.¹⁴

Among the POWC survey respondents, slot die coating was the third-most common coating technique, at 10 percent of all coating stations; and was the most common technique in the photographic film industry segment (at 44 percent). It was also a common technique in the pressure-sensitive tapes and labels industry segment (at 12 percent). No decorative and industrial laminates facilities among the survey respondents used slot die coaters.

2.2.2.1.4 Knife. A knife coater consists of a blade that scrapes off excess coating from the substrate. The tray or trough of coating is located behind the knife blade. A continuous sheet of substrate is drawn between the knife blade and the support roller. As coating is deposited on the substrate, the knife blade spreads it across the substrate to the desired thickness. The position of the knife relative to the substrate surface can be adjusted to control the thickness of the coating. Some knife coaters use high velocity air as the knife blade, these are known as air-knife coaters. A diagram of a floating knife coater is shown in Figure 2-3.

Knife coaters can apply solutions of much higher viscosity than roll coaters, thus less solvent is emitted per pound of coating applied. Knife coaters handle coatings with viscosity up to

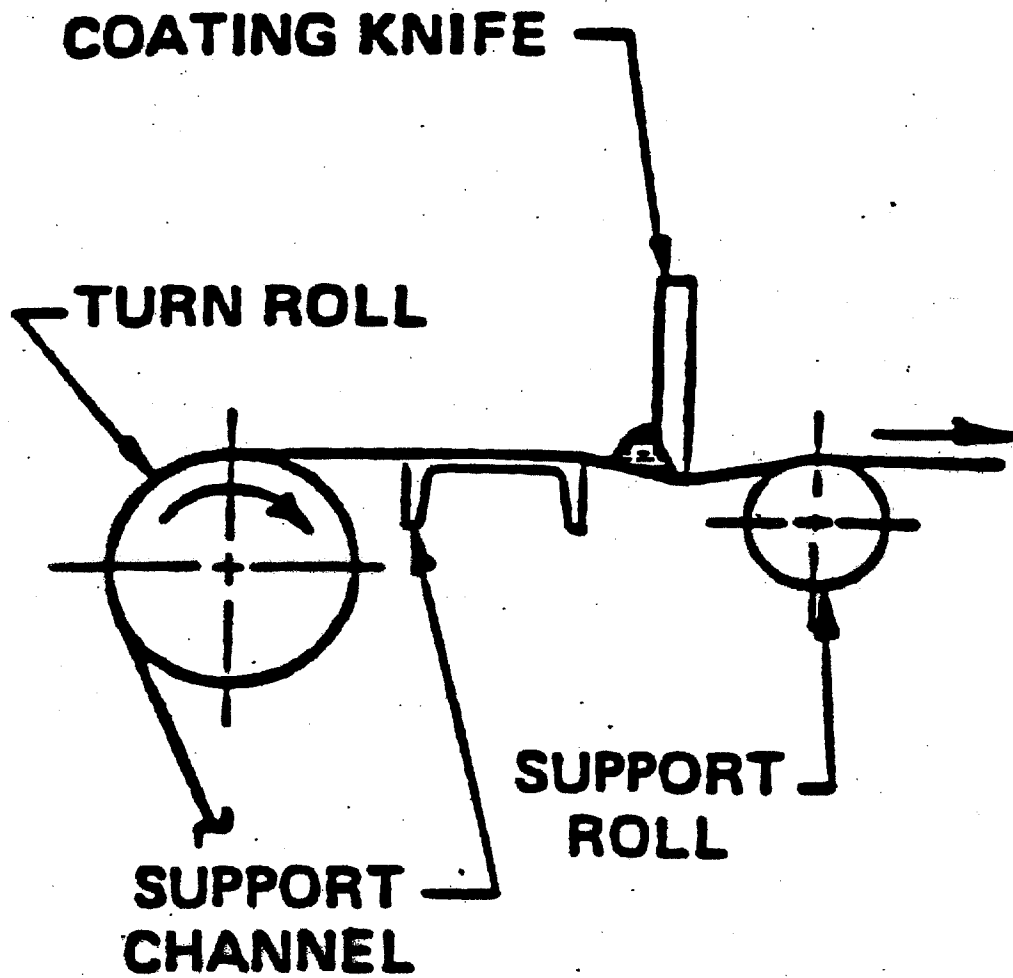


Figure 2-3. Knife Coater.¹⁹

10,000 centipoise (cp), while reverse roll coaters operate best with coatings that have a viscosity ranging from 300 to 1500 cp. Knife coaters, however, usually operate at lower speeds than roll coaters and show a greater tendency to break the web.¹⁶

Among the POWC survey respondents, knife coating was the fourth-most common type of coating application station at 9 percent of all coating stations, with 11 percent of the flexible vinyl coating stations, 11 percent of the photographic film coating stations, 9 percent of the pressure-sensitive tapes and labels coating stations, and 5 percent of the decorative and industrial laminates industry stations having knife coaters.

2.2.2.1.5 Flexography. In flexographic coating, the area to be coated is delineated by a raised surface on a flexible plate that is usually made of rubber or other elastomeric materials.¹⁷ Because of the ease in plate preparation, flexography is more suited to short production runs than gravure.¹⁸

Coating materials applied with flexography must be very fluid to work properly and include waterborne and solvent-based systems. The solvents used must be compatible with the rubber or polymeric plates; thus aromatic solvents are not used. Some of the components of solvent-based flexographic coatings include ethyl, n-propyl, and isopropyl alcohol; glycol ethers; aliphatic hydrocarbons; and esters.²⁰ Flexography is performed both on wide web (<18 inches) and narrow web (<18 inches), and on sheets as well as web.²¹

Among the POWC survey respondents, flexographic coating was the fifth-most common type of coating application station at 8 percent of all coating stations, with 20 percent of the flexible vinyl industry segment and 4 percent of the pressure-sensitive tapes and labels industry segment coating stations having flexographic coaters. No

decorative and industrial laminates facilities among the survey respondents used flexographic coating applicators.

2.2.2.1.6 Mayer Rod. The Mayer rod (or wire-wound rod) coater is a metering device used to control the thickness of an applied coating. Typically, the coating is applied via a roller, and the excess coating is removed by a rod covered by a spiral-wound stainless steel wire. The rod wipes the coating off the substrate except for the portion which escapes through the spaces between the wires. Larger wire diameters result in larger spaces, and therefore heavier coatings.²²

Among the POWC survey respondents, Mayer rod coating was used most often in the pressure-sensitive tapes and labels industry segment, with 11 percent of the coating stations having Mayer rod coaters, and was used by 5 percent of the decorative and industrial laminates, 3 percent of the flexible vinyl, and 2 percent of the photographic film industry segment coating stations.

2.2.2.1.7 Dip and Squeeze. The dip and squeeze coater, also called a dip coater, impregnates or saturates the substrate rather than applying a coating to the web surface.²³ Figure 2-4 shows a diagram of a dip and squeeze coater. The substrate is fed and dipped into a coating-filled pan by a system of rollers. The saturated web is then passed through nip rollers that squeeze off any excess coating.

Among the POWC survey respondents, dip and squeeze coating was the most-common coating station in the decorative and industrial laminates industry segment, at 36 percent of the coating stations. Overall, only 5 percent of the coating stations from the entire survey respondents used dip and squeeze, with 3 percent of the flexible vinyl industry segment and 1 percent of the pressure-sensitive tapes and labels industry segment.

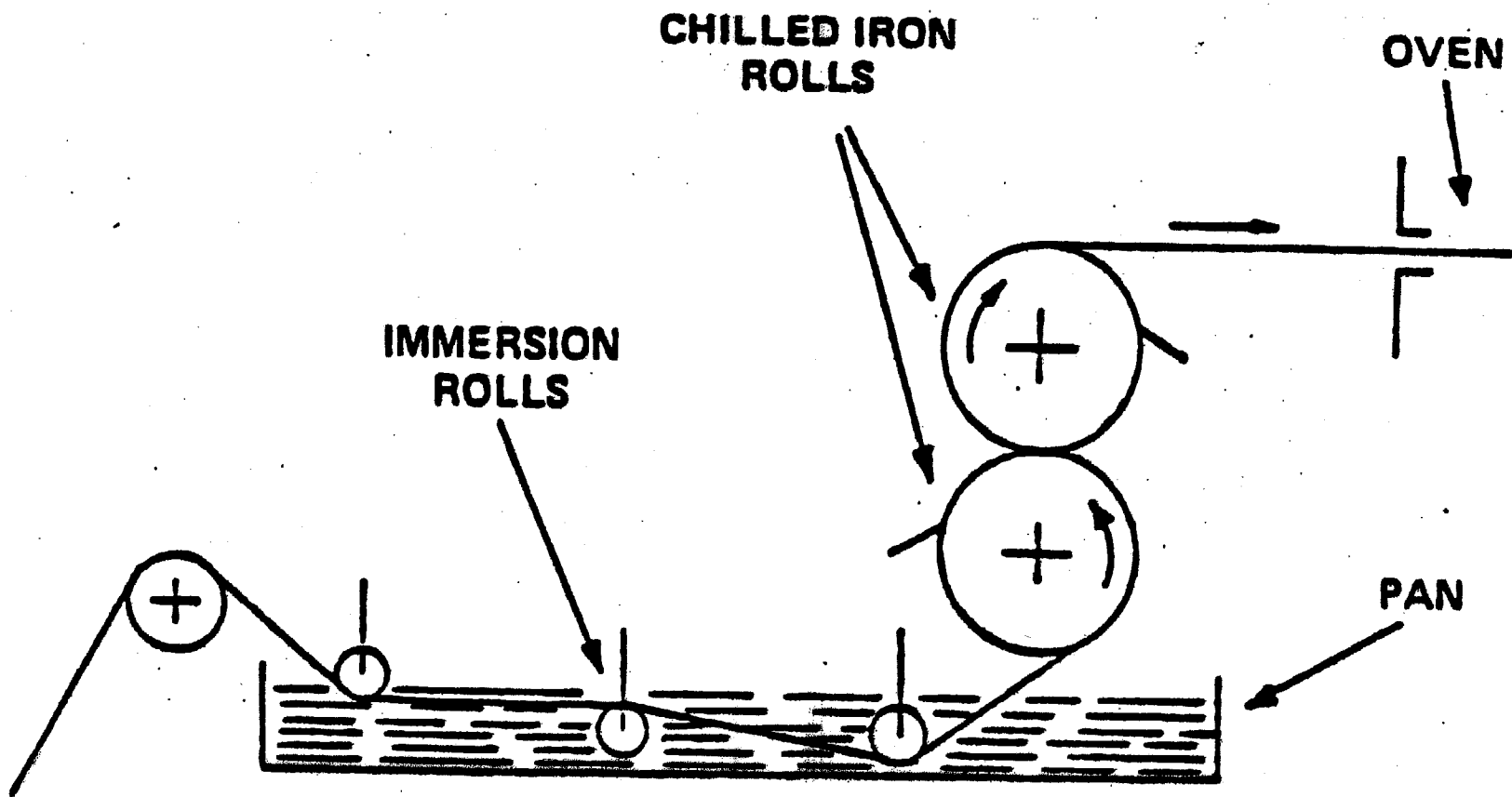


Figure 2-4. Dip and squeeze coater.²⁴

2.2.2.1.8 Extrusion/calendering. The extrusion coater creates a web substrate or applies coating materials to a preformed web substrate by forcing it through a die. A typical extrusion coater forms a plastic film or coating of the hot-melt type by forcing a molten polymer resin through a die as the web or conveyor passes below the die. The extruded web is then cooled to restore the coating to a solid state.²⁵ Nearly all extrusion coatings are made of low-density polyethylene (LDPE). They account for a large portion of the coatings used in the printing product and packaging industry, divided about evenly between cartons/cardboard and flexible materials.²⁶ Figure 2-5 shows a diagram of an extrusion coater.

In calendering, a process similar to extrusion, material is pressed by a roller or between rollers to form a web such as vinyl sheeting. Calendering may also be used to apply a coating to a substrate, as in the manufacture of duct tape.²⁷ Prior to calendering, resins, plasticizers, and pigments are blended together in a series of blenders, mixers, and mills. Plasticizers are used to improve the flexibility of the coating/material.²⁸ After mixing, the mixture is conveyed to the calender. In a typical four-roll calender, the molten coating is rolled into a continuous sheet, which is then cooled. Figure 2-6 shows the calendering process.

Among the POWC survey respondents, extrusion/calendering was used most often in the pressure-sensitive tapes and labels industry segment, at 3 percent of the coating stations, with 2 percent of the coating stations in the photographic film industry segment using extrusion/calendering occurring. No coating stations were reported to use extrusion/calendering in the decorative and industrial laminates industry segment.

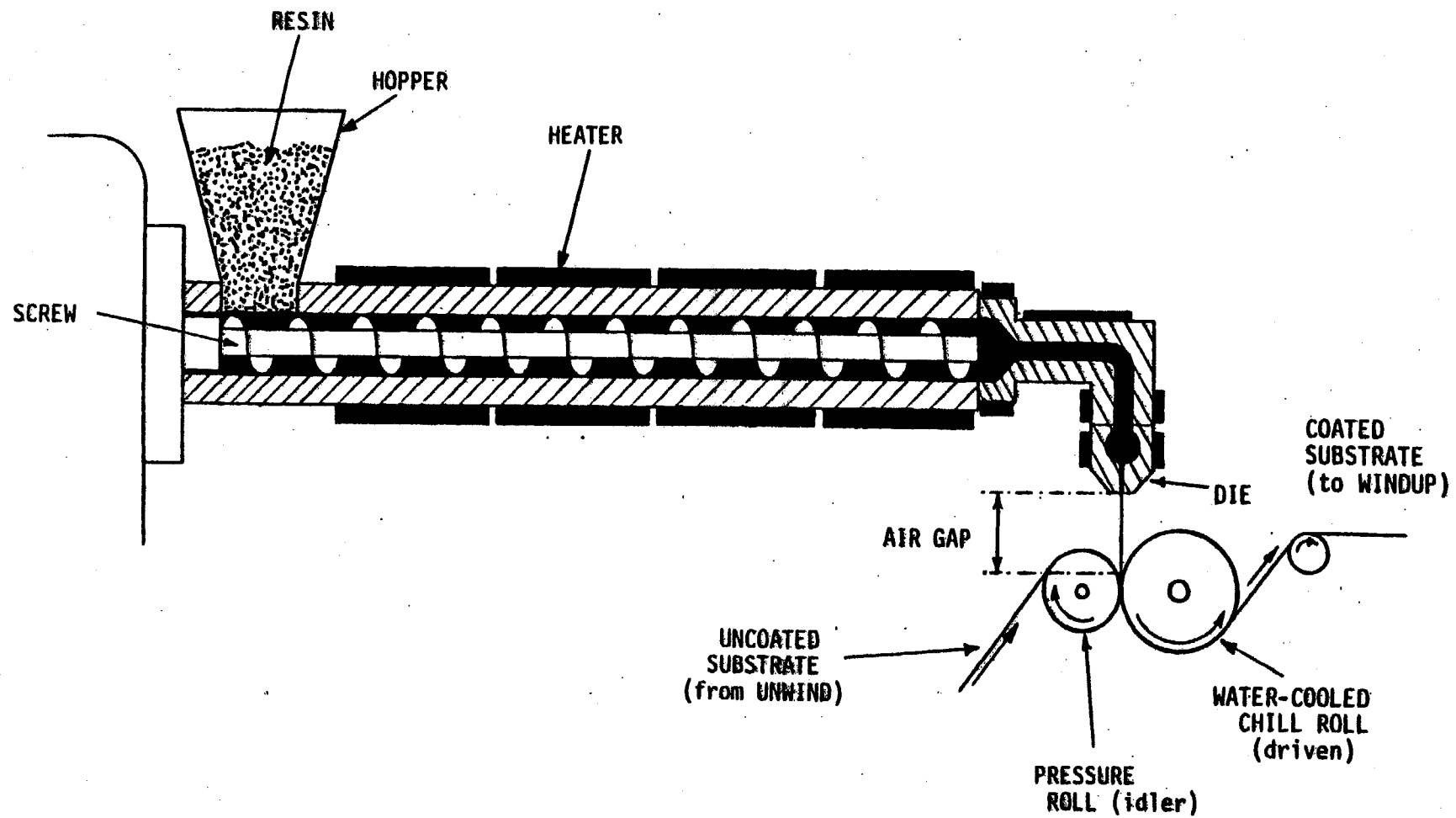


Figure 2-5. Extrusion coater.²⁹

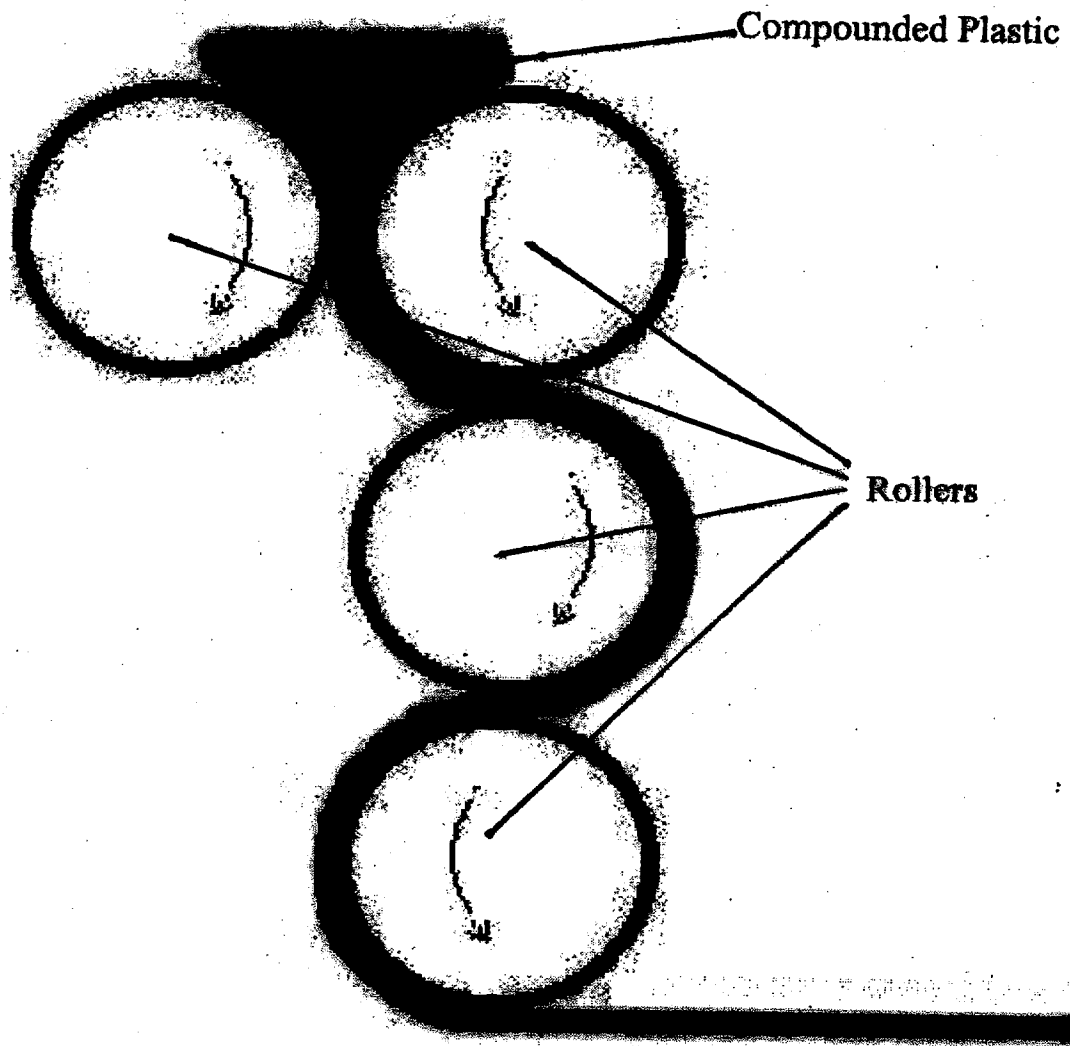


Figure 2-6. Calendaring process.³⁰

2.2.2.2 Coating Ovens. Like the applicator, the oven is a primary piece of equipment on the coating line. The major functions of the oven are to dry the coating by evaporating the solvent and/or finish the curing of a polymeric coating.³¹ The oven exhaust is the largest source of HAP emissions in the coating process.

The important properties of a drying/curing oven include the source of heat, operating temperature, residence time, allowable hydrocarbon concentration, and oven air circulation.³² There are two basic types of heating used in drying ovens, direct and indirect. Direct heating routes the hot products of combustion (blended with ambient air to the proper temperature) directly into the drying zone. The fuels used for a direct-fired oven are usually limited to natural gas or propane because of the requirements for clean burning. Fuel oil, or other heavier fuels, can produce enough soot and other particulates to adversely affect the coating.

In an indirect-heated oven, the incoming air stream exchanges heat with steam or combustion products but does not physically mix with them. The heat transfer may occur in any of several types of heat exchangers, such as shell-and-tube or plate type.

Direct-fired ovens are more common because of their higher thermal efficiency. Indirect-heated ovens lose efficiency both in the production of steam and in the heat transfer from steam to oven air.³³ Indirect heating is usually limited to small ovens, cases where product contamination cannot be tolerated, and where surplus steam is available.

The average oven temperature is important to both the process and the costs of installing add-on control equipment. For drying purposes, the oven must be at a temperature above the boiling point of the solvent(s). If the coating cures by polymerization rather than solvent evaporation, the temperature may have to be even higher.

The average temperature affects the amount of cooling required if the exhaust stream is directed to a carbon adsorber and the amount of preheating required if the exhaust stream is directed to a thermal oxidizer.

The oven temperature profile is also important to product quality. If the initial drying is too fast, flaws in the coating such as craters or fish-eyes may result.³⁴ If the drying is too slow at lower temperatures, a longer oven will be needed to dry the coating. The solution to this problem is multizoned ovens, where the oven is physically divided into several sections, each with its own hot air supply and exhaust. By using a lower temperature in the first zone and then gradually increasing the temperature in subsequent zones, uniform drying can be achieved in a reasonably sized oven.³⁵

For safety, most facilities in the industry try to maintain air flow through their ovens so that the solvent concentration is no greater than 25 percent of the lower explosive limit (LEL). However, newer oven styles safely allow higher solvent concentrations, up to 40 to 50 percent of the LEL. The higher solvent concentrations are allowable due to the increasing use of continuous LEL monitors that sound alarms or shut down the line if the LEL reaches too high a level. With the higher allowable solvent concentrations, the amount of air flow needed through the oven is decreased, resulting in lower energy costs. The higher solvent concentrations also reduce the costs of add-on control devices, which increase in cost as the air flow increases. The exhaust flow rates from ovens used by the industry vary from 5,000 to 35,000 standard cubic feet per minute (scfm). Typical oven exhaust rates are 10,000 to 20,000 scfm.³⁶

2.2.2.3 Inert Ovens. An inert oven is a coating drying method that uses an inert gas (e.g., nitrogen) to replace oxygen in the air

space in the oven. In an inert oven, solvent vapors can be concentrated at levels higher than the LEL to enable efficient collection via condensation. The ovens are also found to be useful with coatings that otherwise would be difficult to apply without forming air bubbles under the coating surfaces.³⁷

There is no oven vent to the atmosphere in an inert oven. Instead, a small diameter pipe conducts superconcentrated exhaust at flow rates of only 100-200 ft³/min to condensation coils. Solvent concentrations may be 100,000 to 200,000 ppm in an inert oven's exhaust, which is above the upper explosive limit (UEL) for most/all solvents. After the solvent condenses out of the gas in the coils, the cleaned gas is returned to the oven; this cycle is a closed loop in terms of the oven gas.³⁸

For proper operation, there must be an oxygen-free dead-zone of air space after the inert oven and before the condenser, where the air flow is balanced between the air pulled in vs. the air pushed out. This situation complicates the use of total enclosures around a coating line with an inert oven. Unfortunately, air flow as little as 200 ft/min can disturb the web in an inert oven and cause a web to break, especially one made of paper. Because of issues such as solvent concentrations above the UEL and static electricity in film coating, safety is another concern with totally enclosing the air space around inert ovens.³⁹

2.2.3 Coating Types

The basic coating types, by composition, used in the POWC industry are solventborne, waterborne, hot-melt, and radiation-cure coatings. These coating types are described in this section, below.

Coatings typically consist of a fluid portion (i.e., solvent(s)), resins, pigments, and additives. The solvents and resins together form the vehicle, which maintains the coating in

liquid form for application; once the coating is deposited on the substrate, the solvents of the vehicle evaporate leaving the resin, and the pigments and additives. The solvent portion of the vehicle transfers the solid portion of the coating to the substrate surface in a uniform layer and typically plays no further role in the coating process.⁴⁰ Coatings can range from 0 to 99 percent solvent. The nonsolvent portions of coatings are called "solids."

The HAP from the coatings may be emitted as fugitive emissions (unless the facility is equipped with a permanent total enclosure) at the point of application and in flash-off areas. The HAP from the coatings are also emitted via exhaust stacks/vents from the ovens used to dry the coatings.

2.2.3.1 Solventborne Coatings. Solventborne coatings are widely used in the POWC industry.⁴¹ The content of the coating vehicle is highly variable in solventborne coatings, and depends primarily on the type of coating applicator used. For solventborne coatings, coating formulations typically range from 40 to 80 percent solvents by weight, as supplied. For use, the solventborne coatings may be diluted with additional solvents. The primary solvents in solventborne coatings that are HAP include methanol, methyl ethyl ketone, toluene, and xylene. Other primary solvents (not HAP) include acetone and ethanol.

Knife coaters, reverse roll coaters, and gravure coaters are commonly used to apply solventborne coatings.⁴²

2.2.3.2 Waterborne Coatings. In waterborne coatings, a significant part of the fluid is made up of water, although some organic solvents may be used at up to 30 percent of the fluid. The EPA Reference Test Method 24 considers a waterborne coating to be one with more than 5 percent water by weight in its volatile fraction.⁴³ Most coating equipment used for solventborne coatings can also be

used for waterborne coatings. However, troughs or trays containing waterborne coatings may have to be mixed more often than with solventborne coatings because waterborne coatings are more susceptible to coagulation or agglomeration of their solids.⁴⁴ Knife coaters and gravure coaters are also particularly well suited to application of waterborne coatings.⁴⁵

Oven temperatures are typically higher with waterborne coatings because water has a higher boiling point and higher heat of vaporization than most organic solvents. However, energy usage may still be lower for waterborne coatings because less dilution air is required.⁴⁶

2.2.3.3 Hot-melt Coatings. Hot-melt coatings are probably the most environmentally friendly of all the coating formulations used by the POWC industry because they contain no solvent, being 100 percent solids in composition.⁴⁷ Unlike solventborne coatings and waterborne coatings, which typically are formulated with some organic solvent, hot-melt coatings emit no volatile organic compounds (VOC). Energy usage with hot-melt coatings is substantially lower than with either waterborne or solventborne coatings. Fire and explosion dangers are also minimized because there are no volatile hydrocarbons.⁴⁸

The application of hot-melt coatings is fairly simple. The solid coating material is heated and delivered to the coater head in a molten state. It is then metered onto the web by a heated gravure coater, a heated roll coater, or an extrusion coater. The coated web is then chilled and the coating restored to its solid state.⁴⁹ However, despite its simplicity, application of hot-melt coatings may have several problems. Controlling the coating weight can be difficult with hot-melt coatings. The coater head is more susceptible to streaking due to plugging or dirt accumulation.

Cleaning the coater head with hot-melt coatings is also more difficult and time consuming.⁵⁰

The use of hot-melt coatings, although growing, is still limited by several factors. Hot-melt adhesives do not have the strength or resistance to environmental stresses such as heat or cold as do solventborne adhesives.⁵¹ The hot-melt adhesives are typically a darker color and, therefore, are not used on transparent surfaces. Hot-melts also cannot be used on film substrates that are sensitive to heat because the substrate could melt during the coating process.⁵²

2.2.3.4 Reactive Coatings. Reactive coatings are coatings that cure via a chemical (usually polymeric) reaction which forms other compounds that are either not HAP's and/or stay with the substrate as a residual HAP which is not emitted with or without drying.

Reactive coatings are frequently used in the decorative and industrial laminates industry segment of the POWC industry and the abrasive subsector of the miscellaneous industry segment, and include styrene formaldehyde, phenolic, melamine, and epoxy resins. In the POWC survey responses in the decorative and industrial laminates industry segment, seven facilities provided test or engineering data on the amount of residual HAP left in the substrate with the use of reactive coatings. These data indicate that anywhere from zero to 50 percent of the coating (by weight) reacts and stays with the substrate/product.⁵³

2.2.3.5 Radiation-Cure Coatings. A special case of reactive coatings, radiation-cure coatings (also called prepolymer coatings⁵⁴) include coatings that are cured by exposure to electron beam (EB) or ultraviolet (UV) radiation. Radiation-cure coatings are solventless and are almost entirely composed of the resins that make up the coating. They are applied in a liquid state via some typical coating

application methods (e.g., gravure and flexography), and polymerize into a solid state upon exposure to UV or EB radiation. Ultra-violet-cured coatings require addition of a photoinitiator to catalyze the polymerization reaction; EB-cured coatings do not, because the highly excited electrons emitted by the EB source are capable of initiating the polymerization reaction.⁵⁵

Benefits of radiation-cured coatings extend beyond decreased solvent usage and the associated emission reductions. The instantaneous nature of the curing process eliminates the need for drying ovens on the production line, which often leads to production increases⁵⁶ and may allow direct integration of ancillary operations (e.g., cutting, slitting, folding) into the production line.⁵⁷ Because no drying ovens are used, energy usage is greatly reduced as is the space required for a coating line.⁵⁸ Since the coatings will not cure unless exposed to the proper type of UV or EB radiation, they will not cure on the production equipment during operation or during process downtime. As a result, it is not necessary to clean application devices at the end of each shift or during breaks, and cleaning is easier when it is performed.⁵⁹

Although industry generally perceives UV coating usage as expensive because it may be costly to switch a coating line from solvent-based coating equipment to radiation-cured systems, there are often savings with the use of radiation-cured coatings due to the above-mentioned benefits that can offset capital costs. Another industry perception is that the coatings themselves are more expensive. This may be true on a volume-to-volume basis comparison, however, a radiation-cured coating will cover a much greater area of substrate (2 to 4 times) than an equal volume of a solvent-based coating because the radiation-cured coating is 100 percent solids and has no loss of volume due to evaporation of solvent.⁶⁰

There are, however, several real limitations to the use of radiation-curable systems. The extent of cure penetration can be a problem if the coating is very thick or heavily pigmented.⁶¹ Because low viscosity solvents are not used, application of the relatively higher viscosity radiation-cured coatings can be problematic; this factor is less important in the application to web substrates than in spray coating.⁶² Also, skin contact with UV-cured coatings should be minimized by the use of gloves because of the potential for irritation and/or allergic reaction with the use of these coatings.⁶³ This is especially true when cleaning is performed, since the combination of cleaning solvents and inks and coatings increases dramatically the level of irritation to the skin.⁶⁴

2.3 INDUSTRY PROFILE

The POWC industry includes the manufacture of a wide range of products. Table 2-2 presents a listing of 18 Standard Industrial Classification codes (SIC) codes for industries that include products or processes that are likely to be manufactured or used, respectively, by the POWC industry. As shown in the table, the POWC industry is thought to encompass a large number of SIC codes. However, there may be facilities operating under other SIC codes not included in Table 2-2 that also apply coating to web substrates, such as paper, plastic, film, foil, and foam. In addition, all facilities operating under these SIC codes are not necessarily members of this source category; many of the 18 SIC codes cover only one or two products that are manufactured with web coating. Some of the 18 SIC codes include facilities that primarily print rather than coat the substrate, that may choose to cover their limited coating operations under the printing and publishing NESHAP. Consequently, while the list of SIC codes presented in Table 2-2 can serve as a guide to identifying many of the facilities in the POWC industry, it should

Table 2-2. The 18 SIC Codes of the Paper and Other Web Coating Industry

SIC Code	Description
2653	Corrugated and solid fiber boxes
2657	Folding paper board boxes, including sanitary
2671	Packaging paper and plastics film, coated and laminated
2672	Coated and laminated paper, not elsewhere classified
2673	Plastics, foil, and coated paper bags
2674	Bags: uncoated paper and multi wall
2675	Die-cut paper and paperboard and cardboard
2679	Converted paper and paper board, not elsewhere classified
2754	Commercial printing, gravure
2761	Manifold business forms
3074	Plastic aseptic packaging
3081	Unsupported plastics film and sheet
3083	Laminated plastics plate, sheet, and profile shapes
3291	Abrasive products
3497	Laminated aluminum (metal) foil and leaf, flexible packaging
3861	Photographic equipment and supplies
3955	Carbon paper and inked ribbons
3996	Linoleum, asphalted-felt-base, and other hard surface floor coverings, not elsewhere classified

Note: There are likely a number of facilities in each SIC that do not do coating and these 18 SIC's are not necessarily an exhaustive list of facilities that may do coating.

not be used to completely define the industries subject to the POWC NESHAP.

Based on emissions estimates from the Toxic Release Inventory (TRI) system⁶⁵ for these SIC's, the POWC data gathering efforts focused on the four largest segments of the POWC industry that were defined by their product and process types: pressure-sensitive tapes and labels (SIC 2672), flexible vinyl (SIC 3081), photographic film (SIC 3861), and decorative and industrial laminates (SIC 3083). Therefore, much of the information in this section focuses on these four industry segments. A fifth segment, called "Miscellaneous Coating," is also discussed that includes a number of industries that are identifiable as having some web coating operations associated with their product manufacturing, such as those facilities that do both printing and coating.

Within 1996 TRI data for the 18 POWC SIC's, the four major POWC SIC's (2672, 3081, 3861, 3083) had the greatest percentages of major source HAP emissions, and together represent 79 percent of the TRI emissions and 82 percent of the facilities (if the six Printing and Publishing SIC codes are excluded from the analysis).

The POWC data gathering efforts focused on identifying the activities within the major industry segments that generated HAP and on variations in the coating processes and control techniques. It was found that the web coating operations (described in Section 2.2) and control techniques (described in Chapter 3) do not vary significantly among the segments of the POWC industry.

Most segments of the industry have some operations that are unique to those segments. The discussion below includes information on the types of coatings and coating applicators used by each major segment, and the primary HAP emitted by each industry segment. It

also includes a discussion of operations that are specific to each industry segment.

2.3.1 Pressure-sensitive Tapes and Labels

The pressure-sensitive tape and label industry segment is one of the largest segments of the POWC industries, based on 1996 TRI emissions.⁶⁶ It includes the manufacture of all types of tapes and labels, including masking tape, strapping tape, duct tape, transparent tape, electrical tape, and medical tapes and labels. It also includes the manufacture of metallized labels and self-adhesive labels.⁶⁷ Demand for pressure-sensitive labels has increased as the demand for glue-applied labels has decreased. One pressure sensitive label product, blank roll labels (such as for computer data processing), is viewed as a fast-growing label market. As of 1989, pressure-sensitive labels accounted for as much as 22 percent of all labels.⁶⁸

Survey responses from the pressure-sensitive tapes and labels industry segment, showed that in terms of primary products, bonding and mounting tapes and labels were reported most often (18 percent), with carton sealing, abrasion resistant, and application/pre-mask tapes and/or labels next highest (at 12, 10, and 10 percent, respectively).⁶⁹ Table 2-3 shows the 29 primary products listed in the pressure-sensitive tapes and labels survey responses.⁷⁰

In a survey conducted by the Pressure Sensitive Tape Council in 1994, 39 percent of the responding facilities indicated they manufactured film tape, 25 percent label stock, 15 percent paper tape, 5 percent cloth tape, 2 percent filament tape, and 15 percent other types of tape.⁷¹ Backing materials (substrates) used by the pressure-sensitive tape and label industry segment include paper, a variety of films, foam, metal foil, and fabric. Medical tapes and duct tapes are made with fabric backings.⁷²

Table 2-3. Primary Products of the Pressure-sensitive Tapes and Labels Survey Respondents

Primary Product	Percent of Respondents
bonding and mounting	18
carton sealing	12
abrasion resistant	10
application/pre-mask	10
double side	9
identification/safety, warning	4
anti-skid	3
anti-stick	3
book binding	3
bundling	3
label	3
coated textile for care labels	1
correction/cover-up	1
electrical	1
electronic applications	1
fastening	1
freezer	1
office/stationery	1
packaging	1
printable	1
protective - long term	1
pressure-sensitive adhesive-coated films	1
silicone	1
specialty fabric tapes	1
surface protection	1
trainer tapes - cotton based	1
transfer	1
vibration/sound damping	1
vinyl graphics film	1
Total	100

2.3.1.1 Baseline Emissions. In the POWC data gathering effort, information was collected from 91 facilities in the pressure-sensitive tapes and labels industry segment, of which 44 were determined to be major sources of HAP. The total number of facilities and HAP emissions in the pressure-sensitive tapes and labels industry segment were estimated to be 96 facilities and 8,063 tons per year (tpy) HAP emissions, representing 22 percent of the total number of facilities and 17 percent of total HAP emissions estimated for the POWC source category.⁷³

The total number of major sources and HAP emissions in the pressure-sensitive tapes and labels industry segment were estimated to be 47 facilities and 7,780 tpy HAP emissions, representing 11 percent of the total number of facilities and 16 percent of the total HAP emissions estimated for the POWC source category.

The primary HAP emitted by the pressure-sensitive tapes and labels industry segment are toluene, xylene, methyl ethyl ketone, and methanol.

2.3.1.2 Types of Coatings and Applicators Used. The pressure-sensitive tape and label industry segment primarily uses five classes of coatings: adhesives; release coatings; primers; coloring agents; and saturants. Adhesives are used on all pressure-sensitive tapes and labels.

The pressure-sensitive tape and label industry segment uses a range of coating formulations. According to a survey conducted by the Pressure Sensitive Tape Council,⁷⁴ 84 percent of the facilities responding to the survey indicate they used solventborne coatings, 60 percent waterborne coatings, 43 percent hot-melts, 13 percent calendered adhesives, 8 percent radiation-cured coatings, 8 percent

two-part reactive coatings, and 6 percent other types of coating formulations.

Solventborne coatings are used as adhesives, release coatings, primers, coloring agents, and saturants. They can also be used on all types of backing materials. For some applications--particularly special purpose applications requiring high performance from the adhesive, or applications where the tape is exposed to extreme environmental conditions--solventborne coatings are often the only coatings available that can achieve the performance and durability required.

Waterborne coatings are also used by the pressure-sensitive tape and label industry segment for adhesives and release coatings. Waterborne adhesives are comparable in performance to many solventborne adhesives. They are currently being used for many applications within the industry segment and, as technology continues to improve, the number of waterborne coating applications in the pressure-sensitive tapes and labels industry should increase. In some applications where high performance is required or in extreme environmental conditions, solventborne adhesives may still be required, but eventually waterborne adhesives may also be able to be used for these applications. Drawbacks of using water-based adhesives may include what one company⁷⁵ found was that waterbased adhesives need closer control of process variables and coater conditions, which can lower line speeds and raise cost to the consumer. Waterbased adhesives are thought to be more suited to gravure or slot die coating application techniques than reverse roll in this aspect. Clean-up operations are also reportedly more difficult with waterbased adhesives. In addition, waterbased adhesive-coated products may need to be remoisturized after drying to

reduce curl and to ease laminating, top coating, and finishing operations.

Waterbased release coatings are already being used extensively by the pressure-sensitive tape and label industry segment.⁷⁶ In most cases, the performance of the release coating is not as critical as that of the adhesive, so the pressure-sensitive tape and label industry segment has made more progress in converting to waterborne release coatings.

Hot-melt coatings, especially, adhesives, are used extensively by the pressure-sensitive tape and label industry segment.⁷⁷ Hot-melt coatings are generally considered to be 100 percent solids, and essentially pollution free. The POWC survey responses indicate that of the 21 coatings identified as hot-melt adhesives, 17 were 100 percent solids.⁷⁸ The remaining four hot-melt adhesive coatings had solids contents ranging from 99.90 to 99.96 percent. Only one of these four, however, contained any HAP (naphthalene), at a concentration of 0.04 weight percent.

Although hot-melt adhesives are solvent-free, the possibility exists for the evaporative loss of some of the lighter components in the coating formulation. Most of the applicable coatings are high molecular weight polymers, which may contain trace amounts of unreacted monomers and/or low molecular weight polymers. Some of these may be volatilized at the coating temperatures experienced in hot-melt coating operations. The EPA conducted limited tests to measure evaporative losses from hot-melt coatings. Weight losses of from 0.1 to 12.6 percent occurred.⁷⁹

The types of coating applicators used by survey recipients in the pressure-sensitive tapes and labels industry segment are shown in Table 2-4.⁸⁰ This table shows that 33 percent of the coating stations in the pressure-sensitive tapes and labels survey industry

Table 2-4. Types of Coating Applicators Used by Survey Respondents in the Pressure-sensitive Tapes and Labels Industry Segment

Application Method	Percentage of Application Stations
Gravure	33
Roll, Reverse Roll	26
Slot Die	12
Mayer Rod	11
Knife	9
Flexography	4
Extrusion/calendering	3
Dip	1
Flow	1
Total	100

Note: Seventy-five percent of the flexography coating stations are flexography printing.

segment use gravure coaters, 26 percent use roll and/or reverse roll, 12 percent use slot die, and 11 percent use Mayer rod, with the remaining 19 percent of the stations using five other applicator types.

2.3.1.3 Pressure-sensitive Tapes and Labels Coating Process.

The coating of pressure sensitive tapes and labels is called a "converting" operation, in which some backing material (paper, cloth, cellophane, etc.) is coated one or more times to create a tape or label that will stick on contact for the consumer's purposes. In the pressure-sensitive tape process, the web is unrolled, coated, dried, chilled, and then rolled up. The coating processes may add pre-coats, adhesives, or release coatings.⁸¹

Each pressure sensitive tape and label coating line typically undergoes a minimum of two coating operations. These may be done separately on discrete coating lines, or a single tandem coating line may be used where the web undergoes a sequence of coating and drying steps without being rewound between steps. Tandem coating lines are usually used for large volume products with relatively long runs times, since the flexibility of a coating line is reduced with a tandem set-up.⁸²

With most pressure-sensitive tapes and labels, release coatings are applied to the backside of the tape or the mounting paper for labels. The labels may be pre-printed. The function of the release coating is to allow smooth and easy unrolling of the tape or removal of the label from the mounting paper. In some cases, primers are applied to the backing material before the adhesive is applied. The primer improves the bond between the backing material and the adhesive. Coloring agents may be coated onto the backing or in some cases may saturate the backing for decorative purposes. For some applications, the backing may be saturated with various materials to modify the properties of the backing. For example, a paper backing may be saturated with synthetic rubber to increase its tensile strength and flexibility.

2.3.2 Flexible Vinyl

This segment of the POWC industry includes facilities manufacturing a range of products from flexible vinyl. Polyvinyl chloride (PVC) is the primary substrate used to manufacture flexible vinyl products. Products manufactured by the flexible vinyl products industry segment include wall coverings, automotive upholstery, furniture upholstery, tablecloths, luggage, and shower curtains.⁸³ Most products are manufactured from PVC film supported by fabric, paper, or foam. The PVC is used as a substrate and as a dispersion

coating layer in the manufacture of wall coverings. Unsupported vinyl products include shower curtain liners, pool liners, and some window shades.⁸⁴

According to an estimate by the Gravure Association of America, nearly 50 percent of the 1981 value of supported vinyl products was attributable to wall coverings. According to the Adhesives and Sealant Council, more than 75 percent of residential wall coverings are pre-pasted strippable products. Another 20 percent are fabric-backed vinyl, and the remaining 5 percent are specialty items (metallics, grass cloth, rice paper, or other unusual substrates).⁸⁵ Production of vinyl products has been declining since the 1980s, especially for automotive upholstery and trim. A further decline in automotive vinyls production is likely.⁸⁶

In the responses to the EPA POWC survey, among 47 flexible vinyl segment facilities, 38 percent indicated that they perform substrate formation at their facility.

2.3.2.1 Baseline Emissions. In the POWC data gathering effort, information was collected from 47 facilities in the flexible vinyl industry segment, of which 20 were determined to be major sources of HAP's. The total number of facilities and HAP emissions in the flexible vinyl industry segment were estimated to be 112 facilities and 13,878 tpy HAP emissions, representing 26 percent of the facilities and 28 percent of the total HAP emissions estimated for the POWC source category.⁸⁷

The total number of major sources and HAP emissions in the flexible vinyl industry segment were estimated to be 49 facilities and 13,257 tpy HAP emissions, representing 11 percent of the total facilities and 27 percent of the total HAP emissions estimated for the POWC source category.⁸⁸

2.3.2.2 Types of Coatings and Applicators Used. The flexible vinyl industry segment primarily uses a number of functional types of coatings: base coats, primers, topcoats, photo-reactive, laminating (for support), adhesion, and substrate forming. The flexible vinyl industry segment uses a range of coating formulations: solventborne, waterborne, hot melt, and UV-cured.

Solventborne, waterborne, and high-solids coatings are used for laminating flexible vinyl products where adhesives are required. However, in some cases, an adhesive is not used for bonding the vinyl to fabric; instead, the vinyl sheet is bonded to the fabric by either compression between two rollers or by casting directly onto the fabric.

The use of waterborne and high-solids primers and topcoats is still limited in the flexible vinyl industry. For example, waterborne topcoats cannot be used for automotive parts such as dashboards and vinyl roofs that are exposed to the sun as they do not provide the same resistance to ultraviolet light as solventborne topcoats.^{89,90} Most of the coatings and inks used to coat a PVC web are solvent solutions of vinyl chloride/vinyl acetate copolymers and PVC resins. A typical ink or coating used in the manufacture of flexible vinyl products is 85 percent solvent and 15 percent solids.⁹¹

The types of coating applicators used by survey recipients in the flexible vinyl industry segment are shown in Table 2-5.⁹² Table 2-5 shows that for the flexible vinyl industry segment, 40 percent of the coating stations used gravure coating, 20 percent used flexographic coating, 11 percent use knife or air knife, 9 percent used a roll or reverse roll coater, and 7 percent used rotary screen coating. The remaining 13 percent

Table 2-5. Types of Coating Applicators Used by Survey Respondents in the Flexible Vinyl Film Industry Segment

Application Method	Percentage of Application Stations
Gravure	40
Flexography	20
Knife/Air Knife	11
Roll/Reverse Roll	9
Rotary screen	7
Dip	3
Die	3
Mayer Rod	3
Other ^a	4
Total	100

^a Including flow coater, spray, squeeze, calender, and electrostatic.

are distributed among ten different coating application types.

2.3.2.3 Flexible Vinyl Coating Process. The process used to produce flexible vinyl products consists of web formation, finishing (which may include both printing and coating), and embossing.

The vinyl web formation process consists of vinyl coating preparation, vinyl coating formation or application to the web, and, in some cases, expansion of the web. Vinyl substrates are formed by calendaring, extruding, casting, and knife/roll coating.⁹³ All except knife/roll coating use plasticizers, which improve the flexibility of the coating/material.

Extruding, calendaring, and knife/roll coating techniques were discussed above in Section 2.2.2. In the casting process, a vinyl web is cast or coated onto a paper carrier web using roll coating or knife coating. This paper is ultimately removed and reused. The vinyl web surface next to the paper becomes the finished product

surface. The paper carrier may impart a mirror-like finish or a textured surface to the vinyl web.

Most resins used in vinyl web formation are composed primarily of polymers of high molecular weight. These polymers are generally not volatile, and, therefore, VOC and HAP emissions are negligible.⁹⁴ Traces of solvent may be emitted from the ovens; some of these vapors are captured by the ovens and controlled.

The emissions from vinyl web formation are mostly high molecular weight organic compounds which condense into aerosols. These compounds are primarily vaporized plasticizers from the heated materials as it is blended, mixed, conveyed, calendared, and cooled. Some of these plasticizers may be HAP. The compound DEEP, which is a HAP, is often used as a plasticizer. For the reasons discussed above, emissions from vinyl web formation processes, which are primarily aerosol, were not considered in the flexible vinyl NSPS.⁹⁵ In the POWC survey responses, HAP emissions were zero or low in substrate formation in the flexible vinyl industry.⁹⁶

The primer used in the flexible vinyl industry provides an extra-smooth surface for the printing step which often follows. After primer application, the web may be printed, and then a final topcoat is applied. The topcoat provides protection against wear.

Flexible vinyl products are sometimes embossed to improve their appearance or wearability. Most flexible vinyl substrates are embossed as part of the finishing operation that may include laminating or printing. The exception is calendared products, which are embossed as they exit the calendar. The embossing line consists of a support roller and an embossing cylinder. The image pattern is formed in the surface of the cylinder by mechanical or chemical means. The web is heated and continuously drawn between the

embossing and supporting rollers. As it passes through the cooled roller, the image or pattern is set in the hot web surface.⁹⁷

Volatile emissions from the process of embossing are likely to be relatively low. The emissions from the embossing process depend primarily on the type of material and coatings on the web being heated. In embossing of a newly-calendared flexible vinyl substrate, the emissions are high molecular weight organic compounds which condense as they exit the stack gases. These emissions are primarily plasticizers from the heated web. Based on information collected by the EPA from 100 plants in 1980, aerosol emissions from the embossing operation of an average plant were estimated to be 8 tpy; VOC emissions from embossing were estimated to be 10 tpy, or 1.3 percent of the total plant VOC emissions.⁹⁸

A PVC web may be coated, printed, or both. Both coating and printing are typically done with gravure coaters. In the production of vinyl products, printing, coating, embossing, and other finishing processes are almost always performed on a single line (often referred to as "imaging equipment"). Some products are printed by flexography or screen printing and then coated by gravure.⁹⁹ In the manufacture of flexible vinyl products, there is little distinction between the printing and coating operations.

2.3.3 Photographic Film

The photographic film industry segment manufactures film for diverse products such as still cameras and moving pictures, microfiche film, x-ray film, intensifying screens, and decorative window coverings.¹⁰⁰ Both cellulose acetate film and polyester film are used for photographic film, although cellulose acetate is used more than polyester. Facilities manufacturing photographic film may also coat paper for use as photographic paper or as backing material for photographic film.¹⁰¹ These facilities may also coat some

pressure-sensitive tape, which is used at the end of a film roll to hold the roll in place.

In the responses to the EPA POWC survey, among the 15 facilities that responded in the photographic film industry segment, 20 percent reported that they perform film substrate formation on site.

2.3.3.1 Baseline Emissions. In the POWC data gathering effort, information was collected from 15 facilities in the photographic film industry segment, of which 11 were determined to be major sources of HAP's.¹⁰²

The total number of facilities and HAP emissions in the photographic film industry segment were estimated to be 36 facilities and 5,306 tpy HAP emissions, representing 8 percent of the total facilities and 11 percent of the total HAP emissions estimated for the POWC source category.¹⁰³ The total number of major sources in the photographic film industry segment were estimated to be 27 facilities and 5,254 tpy HAP emissions, representing 6 percent of the total facilities and approximately 11 percent of the total HAP emissions estimated for the POWC source category.

The primary HAP's emitted by the (photographic) film manufacturing industry segment are methyl ethyl ketone, methylene chloride, and methanol. Methylene chloride is primarily emitted from the formation and coating of cellulose acetate film and polyester film.¹⁰⁴

2.3.3.2 Types of Coatings and Applicators Used. The photographic film industry segment primarily uses a number of functional types of coatings: base coats, primers, topcoats, photo-reactive, laminating (for support), adhesion, and substrate forming. The photographic film industry segment uses a range of coating formulations: solventborne, waterborne, hot melt, and UV-cured.

The base coatings, or sublayers, of photographic film are typically solventborne coatings. These coatings act as an antistatic and provide lubricity. The coatings are formulated with a number of solvents, but methanol is the most commonly used solvent.¹⁰⁵ Some formaldehyde and dimethyl formamide are also used.¹⁰⁶ The number of layers of photosensitization materials that are applied varies according to the complexity of the film. Twelve or more layers may be applied to the more complex films.¹⁰⁷ Unlike most coating processes, multiple layers may be applied simultaneously at the same coating station to photographic film. At some facilities, multiple waterbased coating layers are applied at the same station. The coatings do not mix because each coating has a different viscosity.¹⁰⁸ All coating of photosensitization materials is done in the absence of light.¹⁰⁹ The coatings used in the photosensitization process are waterborne emulsions. Some of these coatings may contain small concentrations of methanol, but water is the primary solvent.

In coatings used for x-rays and intensifying screens, acetone (not a HAP), methylene chloride, and methanol are the primary solvents.¹¹⁰ As with photographic film production, waterborne coatings are used in the photosensitization coating process.

The types of coating applicators used by survey recipients in the photographic film industry segment are shown in Table 2-6.¹¹¹ Table 2-6 shows that for the photographic film industry segment, 44 percent of the coating stations used a die, 28 percent used roll or reverse roll coating, 12 percent used gravure coating. The remaining 16 percent are distributed among four different coating application types.

2.3.3.3 Photographic Film Coating Process. The coating process for photographic film is similar to that for other segments of the industry. The web is unwound, coated, and then rewound. However,

Table 2-6. Types of Coating Applicators Used by Survey Respondents in the Photographic Film Industry Segment

Application Method	Percentage of Application Stations
Die	44
Roll/reverse roll	28
Gravure	12
Knife/Air knife	11
Mayer Rod	2
Calender	2
Flow	1
Total	100

different types of coatings may be applied on different lines. For example, base coatings are applied on one line, and the web is then rewound and moved to another line where the web is unwound, coated with photosensitization materials, and then rewound. The coating process for x-rays and for intensifying screens, which are often used in place of the traditional x-rays, is similar to that for photographic film. The intensifying screens are first coated with three types of solventborne coatings overcoat for protection; and an anti-curl layer. The substrate is then rewound and transferred to another line for the application of the photosensitization materials.¹¹²

Some film facilities manufacture their film onsite. In the formation of cellulose acetate film, cellulose acetate is dissolved in methylene chloride and cast onto a wheel. As the methylene chloride is driven off, this wheel becomes the unwind reel for the coating line. The formed film is unwound from the wheel, coated, and then rewound; therefore, formation of the substrate can be considered a part of the coating line, as in vinyl film formation.¹¹³ Film

formation itself is not likely to be a significant source of HAP emissions at film manufacturing facilities. In the POWC survey responses, facilities had little or no HAP emissions solely from the formation of the film.¹¹⁴

2.3.4 Decorative and Industrial Laminates

Decorative laminates provide an aesthetically pleasing surface used in products such as kitchen counter tops, and store display shelving. Laminates may also be used in the manufacture of such products as floor coverings and finished particle boards.¹¹⁵

Industrial laminates provide a functional surface with special properties such as fire, electrical, or chemical resistance,¹¹⁶ and are used to manufacture products such as rigid laminates used in furniture manufacturing, interior building construction, printed wiring board (PWB) blanks, industrial tubes, yoke bars, and molded bearings. Flexible laminates are a type of laminate that is bendable, often in cable form, and is used by some electronics manufacturers in automobiles, computers, and radios.

Laminate production facilities may also manufacture adhesives, release coatings, and resins. These facilities may also perform coating operations for production of release paper and printing operations for production of the decorative paper.

Sources of HAP emissions from the manufacture of decorative and industrial laminates include mixing/compounding, coating, drying, curing, pressing, and finishing operations; however, the predominant emission points are from coating, drying, and curing.

2.3.4.1 Baseline Emissions. In the POWC data gathering effort,¹¹⁷ information was collected from 41 facilities in the decorative and industrial laminates industry segment, of which 17 were determined to be major sources of HAP's. The total number of facilities and HAP emissions in the decorative and industrial laminates industry segment

were estimated to be 68 facilities and 8,798 tpy HAP emissions, representing 16 percent of the total facilities and 18 percent of the total HAP emissions estimated for the POWC source category.¹¹⁸ The total number of major sources and HAP emissions in the decorative and industrial laminates industry segment were estimated to be 28 facilities and 8,489 tpy HAP emissions, representing 7 percent of the total facilities and 17 percent of the total HAP emissions estimated for the POWC source category.¹¹⁹

The primary HAP emitted by the decorative and industrial laminates industry segment are methanol, phenol, and toluene. Although release coatings in the past contained chromium, the POWC survey responses indicate this may no longer be true.¹²⁰

2.3.4.2 Types of Coatings and Applicators Used. The decorative and industrial laminates industry segment uses many functional types of coatings: primers, topcoats, lacquers, substrate forming, laminating, fire resisting, chemical resisting, releasing, decorative, and saturating. The coating formulations used are: solventborne, reactive (resins), release coats, and adhesives.¹²¹

Resins used in the laminating process include epoxy, melamine, phenol-formaldehyde, polyester, polyvinyl acetate (PVAC), polyvinyl acrylate (PVA), silicone, styrene-formaldehyde, and urea-formaldehyde.^{122,123,124,125} Laminate producers generally distinguish resins from adhesives by defining a resin as a substance that impregnates or saturates the substrate, while an adhesive is a substance applied to the substrate surface.¹²⁶ The HAP emitted in largest amounts are methanol, phenol, and formaldehyde.

The types of coating applicators used by survey recipients in the decorative and industrial laminates industry segment are shown in Table 2-7.¹²⁷ This table shows that 36 percent of the coating

Table 2-7. Types of Coating Applicators Used by Survey Respondents in the Decorative and Industrial Laminates Industry Segment

Application Method	Percentage of Application Stations
Dip	36
Gravure	34
Roll, Reverse Roll	20
Mayer Rod	5
Knife	5
Total	100

stations are dip, 34 percent are gravure, and 20 percent are roll and/or reverse roll, with the remaining stations being Mayer rod and knife applicators (5 percent of the stations, each).

2.3.4.3 Decorative and Industrial Laminate Coating Process.

In the manufacture of the decorative and industrial laminates, the first operation is known as "compounding," and involves activation of the resins by mixing together precise amounts of the varnish components in a batch tank. This compounding process is referred to as the "A-stage." The amount of each component used is generally controlled by weight; and precise adherence to specified amounts, temperatures, mixing times, and sequence is necessary for a good quality resin. At this point, the varnish is held for a digestion period so the reactivity can stabilize it to a consistent and prescribed level appropriate to the next operation.¹²⁸

After the digestion period, web substrates (e.g., paper or woven fiberglass) are loaded on the coating line (or treater). The web is dipped into a resin tank equipped with metering apparatus, and then to an oven to evaporate the solvent and achieve partial cure of the resin. This process is called the "B-stage." Any decorative or overlay paper used in the product is also treated in the B-stage,

usually by impregnation with resins. Release paper used in the product, if not purchased pre-coated, is dip coated in the B-stage as well.¹²⁹

The next stage, or "C-stage" is a press lamination operation. First, some B-stage products are cut into sheets, and then multiple plies of the sheets are collated according to the ultimate core thickness. With decorative laminates, a decorative overlay (printed or solid pigmented pattern sheet) is also added used. The laminate may also include layers of release paper (paper treated with a release coating) applied during pressing. The release paper allows separation of layers after pressing, so that several sheets of laminate can be produced together. Alternatively, some B-stage products are left uncut to produce continuous laminates. The C-stage operations are done in batch pressings.¹³⁰

The collated laminates are then laid between press plates with copper foil on the surface of the stack. These "books" or packages of laminates undergo high temperature and pressure pressing to cure it to its final form. High-pressure laminates are subject to pressures of between 1,000 and 1,400 pounds per square inch (psi) during manufacture.¹³¹

After the pressed books are removed from the C-stage press, they are transported to a tear down station where the laminate is separated from the press plates. Continuous laminates can be rolled at this point, but only into large-diameter rolls. The C-stage products from PWB manufacture may be left in a roll and sold as pre-preg bonding;¹³² it may undergo additional lamination at other facilities to produce multilayer laminate.¹³³ Other C-stage products may undergo several finishing steps to prepare them for shipment. Preparation for delivery includes labeling and packaging.¹³⁴

Laminates are also produced by application of an adhesive-coated roll of paper or vinyl film to panel substrate. The paper or vinyl film is unwound, coated with a liquid adhesive, and then combined with a substrate at a combining station. The substrate may be panels of particle board, fiberboard, hardboard, etc., fed into the line continuously end to end. Following lamination, the panels are individually stacked.

The flexible laminate manufacturing process is somewhat different than that used by rigid laminate manufacturers. Generally, flexible laminate manufacturers purchase the plastic substrate, which is manufactured elsewhere, and use adhesive to attach copper foil. The adhesive application process is performed on a web, and often the shipped product is still in a web form when it is delivered to the circuit board manufacturer.

2.3.5 Miscellaneous Coating Industries

This industry segment was created primarily to represent the remaining sectors of the POWC, such as the major subsectors of abrasive coating, specialty coaters that coat paper to customer specifications as it is obtained from paper manufacturers, and rotogravure and wide-web flexography coating (primarily in the packaging and product subdivision that produces flexible packaging for food). Other, minor subsectors of the POWC industry produce the following products: corrugated and solid fiber boxes; folding paperboard boxes, including sanitary; die-cut paper and paperboard and cardboard; converted paper and paperboard, not elsewhere classified; manifold business forms and related products; plastic aseptic packaging; and carbon paper and inked ribbons. Because rotogravure and wide-web flexographic coating has been previously researched and studied under the printing and publishing NESHAP, this subsector is not further discussed here.¹³⁵

The 1996 TRI emissions for the Miscellaneous POWC industries are shown in Table 2-8. From the information in Table 2-8, it can be seen that the abrasives products subsector has the greatest number of facilities among this group (at 32 percent), and the converted paper and paperboard products not elsewhere classified (gift wrap, paper wall paper, cigarette paper) subsector has the highest per-facility emissions (86 tpy) and highest portion of the emissions (42 percent).

2.3.5.1 Baseline Emissions. Using TRI data from 1996 for SIC codes 2653, 2657, 2675, 2679, 2761, 3074, 3291, and 3955, the total number of facilities and HAP emissions in the miscellaneous industry segment were estimated to be 117 facilities and 13,174 tpy HAP emissions, representing 27 percent of the total facilities and 27 percent of the total HAP emissions estimated for the POWC source category. The total number of major sources and HAP emissions in the miscellaneous industry segment were estimated to be 52 facilities and 12,714 tpy HAP emissions, representing 12 percent of the total facilities and 26 percent of the total HAP emissions estimated for the POWC source category.¹³⁶

2.3.5.2 Abrasive Products. Many abrasive products such as sandpaper are coated products. Paper, film, cloth, and heavy fiber are all substrates used in the manufacture of abrasive products. In particular, the use of films, especially polyester films, is growing. If cloth is used as an abrasive product substrate, the cloth is pretreated to give it body; abrasive cloths are called finishing cloths.¹³⁷

The coating process for abrasive products includes up to three coatings that are applied to the substrate. For a cloth abrasive, a seal coat is applied to the cloth. An adhesive coating is then applied to bind the abrasive to the substrate. The abrasive is

Table 2-8. 1996 TRI Facilities and Emissions for the Miscellaneous POWC Industry Segment(a)

SIC	INDUSTRY DESCRIPTION (b)	Number of TRI Facilities	Percent of TRI Facilities	TRI Emissions (tpy)	Percent of TRI Emissions	Per Facility Emissions (tpy)
2679	Misc. Converted Paper Products Converted paper and paperboard products, nec (gift wrap, paper wall paper, cigarette paper)	38	27%	3,282	42%	86
2653	Paperboard Containers and Boxes Corrugated and solid fiber boxes	19	13%	1,576	20%	83
3291	Misc. Nonmetallic Mineral Products Abrasive products	46	32%	1,422	18%	31
2761	Printing and Publishing Manifold business forms	16	11%	847	11%	53
2657	Paperboard Containers and Boxes Folding paperboard boxes, including sanitary	17	12%	336	4%	20
3955	Pens, Pencils, Office, & Art Supplies Carbon paper and inked ribbons	6	4%	272	3%	45
2675	Misc. Converted Paper Products Die-cut paper and board	1	1%	81	1%	81
3074	Plastic aseptic packaging	0	0%	0	0%	0
Total		143		7,816		

(a) Data is taken directly from TRI and does not account for facilities reporting under multiple SIC codes.

(b) nec = not elsewhere classified.

applied, and, in some cases, another protective coating is applied over the abrasive. Adhesives are applied with a roll coater, while the abrasive is typically applied electrostatically. For some applications, a pressure-sensitive adhesive backing is applied to the abrasive product. Printing is also used with abrasives manufacturing to place the company name on the back of products that include sandpaper. Grit is applied/printed onto the sandpaper backing with a flexography roller.¹³⁸

Most of the coatings and adhesives used by the abrasive products industry segment are waterborne. Some special purpose products may still require solventborne coatings and adhesives, but even these are being reformulated to waterborne. UV-cured coatings are used in the manufacture of ophthalmic abrasives, that are used to grind ophthalmic lenses. This product is amenable to the UV process because of the thinness of the substrate that allows for complete penetration and curing of the coating by the UV radiation.¹³⁹

A phenol-formaldehyde resin is used to bind the abrasive to the substrate. These resins are a source of formaldehyde emissions because they are formulated with excess formaldehyde. However, the amount of excess formaldehyde has decreased dramatically over the years. The resins used to contain as much as 20 percent excess formaldehyde, but they now have less than 1 percent excess formaldehyde.¹⁴⁰ Phenol and formaldehyde are the primary HAP emitted by the abrasive products industry segment.

Based on 1996 TRI data for SIC 3291, the abrasive coating industry subsector has 46 facilities and emits approximately 1,400 tpy HAP.¹⁴¹ The abrasive coating industry consists of only five corporations (of which two are the primary participants), each having facilities at multiple locations. The industry is represented by the Coating Abrasives Manufacturing Industry (CAMI) trade association.¹⁴²

2.3.5.3 Specialty Paper Coating. The term "specialty coating" evolved as a means to distinguish traditional paper manufacturers, who use mostly waterbased coatings in the paper making process, from those facilities (some closely associated with paper manufacturers) that apply solventbased coatings to paper in order to generate products, often for other paper converters who interface with the customers (i.e., consumers or end users). Specialty coating, then, connotes solvent-based web coating by the latter group of facilities.¹⁴³ Specialty-coated products may include some of the products presented above in the discussion of the pressure-sensitive tape and label, flexible vinyl, and photographic film industry segments. However, what differentiates the subset of specialty-coated products from the broad class of web-coated products is the great extent to which their manufacture depends on customer specifications.

The American Forest & Paper Association (AF&PA) represents the majority of the members of the paper industry and has a constituency of twelve companies classified as specialty coaters. Information in this section is largely based on site visits to some of these specialty coating facilities performed with the cooperation and coordination of the AF&PA.

Specialty coaters coat paper, in grades varying from tissue paper to heavy kraft paper, as well as paper/foil laminates, polyester and other films, aluminum foil, vinyl, canvas and other fabrics, and possibly other substrates. Specialty-coated products and/or end-uses include thermal imaging papers (i.e., fax paper, paper for register receipts), pressure-sensitive labels, microfilm for data storage, graphic arts papers, paper for finished stationery products (i.e., notepads, diaries), gift wrap (for sale to distributors), electronic equipment, photography, and printed circuit

boards. Thus, as previously mentioned, specialty coated products are not necessarily products absent from the other web coating industry segments.

Specialty coating facilities are not necessarily small, with some having over 10 coating lines. Facilities that conduct more printing than coating may have longer setup and breakdown periods than facilities that produce only a few products, because the print plates are more likely to need to be switched out between different product runs than coating lines, which can be dedicated to one type of coating process applying a uniform layer across the web.

The types of coating applicators used by the specialty coaters include gravure, roll, rod, slot die, and knife. The types of coatings include solventbased, waterborne, UV-cured, and 100 percent solids. The HAP's used by specialty coaters include vinyl acetate, methanol, toluene, glycol ethers, and methyl ethyl ketone (MEK).

Safety issues at specialty coating facilities arise with the use of some low-HAP coatings, such as the need to use corona dischargers (which generate ozone) to treat film surfaces before applying waterbased coatings, and the allergic reactions in some individuals as a result of working with 100 percent solids, radiation-cured coatings. Technical issues with regard to replacing solventborne coatings in specialty coating include the inability to replace solventborne formulations for applications such as the metallized coating of paper and the manufacture of microfilm, both of which currently require solventbased coating chemistries.

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3.0 EMISSION CONTROL TECHNIQUES

3.1 INTRODUCTION

Emission control techniques applicable to the paper and other web coatings (POWC) industry can be categorized as either:

(1) prevention of emissions (pollution prevention measures); or
(2) control of captured emissions by a control device. Sections 3.2 and 3.3 describe capture systems and control devices, respectively. Section 3.4 describes pollution prevention measures.

3.2 CAPTURE SYSTEMS

Capture systems are used in this industry to collect solvent-laden air containing HAP and direct it to a control device. Often, facilities combine solvent-laden air captured from several coating operations, each with its own capture method, and duct it to a single control device. In heatset coating processes, solvent is removed from the coated substrate by evaporation in a dryer. The exhaust from the dryer can be easily ducted to a control device without additional capture systems in place. Additional capture systems are often used to collect fugitive emissions from solvents that evaporate from other parts of the coating line, such as the coating application and flash-off areas, and exhaust them to a vent or control device.

The design of the capture system, and the choice of control devices, can greatly contribute to the overall HAP control efficiency, which is a combination of both capture and control efficiencies.

Capture methods in use by the POWC industry are generally either hoods or enclosures. They include canopy hoods, floor sweeps, partial enclosure of coating stations, room enclosures, permanent total enclosure (PTE), and ovens operated at negative pressure.^{1,2} Permanent total enclosures (which may include room enclosures) can achieve 100 percent capture. A HAP capture efficiency of 100 percent is assumed for systems meeting the EPA's criteria for PTEs described in EPA test method 204. The other capture methods are not generally associated with a specific capture efficiency. An efficient vapor collection system will maximize the capture of fugitive emissions while minimizing the capture of dilution air.

In responses to POWC surveys sent to the pressure-sensitive tape and label (PST), flexible vinyl, photographic film, and decorative and industrial laminates industry segments, estimates of HAP capture ranged from zero to 100 percent capture, with the average HAP capture efficiency per process greater than 90 percent for operations with control devices.³

Capture systems can be improved to collect previously fugitive solvent in the air surrounding coating lines by construction of additional hooding and/or coating line enclosures. In theory, capture can be improved to 100 percent for any coating line or coating area by retrofitting walls and increasing capture to meet the requirements of a PTE; in practice, retrofitting some existing facilities may be prohibitively expensive.⁴ The installation of a PTE on an existing line, if not designed properly, could increase evaporative losses from a coating line through increased airflow and force the need for additional control devices.⁵

It may be economically advantageous to pretreat air collected by capture systems with solvent concentrator systems. Concentrator systems are designed to adsorb solvents from dilute air streams. The

sorbent (activated carbon or zeolite) is regenerated with hot air. The regeneration air requirement is only about 10 percent of the air treated. Thus, the dilute solvent-laden air stream is converted to a concentrated regeneration air stream, which is exhausted to another control device. If the exhaust from the concentrator system is ducted to an existing solvent recovery system, then some increase in capacity of the existing solvent recovery systems may be required.

A widely used source of information on designing industrial ventilation systems is the Industrial Ventilation manual published by the American Conference of Governmental Industrial Hygienists (ACGIH).⁶ This manual, revised every few years, provides guidance on designing hoods to ventilate many general operations, including open surface tanks (e.g., dip tanks), painting (e.g., spray booths), and miscellaneous operations such as a Banbury mixers and calender rolls. The ACGIH manual also addresses sizing of ducts, selection of fans, and calculation of exhaust system pressure loss.

To determine volatile organic compound (VOC) capture efficiency (i.e., the ratio of VOCs entering the control device to the total VOCs emitted by the process), the EPA has developed a testing procedure that samples both captured VOC emissions and fugitive emissions in the gas phase. Captured VOC emissions are sampled from the process exhaust leading to the control device, and fugitive emissions samples are taken from the exhaust of an enclosure surrounding the process.

Three types of enclosures are recommended by the EPA to isolate VOC sources for capture efficiency testing: temporary total enclosures; building enclosures; and PTEs. During the last several years, PTEs have become more popular as a viable, cost-effective method of demonstrating VOC capture efficiency.⁷ A case study involving construction of a PTE at a printing facility to contain VOC

emissions from two existing flexography presses and a future additional press was presented at the annual meeting of the Air & Waste Management Association in 1997.⁸

A common misconception concerning the installation of PTEs is the assumption that increased air volumes will need to be handled, and, therefore, the control device will need to be up sized to handle the increased airflow. While this is true for some PTE configurations, a well-designed enclosure can be adequately ventilated using the existing process exhaust air flow.^{9,10,11,12,13} By incorporating airflow reduction techniques, such as cascading the exhaust air from a lower concentration source to a higher concentration source, lowering the ceiling/raising the floor, and the use of closed-loop systems, airflows can be sometimes decreased over those associated with the process before the installation of the PTE.^{14,15,16} One company that has retrofitted PTEs at more than 50 plant sites in ten different industries has found that air flows from the workplace can be reduced by 25 to 50 percent while simultaneously enhancing the air quality in the working environment.¹⁷

The EPA has published seven test methods for capture efficiency: Method 204 and Methods 204A through F.¹⁸ Following construction of a temporary or permanent total enclosure, the enclosure must be tested using EPA Method 204 to verify that it meets EPA design criteria. If the enclosure meets the test criteria, no further capture efficiency tests are required because the VOC capture has been established at 100 percent.

In an EPA technical document entitled, "Guidelines for Determining Capture Efficiency,"¹⁹ details are provided for the EPA-approved test methods for determining capture efficiency performance of VOC emission control systems. The guidance also presents two

alternative methods, the data quality objective and lower confidence limit test methods, which do not require use of a total enclosure.

3.3 CONTROL DEVICES

Add-on control devices can be of two types: combustion (destruction) and recovery. Combustion devices (e.g., oxidizers/incinerators) are more commonly used, because they are capable of high removal efficiencies for almost any type of organic vapor. Recovery devices include condensers and adsorbers.²⁰ Design specifications and limitations of these control devices are provided in an EPA handbook of control technologies for hazardous air pollutants.²¹ Without actual source test data for a specific control system and emission stream, HAP removal efficiency of the control devices can be assumed to be equal to VOC removal efficiency.²²

The most common HAP control devices used in the POWC industry are thermal oxidizers (also called oxidizers) and, to a lesser extent, carbon adsorbers. Based on survey responses, condensers for solvent recovery are also used at some POWC facilities. These control devices are discussed in more detail below.

In the POWC survey responses, 387 control devices or recovery methods were cited; oxidizers (both catalytic and thermal), carbon adsorbers, and condensers accounted for 92 percent of these devices or recovery methods.

Liquid absorbers and biofilters were found in use by some facilities in the POWC surveys. Liquid absorbers take advantage of the solubility of the HAP in a liquid (such as water). In a liquid absorber, the gas effluent contacts a circulating absorbing liquid, in usually a counter-current flow direction, as the liquid passes through a tower packed with variously-shaped material or divided by flat plates. The tower's internal configuration is designed to maximize gas contact with the liquid. Efficiencies of these devices

are generally controlled by the following: concentration of the HAP in the air stream; solubility of the HAP in the liquid; HAP absorption rate; and absorber design and operating conditions (e.g., tower height and/or diameter, number of plates, liquid flow rate).²³ Biofilters are control devices made up of microbiological filter media that use hydrocarbons, such as the HAP, for food and emit carbon dioxide as waste products.

Other control devices in use by this industry, such as wet scrubbers and cyclones, are believed to be primarily used for control of particulate matter and may not affect HAP emissions.

Table 3-1 presents HAP control efficiency ranges for each of these control devices, both reported in EPA literature and reported in POWC survey responses from the POWC industry. Thirty percent of POWC facilities responding to the POWC survey operate one or more coating lines without add-on control devices, which corresponds to 29 percent of the coating lines without add-on control devices.

Table 3-1. Common Control Devices and Associated HAP Control Device Efficiency Ranges (Percent)

Control Device	HAP Control Device Efficiency Reported in EPA Literature	HAP Control Device Efficiency Reported in POWC Survey Responses
Thermal oxidizer	98 - 99+ ^{24,25}	86 - 99.96
Catalytic oxidizer	95 - 99 ²⁶	25 - 99.5
Carbon adsorber	95 - 99 ²⁷	40 - 99.9
Condenser	50 - 90 ²⁸	50 - 99.9

The high control efficiencies from the POWC surveys and literature are not necessarily indicative of the overall performance

of control devices in the POWC industry. The high efficiencies in the surveys are for short term performance tests only and do not necessarily reflect longer term evaluations; such tests are more appropriately used to evaluate whether the control device has been designed and installed properly. Long term performance depends on a number of additional considerations. Depending on the conditions of operation during performance tests, e.g., inlet HAP loading to the control device and ambient temperature, control efficiencies may not represent overall control device performance. When facilities report short term efficiency based on testing, the test is often conducted at maximum operating conditions that result in measurement of the highest control efficiencies.

Also, the batch nature of the coating process (i.e., different products with different coating specifications produced on the same line throughout the day) would make it difficult to achieve the high control levels reported in the surveys all the time. Emission stream characteristics (flow rate, concentration, temperature) are often not constant in batch processes and control devices are often designed only for maximum flow rates and concentrations.²⁹ High control device efficiencies reported for this industry are usually for short term performance tests only and do not necessarily reflect longer term evaluations. Such tests are more appropriately used to evaluate whether the control device has been designed and installed properly; long term performance depends on a number of additional considerations, as discussed above.

Information on the specific test conditions for the control efficiency data collected through the surveys was not available. Real-time emission data from a POWC facility does show that coating process variabilities contribute to the inability of a facility to show consistently high levels of control.³⁰ For the reasons

described above, the likelihood that the POWC survey responses included only initial compliance determination data should be considered, and that the data do not necessarily reflect control levels achievable during all of the various coating operations.

Many factors are known to affect the performance of carbon adsorption³¹ and thermal oxidizer³² control devices. These factors are discussed in more detail below.

3.3.1 Oxidizers

3.3.1.1 Thermal oxidizers. Thermal oxidizers are control devices in which solvent-laden air is preheated and then passed to a combustion chamber. In the combustion chamber, volatile organics in the inlet air stream are ignited and combusted to carbon dioxide and water. Dilute gas streams require auxiliary fuel (generally natural gas) to sustain combustion. Also, because the oxidizer must be in operation at times when HAP emissions are very low (e.g., when coating operations are on standby between jobs), supplemental fuel requirements will vary.

The two main types of thermal oxidizers used in this industry are recuperative and regenerative. The recuperative oxidizer employs a heat exchanger to preheat the inlet air stream. Regenerative oxidizers operate in a cyclic mode, employing ceramics to obtain greater energy recovery.^{33,34} Figure 3-1 is a schematic diagram of a thermal recuperative oxidizer.

Thermal oxidizers can be operated at a wide range of control device efficiencies, with efficiencies ranging from 98 to 99 percent.^{35,36} In the POWC survey responses, 278 out of the 387 control devices (or 72 percent) were thermal oxidizers, with destruction efficiencies ranging from 86 to 99.96 percent.

Design parameters critical to successful combustion are turbulence, temperature, and residence time. The combustion chamber

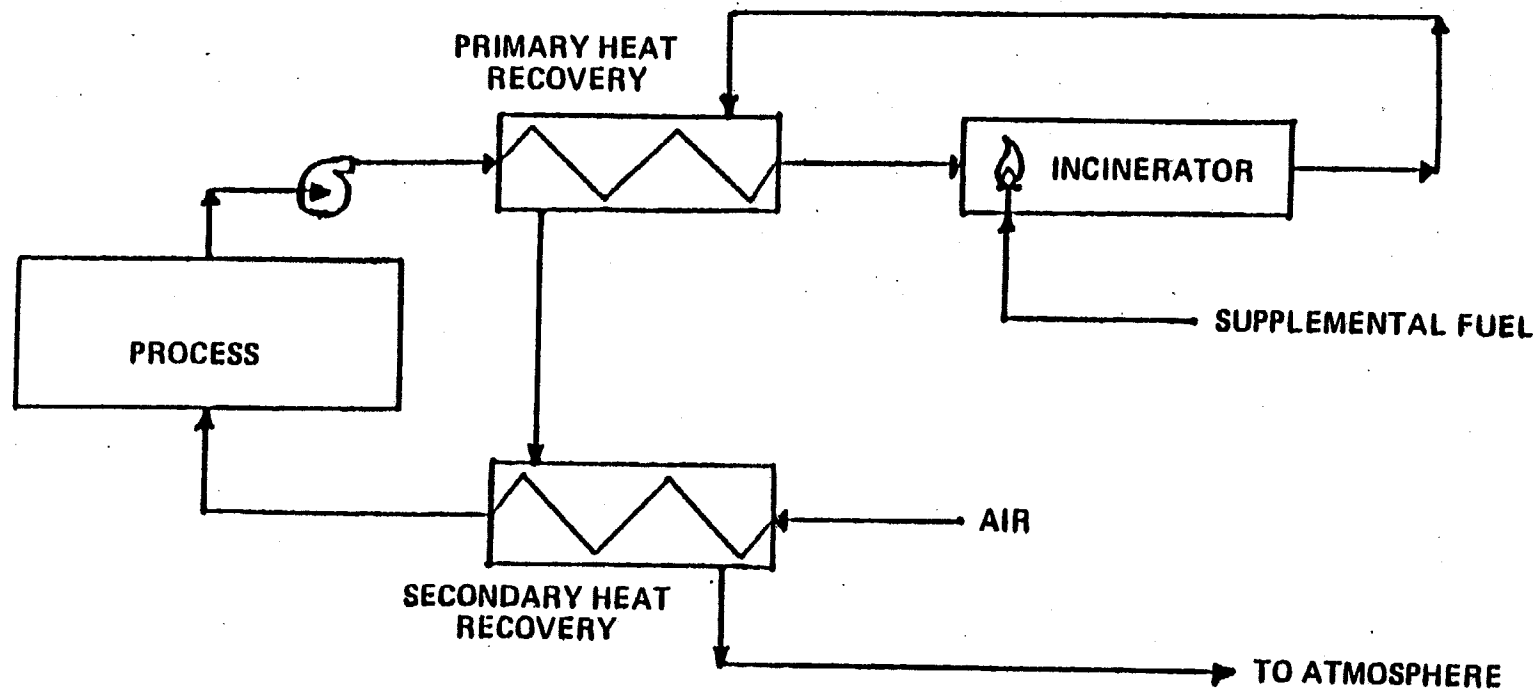


Figure 3-1. Thermal recuperative oxidizer.⁴⁰

must be designed to provide sufficient turbulence to mix the inlet air with any auxiliary fuel. Air temperature and residence time in the combustion chamber must be sufficiently high and long, respectively, to ensure complete combustion.

Test results show that thermal oxidizers can achieve 98 percent destruction efficiency for most VOCs at combustion chamber temperatures ranging from 700 to 1300°C (1300 to 2370°F) and residence times of 0.5 to 1.5 seconds.³⁷ In order to achieve 98 percent destruction of nonhalogenated VOC (and organic HAP), the operating temperature of a thermal oxidizer must be greater than 870°C (1600°F).³⁸ In this temperature range, a residence time of more than 0.75 seconds must be used to ensure 98 percent destruction of nonhalogenated organics.³⁹ The maximum achievable VOC destruction efficiency decreases with decreasing inlet concentration because of the much slower combustion reaction rates at lower inlet VOC concentrations.⁴¹

Oxidizers are equipped with controllers for start-up, to allow the combustion chamber to reach the proper temperature. These controllers can be designed to prevent operation of the emission source (e.g., coating operation) until the oxidizer temperature is adequate to ensure destruction of volatile organics.

To avoid a fire hazard, the inlet air stream to an oxidizer is monitored to ensure that its organic concentration is below the lower explosive limit (LEL). The LEL defines the minimum concentration of a compound that at ambient conditions can produce more energy than is needed to raise its temperature to the ignition point.⁴² The concentration of VOC in the inlet air stream to an oxidizer is typically limited by insurance companies to 25 percent of the LEL for a specific VOC.⁴³

3.3.1.2 Catalytic oxidizers. Catalytic oxidizers, like thermal oxidizers, are control devices in which solvent-laden air is

preheated and then passed to a combustion chamber. In the combustion chamber, volatile organics in the inlet air stream are ignited and combusted to carbon dioxide and water. In the presence of a catalyst, combustion will take place at a lower temperature than that required for thermal oxidizers. Temperatures between 350 and 500°C are common. The catalysts, supported on ceramic or metallic substrates, are metal oxides or precious metals.

Catalytic oxidizers in use by the POWC industry are of the fixed-bed type, using either a monolithic or packed-bed catalyst. The tray type of packed-bed catalytic oxidizer, which uses a pelletized catalyst, is advantageous where large amounts of phosphorus or silicone compounds are present.⁴⁴

Catalytic oxidizers can achieve control device efficiencies of 95 to 99 percent.⁴⁵ In the POWC survey responses, 20 out of the 387 control devices (or 5 percent) were catalytic oxidizers, with destruction efficiencies ranging from 25 to 99.5 percent. Compared with a thermal oxidizer, the lower operating temperature of a catalytic oxidizer can reduce or eliminate the need for supplemental fuel during normal operation. Also, the nitrogen oxides formed is reduced at the lower operating temperature of a catalytic oxidizer.

Chlorinated solvents and some silicone additives in coating formulations will poison or deactivate certain catalysts. However, catalysts now exist that are tolerant of chlorine, sulfur, and other compounds.⁴⁶ The use of chlorinated solvents, however, has decreased dramatically in recent times so that they are now seldom used.⁴⁷

The exhaust from adhesive drying ovens can potentially contain nonvolatile organic matter such as particles of adhesive resins, additives, release compounds, etc. An oxidizer designed to combust volatile organics may not have sufficient residence time to destroy the particles. The emission rate of these particles is usually very low. However, particulate matter can reduce combustion efficiency by

blinding the pores of the catalyst, inhibiting contact between the catalyst active sites and the pollutant gases due to a particulate buildup on the catalyst bed. Also, pressure drop is increased when a particulate buildup occurs, increasing energy requirements of the blower.⁴⁸

3.3.2 Adsorption

Adsorbers in use by this industry use activated carbon as the adsorptive material in a regenerable fixed bed. In a typical carbon adsorber, solvent-laden air is passed through a fixed bed of granular activated carbon. Volatile organics in the entering air stream are adsorbed onto active sites on the surface area of the carbon, until at some point the capacity of the carbon is exhausted, allowing organics to pass through unadsorbed (called breakthrough). Adsorber beds are typically operated in parallel so that when the adsorption capacity of one bed is exhausted, it can be removed from service and a second adsorber bed can be put into service. The spent carbon in the first adsorber bed is then regenerated. A changeover from one adsorber bed to another is automatically initiated either at a preset interval or when an outlet concentration of VOC exceeds the breakthrough setpoint according to a gas monitor on the adsorber outlet. Figure 3-2 is a schematic diagram of a two-bed carbon adsorber.

Carbon adsorption systems can achieve control device efficiencies between 95 and 99 percent for some organic HAP.⁴⁹ In the POWC survey responses, 39 out of the 387 control devices (or 10 percent) were carbon adsorbers, with control device efficiencies ranging from 40 to 99.9+ percent.

In contrast to combustion, carbon adsorption does not destroy the HAP it removes from the air stream. Carbon adsorbers in this industry are thermally regenerated, usually by passing steam through

the carbon beds.⁵⁰ The HAP is thereby removed from the carbon (desorbed) and transferred to the steam. The HAP-containing steam is then condensed, and the solvent separates from the water. The solvent can then be decanted for sale or reuse. Regeneration can also be achieved with hot air. Hot-air regeneration can be quite attractive when dealing with water soluble solvents.⁵¹ Carbon adsorption is most easily adaptable to coating lines that use a single solvent; if solvent mixtures are collected by adsorbers, they usually are distilled for reuse.⁵²

There are two options for disposing of recovered solvent that cannot be reused. The first is to sell the material back to the solvent supplier or an independent firm that specializes in reclaiming contaminated solvents. The other option is to use the recovered solvent as a fuel in coating ovens or in boilers. However, many coating ovens and boilers are gas-fired and would require burner modifications to burn solvent. Carbon adsorption is generally economically attractive only if the recovered solvent can be reused directly.⁵³

Carbon adsorbers are most suitable for solvent systems that are immiscible with water, such as toluene and xylene, but are not recommended for ketones such as methyl ethyl ketone and methyl isobutyl ketone.

The presence of solid particles or polymerizable substances in the inlet air stream to a carbon adsorber may require pretreatment of the inlet air. Cooling and dehumidification may also be required as pretreatment in some cases.⁵⁵

The concentration of VOC in the inlet air stream to a carbon adsorber is typically limited by insurance companies to 25 percent of the LEL. If proper controls and monitors are used, LEL levels of up to 50 percent may be allowed.⁵⁶

3.3.3 Condensation

Condensation is a control technique in which one or more volatile components of a solvent-laden air stream are separated from the remaining vapor through saturation followed by a gas-to-liquid phase conversion (i.e., condensation). The recovered organic components can be reused or sold. The more volatile a compound, the lower the temperature required for condensation, so refrigeration is often employed to obtain the low temperatures required for acceptable removal efficiencies.⁵⁷ Removal efficiencies obtained by condensers usually range from 50 to 90 percent.⁵⁸ In the POWC survey responses, 15 out of the 387 control devices (or 4 percent) were condensers, with removal efficiencies ranging from 50 to 99.9 percent.

The most common types of condensers used are surface and contact condensers. In surface condensers, the coolant does not contact the gas stream. Most surface condensers in refrigerated systems are of the shell-and-tube type, where coolant is circulated through tubes and the volatile organics condense on the outside of the tubes. Surface condensers allow for direct recovery of volatile organics from the gas stream.⁵⁹ Figure 3-3 is a schematic diagram of a shell-and-tube surface condenser. Contact condensers, unlike surface condensers, cool through direct contact of the coolant with the gas stream. The contact condenser coolant is a liquid, at ambient or chilled temperature, sprayed into the gas stream. In a contact condenser, the condensed volatile organics are contaminated with coolant, so they cannot usually be reused directly or recovered without further processing.⁶¹

Based on the survey responses, condensers with solvent recovery units are used more commonly by manufacturers of pressure-sensitive tapes and labels than by other industry sectors. Most if not all condensers used in the pressure-sensitive tapes and labels industry sector are surface condensers.⁶²

Figure 3-3. Shell-and-tube surface condenser.⁶⁰

To achieve extremely low outlet organic concentrations, condensation alone is usually inadequate.⁶³ In the POWC survey responses, one facility used a condenser in combination with carbon adsorbers to achieve >99 percent control of HAP. Condensers can usually be used alone successfully if emission streams contain high inlet concentrations of volatile organics. Condenser removal efficiencies greater than 85 percent usually require volatile organics concentrations of 10,000 ppmv or greater.⁶⁴ In the POWC survey responses, there were three facilities that used condensers alone to achieve greater than 90 percent control efficiency; all three of these facilities were in the pressure-sensitive tape industry segment. Condensers are also used with coating lines that use inert ovens. An inert oven is a coating drying method that uses an inert gas (e.g., nitrogen) to replace oxygen in the air space in the oven. Inert ovens are used with coatings that otherwise would be difficult to apply without forming air bubbles under the coating surfaces.⁶⁵ There is no oven vent to the atmosphere in an inert oven. Instead, a small diameter pipe conducts superconcentrated exhaust at flow rates of only 100-200 ft³/min to condensation coils. Solvent concentrations may be 100,000 to 200,000 ppm in an inert oven's exhaust, which is above the upper explosive limit (UEL) for most/all solvents. After the solvent condenses out of the gas in the coils, the cleaned gas is returned to the oven; this cycle is a closed loop in terms of the oven gas.⁶⁶

For proper operation, there must be an oxygen-free dead-zone of air space after the inert oven, where the air flow is balanced between the air pulled in vs. the air pushed out. This situation complicates the use of total enclosures around a coating line with an inert oven. Also, air flow within the oven would need to be increased to achieve total enclosure. Unfortunately, air flow as little as 200 ft/min can disturb the web in an inert oven and cause a

web, especially one made of paper, to break. Because of issues such as solvent concentrations above the UEL and static electricity in film coating, safety is another concern with totally enclosing the air space around inert ovens.⁶⁷

3.4 PREVENTIVE MEASURES

3.4.1 Product Substitution/Reformulation

Many facilities in the POWC industry have adopted air pollution control strategies that have included substitution of lower-solvent coatings for higher-solvent coatings, or a conversion from solventborne coatings to waterborne coatings. For some products, substitute coatings have not been developed to meet performance requirements, therefore, substitution or reformulation of coatings is not presently an option. Also, it may be the case that a single coating line could be used with a low-solvent coating for one product, but may need to use a higher-solvent coating for another product because an alternative coating is not available for this end use.

In the POWC surveys, the use of low-HAP coatings, such as waterborne, ultraviolet cured, hot-melt, and reactive resins were reported in use by many facilities. In the flexible vinyl and film industry segment, 74 percent (40 out of 58) of the facilities cited the use of low-HAP coatings. In the pressure-sensitive tape industry segment, low HAP coatings were used in 54 percent (49 out of 91) of the facilities. In the decorative and industrial laminates sector, 12 percent (5 out of 41) of the facilities cited the use of low-HAP coatings.

One problem with lower-solvent coatings is that, although there are nonzero HAP emissions from these coatings, the concentration of HAP in the coating oven/area exhaust is too low to be efficiently controlled in a normally-sized add-on control device. Also, since the exhaust contains a relatively high water content along with a low

HAP concentration, there is too little heat value for combustion of the exhaust. Consequently, HAP standards developed for the industry will provide alternatives to a percentage emission reduction; otherwise, a facility might be prevented from switching from a solventborne coating to a waterborne coating when the substitution is possible.

3.4.2 Work Practice Procedures

Work practice procedures are physical actions intended directly to affect emission reductions. Because work practice procedures are specifically tailored to an industry, they may vary from a few manual operations to a complex program.

For situations where an emission standard for control of a HAP is not feasible, then design standards, equipment standards, operational standards, and/or work practice standards can be promulgated instead of an emission standard. As described in section 112(h) of the CAA, situations where an emission standard is not feasible are when a HAP cannot be directed through a capture device (or when use of the capture device would be inconsistent with Federal, State, or local law) or when the application of measurement methodology to a class of sources is not practicable due to technological and economic limitations.

For the POWC industry, work practice procedures may be appropriate for some activities, such as the following: solvents in maintenance operations; solvent handling and transfer; spraying operations and booths; drying and squeegee operations; and open vessels. Examples of such work practice standards are provided in Table 3-2.

Table 3-2. Examples of Work Practice Standards

Activity	Example Work Practice Standard
Solvents use in cleaning	<p>--Used cleaning solvents must be put into an enclosed container.</p> <p>--During atomized cleaning of a spray gun, the cleaning solvent must be directed into a waste container fitted with a capture device.</p>
Solvent handling and transfer	<p>--Handling and transfer of solvents must be conducted in such a manner to reduce spills. Spills must be wiped up immediately and the wipe rags stored in covered containers.</p>
Open vessels	<p>--Waste solvent will be stored in closed containers that may have an opening for pressure relief but do not allow for liquid to drain.</p>

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4.0 MODEL PLANTS, CONTROL OPTIONS, AND ENHANCED MONITORING

4.1 INTRODUCTION

This chapter describes model plants, control options, and enhanced monitoring options for the paper and other web coating (POWC) industry. Model plants were developed to evaluate the effects of the control options on major sources in the POWC source category. Control options were selected based on the application of currently available control devices and levels of capture consistent with the levels of overall achievable control. Enhanced monitoring options are specified to ensure the consistent performance of control devices.

4.2 MODEL PLANTS

Model plants have been specified to represent the range of capacity and overall control efficiency (OCE) at major sources in the POWC industry, as determined primarily by responses to EPA surveys of four POWC industry segments: pressure sensitive tapes and labels; flexible vinyl; photographic film; and decorative and industrial laminates industries. According to one estimate, based on a comparison of POWC survey efforts and Toxic Release Inventory (TRI) data, these four industry segments represent approximately 80 percent of the major sources and HAP emissions of the TRI facilities in the nonprinting portion of the POWC industry.¹

In the POWC survey responses, it was found that HAP OCE was a function of control device operation and capture efficiency. The overall level of control was distributed in the surveyed facilities

from zero to more than 95 percent, with approximately 20 percent of the facilities reporting zero control, 50 percent reporting between zero and 90 percent, and the remaining 30 percent reporting more than 90 percent control.

It was also found in the POWC survey responses that HAP usage varied widely among facilities. Six facilities reported zero HAP usage. On the average in the surveyed facilities, more than 80 percent of the HAP emitted was from the coating lines and associated processes. The other sources of HAP emissions include mixing, cleaning, and storage. These sources are mostly uncontrolled, with the unenclosed processes not as amenable to capture and control as enclosed processes. Little data were available on the control of these sources. Consequently, HAP usage for sources of HAP other than coating lines was not addressed in the model plants.

Model plants were developed from the 89 identifiable major sources in the POWC survey responses. While these model plants represent the sources that will be regulated, they are not necessarily representative of all plants in the entire industry, since major sources are only the highest emitters of HAP emissions by the industry.

The two parameters used to develop the model plants were the coating line HAP OCE and the coating line HAP emissions after control. These parameters were chosen because they were the plant parameters that best differentiated the plants into groups, and because they are the most important parameters in cost and impact analyses.

Five separate coating line OCE groups corresponding to 0, 50, 80, 90, and 95 percent OCE are represented by the POWC model plants. Within each OCE group, the controlled coating line HAP emissions were examined and subcategories were created where the HAP emissions

within each OCE group covered too wide a range to be represented by a simple average. For model plants with OCE's of 0, 50, and 80 percent OCE (Model Plant groups 1, 2, and 3), two subcategories were created for this purpose. In each case, the "a" group had controlled HAP emissions less than 200 tons per year (tpy) and the "b" group had HAP emissions greater than 200 tpy. It was also the case that the "a" groups had fewer coating lines than the "b" groups, with the "a" groups having five or fewer coating lines. For Model Plant group 1, a third "c" category was created to represent the facilities that are likely using compliant coatings; facilities in this group had coating HAP emissions less than or equal to 0.2 pounds (lb) HAP emitted per lb of coating solids applied. Specifications for the POWC model plants are given in Table 4-1.

4.3 CONTROL OPTIONS

Table 4-2 presents the three control options for the POWC industry that include ranges in capture system and add-on control performance, and the use of low-HAP coatings. For add-on controls, any combination of capture and control device efficiency that produces an OCE of 95 percent is equivalent to the control option. For low-HAP coatings, the control option is a level of 0.2 pounds (lb) of HAP emitted per lb of coating solids applied.

The add-on control systems of demonstrated control effectiveness in the POWC industry are composed of a HAP capture system achieved by permanent total enclosures (PTEs) and a HAP destruction or recovery system achieved by thermal or catalytic oxidizers, or carbon adsorbers, condensers, and other solvent recovery systems. These devices are discussed in Chapter 3.

Table 4-1. Specifications for Model Plants Representing the POWC Industry^a

Model Plant No.	Coating Line Overall HAP Control Efficiency, percent	Controlled Coating Line HAP Emissions, tpy	Coating Use, tpy	Average Number of Coating Lines	Average Number of Coating Stations	Uncontrolled Coating Line HAP Emissions, tpy	HAP Capture Efficiency, percent	HAP Destruction Efficiency, percent	Percent of Database Major Sources
1a	0	99	2,108	2	5	99	0	0	20
1b	0	1,765	7,521	12	9	1,765	0	0	3
1c ^b	0	48	6,597	3	17	48	0	0	10
2a	50	138	8,607	5	11	276	55	90	25
2b	50	1,261	369,929	31	154	2,522	53	95	1
3a	80	183	7,518	3	8	915	89	90	11
3b	80	1,378	14,516	8	15	6,890	84	95	1
4	90	99	3,431	4	12	990	95	95	24
5	95	40	5,498	5	19	800	97	98	5

^a tpy = tons per year.

^b Although a control efficiency of zero is stated, this model plant is assumed to be using compliant coatings with #0.20 pound HAP per pound coating solids.

Table 4-2. Control Options for the POWC Industry

Control Option	Overall Facility Coating Line Average			
	HAP Capture Efficiency, percent	HAP Collection/ Destruction Efficiency, percent	Type of Control	Overall HAP Control Efficiency, percent
1	95-100	95-100	thermal oxidizer, carbon adsorber/ solvent recovery	95
2	95-99	95-100	inert oven/ condensation	95
3	NA	NA	low-HAP coatings (#0.2 lb HAP per lb coating solids)	NA

Note: NA = Not applicable.

Improved capture involves containment of previously uncollected HAP emissions. Capture technologies include canopy hoods, floor sweeps, partial enclosure of coating stations, room enclosures, and PTEs (which may include room enclosures). Control options involving air handling can be specified as varying degrees of air collection, up to and including construction of (or conversion of existing coating operation rooms to PTEs), with many gradations existing between current capture systems and PTEs. The specifications of ventilation, hooding, and ducting for incremental improvements to existing systems are site-specific.

Substitution of coatings with lower HAP content may be an important pollution prevention control technique at some facilities. A reduction in HAP emissions through substitution of nonHAP solvents for some HAP solvents in the coatings can achieve the same reduction in HAP emissions as that of the add-on control techniques.

Facilities that operate efficient HAP add-on control systems,

however, may have little incentive to reduce the HAP content of their coatings.

Reducing the HAP content of coatings also may not be appropriate for all facilities or product types. From the available information, it appears that the cost and effects on output quality resulting from substitution of nonHAP solvents for HAP solvents are product-specific, with notable success in some areas and notable lack of success in others.² Existing control devices (which are usually designed and operated for volatile organic compounds (VOC) control) may not be compatible with low-HAP formulations, because of the potential for low HAP/VOC inlet concentrations.

While substitution of nonHAP solvents for HAP should be encouraged as a pollution prevention option, it may affect VOC emissions if VOC solvents are substituted for HAP solvents. Some plants have adopted waterborne or radiation-cured coating technologies to reduce VOC emissions. Some of these formulations are totally HAP-free, although many low-VOC waterborne coating systems do contain small percentages of HAP (typically glycols, glycol ethers, or alcohols), with or without a small amount of nonHAP VOC as well. Usually, low-VOC, low-HAP coating formulations are used with no control devices.

Control strategies for the POWC industry are influenced by the composition of coatings and other materials applied on the coating line and by regulatory requirements. Often, regulations presently in effect limit emissions of VOC. Existing control devices are, for the most part, currently specified and operated to meet VOC emission requirements. However, most of the organic HAP are VOC and, therefore, the control efficiency for HAP is expected to be the same as for VOC.³

New control devices can be selected based on the coating system in use or, if more than one type of device is potentially suitable,

based on cost or requirements of other regulations, if also applicable. Usually, if capture efficiency is maximized at 100 percent with PTEs, greater flexibility of control device operation can be realized to meet the needs of daily operations.

As noted in Chapter 3, all control devices currently in use in the POWC industry can achieve efficiencies of at least 95 percent. Although higher efficiencies are achievable, consistent high inlet concentrations of HAP are needed; therefore, reaching high efficiencies at lower inlet HAP concentrations may be difficult and not possible all of the time because of the batch nature of the POWC processes (i.e., different products with different coating specifications produced on the same line throughout the day). Emission stream characteristics (flow rate, concentration, temperature) are often not constant in batch processes and control devices are often designed only for maximum flow rates and concentrations.⁴ High control device efficiencies reported for this industry are usually for short term performance tests only and do not necessarily reflect longer term evaluations. Such tests are more appropriately used to evaluate whether the control device has been designed and installed properly. Long term performance depends on a number of additional considerations, as discussed above.

The one exception to achieving 100 percent capture is where the particular product or substrate requires the use of a nitrogen-blanketed inert drying oven. These devices allow for coating operations within a low air flow/high solvent vapor zone without risk of an explosion with high nitrogen and low oxygen levels within the oven. For proper operation and safety, there must be an oxygen-free dead-zone air space after the inert oven.⁵ This precludes the use of a PTE, where air is continuously exhausted throughout the coating area.

4.4 ENHANCED MONITORING

Facilities in the POWC industry that operate thermal incinerators or catalytic incinerators usually continuously monitor control device operating parameters, since variations in combustion temperature affect, and are directly related to, performance of the control devices. In this situation, the operators of thermal and catalytic incinerators install, calibrate, operate, and maintain the temperature monitoring devices following manufacturers' specifications. The temperature of the control device is maintained at a level equal to or higher than the temperature at which compliance was demonstrated. Continuous emission monitoring systems (CEMS) may not be reliable for the coating industry, where the HAP in the emission streams may comprise only a small percentage of the VOC present. Also, the output of CEMS may not accurately reflect the HAP concentration of the emission stream due to differences in responses among the HAP, nonHAP VOC, and products of incomplete combustion, and the presence of reactive and/or condensable emissions. How to integrate CEMS software with existing facility software and provide reports are other challenges in the use of CEMS for any facility in the coating industry, where starts, stops, and process variations occur regularly in job shops that coat many and different product types. Accommodations in reporting requirements are also needed for the inevitable problems at coating facilities, such as: automatic shutdowns; back pressure and valve venting; and outages due to regular on-line maintenance, such as carbon replacement.⁶

Facilities in the POWC coating industry that operate solvent recovery systems monitor control system performance using liquid-liquid mass balances. These mass balances provide recovery data averaged over the reporting period. Because the HAP emissions are recovered rather than destroyed, a mass balance at any point in time within the reporting period will reflect any intermittent system

failures or fluctuations in control device efficiency. Since the efficiency of the solvent recovery system during the reporting period is not based on the average of discrete measurements of efficiency, any individually measured control efficiency during the reporting period may not agree with the overall efficiency calculated at the end of the reporting period.

Facilities in the POWC industry that control HAP emissions with low-HAP coating formulations need to maintain documentation confirming the HAP content of the materials applied. If specifications provided by coating suppliers are inadequate to establish the HAP content, additional compositional analyses need to be conducted by the facility.

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5.0 ENVIRONMENTAL AND ENERGY IMPACTS OF CONTROL OPTIONS

5.1 INTRODUCTION

The impact analyses in this chapter are based on the application of Control Option 1 to the model plants developed to represent the paper and other web coating (POWC) major sources. As discussed in Chapter 4, Control Option 1 corresponds to an overall control efficiency (OCE) of 95 percent. Thermal oxidation was selected as the control device used to estimate the worst-case environmental and energy impacts, since oxidation would generate the greatest secondary emissions. Also discussed in this chapter are qualitative assessments of the impacts of using the other two control options discussed in Chapter 4, which involve the use of inert ovens with solvent recovery (Control Option 2) and the use of coatings with low levels of hazardous air pollutants (HAP) as in Control Option 3. The use of solvent recovery via carbon adsorption instead of thermal oxidizers in Control Option 1 is also discussed.

Table 5-1 shows the nine POWC model plants and the estimated number of facilities nationwide represented by each model plant category.¹ Note that although Model Plant 1c corresponds to an OCE of 0 percent, the model plant group corresponds to facilities using low-HAP coatings with less than or equal to 0.2 pounds (lb)HAP per lb of solids emitted or applied. Accordingly, no energy and emissions impacts for Model Plant 1c are expected. Similarly, since Model Plant 5 has an OCE of 95 percent that is equal to Option 1, no energy

Table 5-1. POWC Model Plants and Their Estimated Correspondence to the National POWC Industry

Model Plant	Coating Line OCE, percent	HAP Capture Efficiency, percent	HAP Destruction Efficiency, percent	Number of Major Sources in POWC Database	Percent of Database Major Sources, percent	Estimated Number of U.S. Facilities
1a	0	0	0	18	20	41
1b	0	0	0	3	3	7
1c ^a	0	0	0	9	10	21
2a	50	55	90	22	25	50
2b	50	53	95	1	1	2
3a	80	89	90	10	11	23
3b	80	84	95	1	1	2
4	90	95	95	21	24	48
5	95	97	98	4	5	9
Total				89	100	203

^a Model Plant 1c consists of facilities using low-HAP coatings that meet the criteria of # 0.2 lb HAP per lb solids (Option 3).

And emissions impacts were estimated for this model plant group as well.

5.2 ENERGY IMPACTS

The energy requirements for implementation of Option 1 for the POWC industry include electricity to collect and process ventilation air and natural gas for thermal oxidizer fuel. The energy impact estimates are based on the installation of new capture systems for all model plants except Model Plants 1c and 5, new thermal oxidizers for Model Plants 1a and 1b, and improved destruction efficiency of existing oxidizers for Model Plants 2a and 3a. Table 5-2 shows the energy impacts for the POWC model plants in terms of incremental

Table 5-2. Energy Impacts of Control Option 1
for the POWC Model Plants

Model Plant	Energy Impacts of Control Option 1	
	Fan Power, 10 ⁶ kW-hr/yr	Natural Gas, 10 ⁶ scf/yr
1a	2.2	43.5
1b	7.5	92.5
1c	0	0
2a	1.1	17.8
2b	16.4	0
3a	1.1	16.7
3b	2.2	0
4	1.1	0
5	0	0

Note: This analysis assumes the use of thermal oxidizers for Control Option 1.

increases in power consumption (fan electricity) in kilowatt-hours per year (kW-hr/yr) and natural gas in standard cubic feet per year (scf/yr).

Average electricity and gas consumption factors were calculated for the model plants from the energy impacts. For Model Plants 2b, 3b, 4, and 5, that have oxidizers with destruction efficiencies of 95 percent or above, the average amount of electricity consumed for improved capture systems is 4.8 kW-hr/yr per lb of incrementally controlled HAP. For Model Plants 1a, 1b, 2a, and 3a, the average amounts of electricity and natural gas consumed for new capture and control systems are 5.6 kW-hr/yr and 100 scf/yr per lb of incrementally controlled HAP, respectively.

Table 5-3 shows the estimated national energy impacts of the application of control option 1 to the POWC industry. This estimate was developed by scaling up the model plant energy impacts to the estimated 203 POWC major sources in the U.S. Scale-up factors were developed from the proportion of major sources in the POWC database represented by each model plant group (see Table 5-1) applied to the estimated total number of POWC major sources in the U.S.

Table 5-3. Total Estimated Energy Impacts of Control Option 1 for the National POWC Industry

Energy Impacts	Total U.S. Impact for Control Option 1
Fan Power, 10 ⁶ kW-hr/yr	313
Natural Gas, 10 ⁹ scf/yr	3.7

Note: This analysis assumes the use of thermal oxidizers for Control Option 1.

The use of Option 1 with carbon adsorption is expected to entail lower incremental energy consumption. According to an EPA study, electricity consumption for a regenerable, fixed bed carbon adsorber was estimated to be between 14 and 30 percent of the electricity demand for a regenerative thermal incinerator, for equivalent process stream compositions and flowrates.² No natural gas use is expected for carbon adsorption, assuming that steam for desorption (carbon regeneration) is available on-site. Moreover, carbon adsorption as part of a solvent recovery system may provide solvent for reuse in the manufacturing process. At minimum, solvent recovery is expected to yield fuel that can be burned on-site, resulting in energy savings.

Option 2 is expected to have incremental electricity consumption similar to Option 1 with carbon adsorption. Also, Option

2 would correspond to lower incremental natural gas consumption, since oxidizers would not be operated. The source reduction benefit of recovered solvent and energy savings of usable fuel are expected with this control option as well.

Conversion to low-HAP coatings (Option 3), usually, would represent a decrease in the total energy requirement associated with HAP control, since the energy associated with stream capture and control would not be needed. However, special cases in which the full energy savings may not be realized include: (1) tandem coating operations, in which water-based coatings and solvent-based coatings are applied on the same coating line to the same products; (2) reformulation involving the substitution of HAP components with volatile organic compounds (VOC) that are not HAP; and, (3) water-based coatings for film coating. The first case may involve higher natural gas consumption by add-on controls on the coating line because of a lower exhaust inlet temperature due to drying high-moisture coatings. Higher electricity consumption may also be associated with greater dryer airflow to dry high-moisture coatings.³ In the second case, the facility may not be able to discontinue the use of add-on controls because of State regulations for VOC control and emissions. In the third case, corona treaters may be needed to be operated to treat surfaces of films so that they accept water-based formulations.

5.3 AIR IMPACTS

The primary air impact of implementing the control options is reduced emissions of HAP to the atmosphere. Based on POWC survey responses,⁴ similar reductions are expected for VOC. Emissions of other pollutants are generated with Option 1 due to the burning of fuel and the production of electricity required for fan power. Secondary emissions were estimated for the following pollutants: nitrogen oxides (NO_x), sulfur dioxide (SO₂), carbon monoxide (CO),

carbon dioxide (CO₂), and particulate matter (PM). Complete combustion of hydrocarbons generates CO₂, water, and PM; incomplete combustion generates, in addition, CO and SO₂. All types of combustion in air generate NO_x, with more generated during incomplete combustion.

Table 5-4 shows the emissions impacts of Option 1 with thermal oxidation, in terms of incremental HAP reduced and secondary pollutant emissions for each of the POWC model plants. Secondary emissions from natural gas combustion in thermal oxidizers were calculated using the following emission factors: 100 lb NO_x per million scf of natural gas, 0.6 lb SO₂ per million scf, 84 lb CO per million scf, 120,000 lb CO₂ per million scf, and 7.6 lb PM per million scf.⁵ Secondary emissions from electric power production were calculated using the following emission factors: 1.9 lb NO_x per thousand kW-hr, 4.25 lb SO₂ per thousand kW-hr, 702 lb CO₂ per thousand kW-hr,⁶ 0.078 lb CO per thousand kW-hr, and 0.081 lb PM per thousand kW-hr.⁷ Electricity production was assumed to be entirely from coal combustion to correspond to a worst-case estimate; electricity production via "cleaner" methods (i.e., hydroelectric or nuclear power) would result in lower pollutant emissions.

Table 5-5 shows the estimated national emissions impacts of the application of Option 1 with thermal oxidation. This estimate was developed by scaling up the model plant energy impacts to the 203 estimated major sources in the U.S. Scale-up factors were developed from the proportion of major sources in the POWC database represented by each model plant group (see Table 5-1) applied to the estimated total number of POWC major sources in the U.S.

Selection of other control options could result in equivalent HAP/VOC reductions. However, other control options would generate different incremental changes in secondary pollutant emissions. The use of Option 1 with carbon adsorption is expected to correspond to

Table 5-4. Air Impacts of Control Option 1
for the POWC Model Plants

Model Plant	Air Impacts of Control Option 1, tons per year					
	HAP/VOC Reduced	NO _x Emitted	SO ₂ Emitted	CO Emitted	CO ₂ Emitted	PM Emitted
1a	94	4.3	4.7	1.9	3,382	0.3
1b	1,677	11.8	16.1	4.2	8,194	0.7
1c	0	0	0	0	0	0
2a	124	2.0	2.4	0.8	1,459	0.1
2b	1,135	15.6	34.8	0.6	5,739	0.7
3a	137	1.8	2.2	0.7	1,370	0.1
3b	1,034	2.1	4.6	0.1	755	0.1
4	50	1.0	2.3	0.04	386	0.04
5	0	0	0	0	0	0

Note: This analysis assumes the use of thermal oxidizers for Control Option 1.

Table 5-5. Total Estimated Air Impacts of Control Option 1
for the National POWC Industry

Air Impact	Total U.S. Impacts of Control Option 1, tons per year
HAP/VOC Reduced	31,673
NO _x Emitted	484
SO ₂ Emitted	666
CO Emitted	168
CO ₂ Emitted	331,986
PM Emitted	27

Note: This analysis assumes the use of thermal oxidizers for Control Option 1.

lower incremental secondary emissions from electricity production, since carbon adsorption has lower electricity consumption as compared with thermal oxidation, as previously discussed. Option 2 is expected to correspond to similar incremental secondary pollutant emissions from electricity production as with carbon adsorption. Secondary emissions from natural gas use are not expected, since oxidizers would not be operated.

Conversion to low-HAP coatings (Option 3) is a pollution prevention measure, with capture and control systems generally not needed. However, in the previously discussed exception where low-HAP coatings and solvent-based coatings are applied on the same coating line to the same products, more secondary emissions due to natural gas combustion may be generated due to a lower exhaust inlet temperature from the drying of high-moisture coatings.⁸ Also, when HAP chemicals are replaced with VOC chemicals in coating formulations, add-on controls may not be discontinued because of State regulations for VOC control and emissions. Little change in the amount of secondary emissions from existing control systems are then expected.

5.4 WATER IMPACTS

Water impacts resulting from the implementation of the control options at POWC plants are expected to be small. No significant amount of liquid waste is generated from the use of thermal oxidizers.⁹ Incremental increases in wastewater may result from the following: (1) plants that use steam for carbon bed desorption in new or improved solvent recovery systems; and, (2) plants that reformulate to water-based coatings. In the latter case, there may be some increase in wastewater generated, since cleaning operations are more likely to involve water.

5.5 SOLID WASTE IMPACTS

Solid waste impacts resulting from the implementation of the control options at POWC plants are not expected to be significant. No solid or hazardous wastes are generated from the use of thermal oxidizers.¹⁰ Cases that could involve incremental increases in solid waste include: (1) plants that use new or improved catalytic oxidizers and, (2) plants that upgrade carbon adsorbers for existing or new solvent recovery systems. In the first case, spent catalysts may require disposal as hazardous waste. However, due to the cost of the catalyst, it is expected that the incinerator would be operated in a way that maximizes the catalyst life (expected to be more than 10 years). In the second case, although most of the spent carbon could be sold for reprocessing, the remainder would become solid waste.

5.6 REFERENCES

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6.0 MODEL PLANT CONTROL OPTION COSTS

6.1 INTRODUCTION

This chapter presents the estimated costs of applying Control Option 1 with the use of thermal oxidizers to the paper and other web coating (POWC) model plants. This control option involves the use of permanent total enclosures (PTEs) and thermal oxidizers to achieve an 95 percent HAP overall control efficiency (OCE). The model plants and the criteria used to choose them were described in Chapter 4. Control options applicable to the POWC industry were also described in Chapter 4. Costs are presented for both existing and new facilities.

Control Option 1 with thermal oxidizers was chosen because this option was expected to be the worst-case for costs and impacts. All other control options, therefore, are expected to have lower costs (and less energy impacts).

Sometimes, catalytic incineration may be more appropriate for the solvents in use at POWC facilities. Catalytic incineration systems would have lower operating costs and may have total annualized costs less than the estimates for thermal oxidation systems. Concentrator systems may be used to reduce the size and, therefore, the capital and operating costs of the catalytic oxidizer.

Similarly, solvent recovery may be more appropriate as a control method. As discussed in Chapter 5, the electricity consumption is expected to be lower for a solvent recovery system than for a thermal oxidizer.¹ In addition, the associated natural

gas use is expected to be no more than that required for the thermal oxidizer, and the recovered solvent would have some additional fuel value. Thus, overall costs for a solvent recovery system are expected to be lower.

Alternatively, some facilities may choose to switch to low HAP coatings. Switching to low HAP coatings could, sometimes, represent a net savings over baseline levels of control. The applicability of this option depends largely on the type of coating and the performance requirements of the product. Where feasible, conversion to low HAP coatings could result in substantial reductions in operating costs, compared with the use of add-on controls. Note that low HAP coatings may still require operation of a control device to meet volatile organic compound (VOC) emissions standards established by other regulations if VOC has been substituted for the HAP eliminated.

New source costs were based on upgrading to the new source MACT level of control (98 percent OCE) a facility with an emission control configuration that would be expected in the absence of any new regulation. This emission control configuration was assumed to be a PTE and a thermal oxidizer operating at 95 percent destruction efficiency. The upgraded facility was based on the same control configuration, but the thermal oxidizer destruction efficiency was increased to 98 percent. Model plant 4 was chosen as the best representation of this facility for costing purposes.

6.2 CAPTURE AND CONTROL APPROACH

The POWC model plants are presented in Table 6-1. The capture and control approaches to implementing Control Option 1 for the model plants are summarized in Table 6-2.

Table 6-1. Specifications for Model Plants Representing the POWC Industry^a

Model Plant No.	Coating Line Overall HAP Control Efficiency, percent	Controlled Coating Line HAP Emissions, tpy	Coating Use, tpy	Average Number of Coating Lines	Average Number of Coating Stations	Uncontrolled Coating Line HAP Emissions, tpy	HAP Capture Efficiency, percent	HAP Destruction Efficiency, percent
1a	0	99	2,108	2	5	99	0	0
1b	0	1,765	7,521	12	9	1,765	0	0
1c ^b	0	48	6,597	3	17	48	0	0
2a	50	138	8,607	5	11	276	55	90
2b	50	1,261	369,929	31	154	2,522	53	95
3a	80	183	7,518	3	8	915	89	90
3b	80	1,378	14,516	8	15	6,890	84	95
4	90	99	3,431	4	12	990	95	95
5	95	40	5,498	5	19	800	97	98

^a tpy = tons per year.

^b Although a control efficiency of zero is stated, this model plant is assumed to be using compliant coatings with less than or equal to 0.20 lb HAP per lb coating solids that are considered equivalent to 95 percent overall control. Therefore, no additional control is needed to comply with Control Option 1.

Table 6-2. Capture and Control Approach for the POWC Model Plants with Control Option 1

Model Plant	Model Plant Coating Line Overall HAP Control Efficiency, percent	Model Plant HAP Capture Efficiency, percent	Model Plant HAP Destruction Efficiency, percent	Approach for Capture and Control to Comply with Control Option 1 ^{a,b}
1a	0	0	0	PTE and new T.O., plus MR&R
1b	0	0	0	PTE and new T.O., plus MR&R
1c	0	0	0	MR&R
2a	50	55	90	PTE and increase T.O. destruction efficiency, plus MR&R
2b	50	53	95	PTE, plus MR&R
3a	80	89	90	PTE and increase T.O. destruction efficiency, plus MR&R
3b	80	84	95	PTE, plus MR&R
4	90	95	95	PTE, plus MR&R
5	95	97	98	MR&R

^a PTE = permanent total enclosure; T.O. = thermal oxidizer; MR&R = monitoring, recording, and recordkeeping.

^b Control Option 1 is the use of a PTE and a thermal oxidizer operating at 95 percent destruction efficiency to achieve an OCE of 95 percent.

As shown in Table 6-1, Model Plants 1a and 1b do not have any capture or control devices. To implement Control Option 1, it was assumed that a PTE would be installed to increase the capture efficiency to 100 percent, and a new thermal oxidizer (T.O.) with a destruction efficiency of 95 percent would be added, to produce an overall control efficiency of 95 percent. Model plant 1c uses compliant coatings equal to an OCE of 95 percent and, thus, no additional control was needed to meet the requirements of Control Option 1.

Model Plants 2a and 3a have less than 100 percent capture and destruction efficiencies of 90 percent. The approach to implement Control Option 1 for these model plants included installing a permanent total enclosure, and increasing the destruction efficiency of the existing thermal oxidizers from 90 to 95 percent.

Three of the remaining model plants (2b, 3b, and 4) have destruction efficiencies equal to 95 percent and capture efficiencies less than 100 percent. Therefore, it was assumed that a PTE would be installed at these facilities to implement Control Option 1, increasing the capture efficiency to 100 percent and the corresponding OCE to 95 percent. Since Model Plant 5 has an OCE of 95 percent, no increase in capture or destruction efficiency was needed to implement Control Option 1. Because monitoring, reporting, and recordkeeping (MR&R) costs apply to all facilities, these costs were applied to each model plant, including Model Plants 1c and 5.

6.3 MODEL PLANT CAPITAL AND ANNUAL COSTS - EXISTING SOURCES

The capital and annual costs of the four primary cost items to meet Control Option 1 are presented in this section. The four cost items are: (1) installation of a permanent total enclosure, (2) a new thermal oxidizer, (3) increasing destruction efficiency of existing thermal oxidizers from 90 to 95 percent, and (4) monitoring,

reporting, and recordkeeping. Each of the model plants will incur at least one of these cost items and some combination, but not all, of the others.

6.3.1 Permanent Total Enclosures--Cost Related Background

A PTE is an enclosure that surrounds a source of emissions such that all emissions are captured and contained, usually for discharge to a control device. If the EPA's five point criteria for a fully enclosed room from Method 204 are met, 100 percent capture of the contaminants in the room can be assumed. These criteria are not discussed here, but detailed discussions can be found in the literature.^{2,3,4}

The process of designing a PTE for any given capture application can be broken down into four basic areas of concern: regulatory, operational, safety and health, and economic. Each area must be considered alone and with the others. For example, designing an enclosure based solely on regulatory requirements would not ensure operator safety. Similarly, a PTE designed solely with safety in mind could result in several operational and economic deficiencies.^{5,6}

The regulatory issues consist primarily of meeting the five criteria established for PTEs in Method 204 as mentioned above. Operational considerations include material selection and process/operator needs. Common PTE materials of construction are plastic over frame, frame and drywall, sheet metal, prefabricated panels, plywood, and cinder block. Important process/operator needs include optimum product flow, operator access, maintenance accessibility, and expansion capability.^{7,8}

Safety and health considerations have a significant impact on all the other areas of PTE design consideration. Room ventilation and air changes must be considered for their effect on health and safety. There is no specific ventilation or air change requirements

established by the EPA for PTE design. The Occupational Safety and Health Administration (OSHA) does recommend four air changes per hour in dusty environments, but does not address gaseous environments. Some industry experts recommend between four and twelve air changes for gaseous environments, depending on the application.⁹ One recognized PTE expert who has been involved with more than 100 PTE installations, believes PTEs with less than four room air changes per hour are uncomfortable for workers and may result in product quality problems for facilities; further, all PTEs should be designed for at least ten room air changes per hour, whenever possible.⁹ The airflow characteristics of the PTE are important to insure that a steady flow of fresh air is supplied around or past operator work stations. Odors and explosion potential are additional health and safety concerns that must be considered in the design of a PTE.¹⁰

There are also economic considerations involved in designing a PTE. The costs associated with PTE installations vary with the scope of the project. The construction cost of a PTE is dependent upon how much cutting is needed to place walls or ceilings, the type of doors used, the amount of duct work that has to be modified to meet the Method 204 criteria, how much air conditioning is needed (if any), and the degree to which modifications to the make up air system are required.¹¹ One consulting firm with experience in more than 100 PTE installations reports that total PTE installation costs can range from \$8,000 to \$200,000, depending on the size and scope of the work involved.^{12,13} Costs for a PTE can be higher where substantial air-conditioning changes are required, or cuts are needed for conduits, ducts, pipes, electrical switchgear, etc.^{14,15}

A common misconception concerning the installation of PTEs is the assumption that increased air volumes will need to be handled, and, therefore, the control device will need to be bigger to handle the increased airflow. While this is true for some PTE

configurations, a well-designed enclosure can be adequately ventilated using the existing process exhaust air flow.^{16,17,18,19,20} By incorporating airflow reduction techniques, such as cascading the exhaust air from a lower concentration source to a higher concentration source, lowering the ceiling/raising the floor, and the use of closed-loop systems, air flows can be sometimes decreased over those associated with the process before the installation of the PTE.^{21,22,23} One company that has retrofitted PTEs at more than 50 plant sites in ten different industries has found that air flows from the workplace can be reduced by 25 to 50 percent while simultaneously enhancing the air quality in the working environment.²⁴

Another popular misconception concerning PTE use is that the operator's environment is necessarily compromised due to the concentration of contaminants in the reduced work area. In a well-designed PTE with appropriate room air changes, well-designed ventilation pattern, and sometimes, addition of a closed-loop air-conditioning system, the air quality within the enclosure is often far better than pre-PTE conditions.^{25,26,27,28}

There are five basic designs for the PTEs built over the last ten years. These include: (1) large room/building PTE using existing walls; (2) PTE for one or more sources using newly constructed walls; (3) PTE around the wet end of equipment (manned); (4) PTE attached to or made part of the equipment (unmanned); and (5) PTE within a PTE (for use of compliant and noncompliant materials).²⁹ One firm with extensive PTE installation experience has found that most facility owners/operators initially desire that the entire room be the enclosure with little modification and little disruption to their existing operations. Worker comfort and lower explosive limit evaluations lead to other decisions on PTE designs.³⁰ This costing analysis assumes that the PTE would consist of either the entire coating room or completely cover each of the coating lines.

6.3.2 PTEs for the Model Plants

The costs of the PTEs for the model plants were based on case study information from the literature,³¹ adjusted to reflect the estimated relative size of the coating rooms and anticipated difficulty of installation (number of cuts needed, etc.).³² Since the PTEs must be custom-designed for each facility, it was not clear if these engineering/design costs were fully accounted for in the case study costs. Therefore, an additional engineering cost, equal to 10 percent of the cost of the PTE, was assumed for the model plants. Further, it was assumed that spot air conditioning (AC) would be installed along with the PTE, with the cost of the AC estimated based on the exhaust flowrates for each model plant.³³ The total model plant capital costs of the PTE-related components varied from \$110,000 to \$1.7 million. The capital costs associated with the design and installation of a PTE for the POWC model plants are presented in Table 6-3.³⁴

The annual PTE costs are presented for each of the model plants in Table 6-4. These costs include the capital recovery costs associated with the capital investment, plus the electricity required to operate the spot air conditioning. The annual model plant costs of the PTEs range from approximately \$37,000 to \$873,000.³⁵

6.3.3 New Thermal Oxidizers

For Model Plants 1a and 1b, which have no capture or control systems, costs for new thermal oxidizers were estimated, along with the costs associated with the installation and operation of PTEs. Because of the relatively high air flows associated with these two model plants, it was assumed to be reasonable that regenerative thermal oxidizers would be chosen. The costs associated with the new regenerative thermal oxidizers were estimated using costing spreadsheets developed by the EPA.³⁶

Table 6-3. Capital Costs of Permanent Total Enclosures
for the POWC Model Plants

Model Plant	Exhaust, scfm	PTE Cost, \$	Engineering Cost, \$	Air- conditioning Capital Cost, \$	Total PTE- related Capital Cost, \$
1a	61,829	20,000	2,000	106,000	128,000
1b	212,620	130,000	13,000	170,000	313,000
1c	71,089	N/A	N/A	N/A	N/A
2a	115,751	50,000	5,000	94,000	149,000
2b	1,690,700	260,000	26,000	1,400,000	1,690,000
3a	108,703	20,000	2,000	88,000	110,000
3b	222,390	100,000	10,000	180,000	290,000
4	113,698	50,000	5,000	92,000	147,000
5	92,320	N/A	N/A	N/A	N/A

Assumptions:

- 1) All costs 1998 dollars.
- 2) Base permanent total enclosure (PTE) cost based on case studies^{37,38} and engineering judgement.³⁹
- 3) PTE costs of individual model plants based on estimated relative size of coating room, and engineering judgement.⁴⁰
- 4) Engineering cost estimated as 10 percent of PTE cost.⁴¹
- 5) Air conditioning (AC) calculations assume spot air conditioning is installed.
- 6) Air-conditioning cost based on cost factors of 25 tons per 20,000 scfm, and \$30,000 per 25 tons capacities.⁴²
- 7) Electricity required for AC capacity calculated using an equation from the literature.⁴³

Table 6-4. Annual Costs Associated with Installation and Operation of Permanent Total Enclosures (PTE) for the POWC Model Plants

Model Plant	1a	1b	1c	2a	2b	3a	3b	4	5
Total Capital Investment, \$	128,000	313,000	N/A	149,000	1,686,000	110,000	290,000	147,000	N/A
ANNUAL COSTS, 1998 DOLLARS									
Electricity, \$/yr	26,967	92,737	N/A	50,486	737,418	47,412	96,998	49,591	N/A
Capital Recovery, \$/yr	10,315	25,224	N/A	12,007	135,869	8,865	23,370	11,846	N/A
Total Annual Costs	\$37,282	\$117,960	N/A	\$62,493	\$873,287	\$56,277	\$120,368	\$61,437	N/A

Assumptions:

- 1) Total capital investment includes cost of PTE, engineering, and spot air conditioning capacity, as described in Table 6-3.⁴⁴
- 2) PTE capital costs based on estimated size of coating room, case study cost data, and engineering judgement.^{45,46}
- 3) Electricity required for calculated AC capacity calculated using equation presented in the literature.⁴⁷
- 4) Capital recovery based on a 10-year equipment life, 7 percent interest rate.^{48,49,50}
- 5) Electricity costs based on 6,600 hours of operation per year and a unit rate of \$0.0451/kWh, based on information from Energy Information Administration for 1998.⁵¹

The capital costs associated with installation of new thermal oxidizers and associated PTEs at model plants 1a and 1b are presented in Table 6-5. The capital costs are those associated with (1) the new regenerative thermal oxidizer, and (2) the PTE. The capital costs for Model Plants 1a and 1b were estimated at approximately \$2.5 million and \$6.8 million, respectively.

The annual costs associated with installation of new thermal oxidizers and associated PTEs at model plants 1a and 1b are also presented in Table 6-5. Besides capital recovery costs, these annual costs also include annual costs for labor and maintenance materials; natural gas for the thermal oxidizer; electricity for the thermal oxidizer and the PTE air conditioning; annual monitoring, reporting, and recordkeeping costs; and overhead and other miscellaneous costs. The annualized costs of new thermal oxidizers and associated PTEs for Model Plants 1a and 1b were approximately \$725,000 and \$1.9 million, respectively.

6.3.4 Increasing Destruction Efficiency of Existing Thermal Oxidizers

To meet the requirements of Control Option 1 with Model Plants 2a and 3a, the destruction efficiencies of the existing thermal oxidizers were increased from 90 to 95 percent and a PTE was used to increase the capture efficiency to 100 percent. The capital costs of this capture and control approach are presented for Model Plants 2a and 3a in Table 6-6. The capital costs associated with any capital improvements to the existing thermal oxidizers that may be needed were estimated as 10 percent of the cost of a new regenerative thermal oxidizer. The capital costs of PTE and monitoring, reporting, and recordkeeping requirements were calculated as described for the other model plants, above.

Table 6-5. Regenerative Thermal Oxidizer Capital and Annual Operating Costs for POWC Model Plants^{a,b,c}

Model Plant	1a	1b
Flowrate to Thermal Oxidizer, scfm	61,829	212,620
CAPITAL INVESTMENT		
T.O. and auxiliaries (A)	\$2,351,820	\$6,467,733
PTE (B)	\$128,000	\$313,000
MR&R (C)	\$0	\$0
Total Capital Investment (A+B+C)	\$2,479,820	\$6,780,733
ANNUAL COSTS		
Operating labor	\$15,515	\$15,515
Supervisory labor	\$2,327	\$2,327
Maintenance labor	\$2,151	\$2,151
Maintenance materials	\$2,151	\$2,151
Natural gas	\$134,940	\$286,649
Electricity associated with T.O. operation	\$71,903	\$247,096
Electricity associated with PTE operation	\$26,967	\$92,737
Overhead	\$13,287	\$13,287
Taxes, insurance, administration	\$99,193	\$271,229
Capital recovery for T.O. and PTE	\$345,161	\$960,648
Capital recovery for MR&R	\$0	\$0
MR&R	\$11,827	\$11,827
Total Annual Costs	\$725,422	\$1,935,616

^a Calculated using the EPA cost spreadsheet program for regenerative thermal oxidizers.⁵²

^b In 1998 dollars.

^c T.O. = thermal oxidizer, PTE = permanent total enclosure, MR&R = monitoring, recording, and recordkeeping

Assumptions:

- 1) Permanent total enclosure (PTE) costs estimated based on case studies and engineering judgement.^{53,54,55}
- 2) PTE costs assume engineering = 10 percent PTE cost; spot air conditioning, 10-year life, 7 percent interest rate.^{56,57,58,59}
- 3) Because regenerative thermal oxidizers are field built, it was assumed that ductwork costs are included in the Total Capital Investment estimate.^{60,61}
- 4) Assumes 95 percent heat recovery, 20 inch pressure drop, 6,600 operating hours per year.⁶²
- 5) Operator labor rate = \$37.61/hr, maintenance labor rate = 1.1*operator rate = \$41.37/hr. Both based on escalated Bureau of Labor Statistics data for 1998.⁶³
- 6) Electricity cost \$0.0451/kWh, natural gas cost \$3.099/mscf, both based on information from Energy Information Administration for 1998.^{64,65}

Table 6-6. Capital and Annual Costs of Increasing Destruction Efficiency of Existing T.O.s in the POWC Industry ^{a,b}

MODEL PLANT	2a	3a
CAPITAL COSTS		
Improvements to existing T.O. (A)	\$382,480	\$363,044
PTE (B)	\$149,000	\$110,000
MR&R (C)	\$0	\$0
Total Capital Costs (A+B+C)	\$531,480	\$473,044
ANNUAL COSTS		
Capital recovery of A,B,C above	\$68,585	\$62,121
Increased fuel and electricity (T.O.)	\$55,090	\$51,718
Increased electricity for PTE	\$50,486	\$47,412
MR&R	\$11,827	\$11,827
Total Annual Costs	\$185,988	\$173,078

^a All costs in 1998 dollars.

^b T.O. = thermal oxidizer. PTE = permanent total enclosure
MR&R = monitoring, reporting, and recordkeeping

Assumptions:

- 1) Overall control efficiencies of existing oxidizers were increased to 95 percent by a) adding a PTE, b) increasing combustion temperature, and c) making any necessary capital improvements to the existing oxidizers to allow increased destruction efficiency to be achieved.

- 2) Cost of capital recovery calculated based on a 10-year equipment life and 7 percent interest rate (according to OMB guidance).^{66,67,68}
- 3) Increased fuel and electricity costs for thermal oxidizer were calculated (using the EPA regenerative thermal oxidizer spreadsheet) as the difference in fuel and electricity costs for an oxidizer of the appropriate size operating at combustion temperatures of 1300°F and 1600°F.⁶⁹
- 4) Operator labor rate = \$37.61/hr, maintenance labor rate = 1.1*operator rate = \$41.37/hr. Both based on escalated Bureau of Labor Statistics data for 1998.⁷⁰
- 5) Electricity cost \$0.0451/kWh, natural gas cost \$3.099/mscf, both based on information from Energy Information Administration for 1998.^{71,72}

The annual costs of increasing the destruction efficiency of the existing thermal oxidizers at Model Plants 2a and 3a, including those associated with the PTE and monitoring, reporting, and recordkeeping, are also presented in Table 6-6.

The increased natural gas and electricity usage associated with increasing the destruction efficiency from 90 to 95 percent was calculated (using the EPA costing spreadsheets) as the difference in fuel and electricity use for an appropriately-sized regenerative thermal oxidizer operating at 1300°F and 1600°F.⁷³ The costs of capital recovery were added to these increased fuel and electricity costs to estimate the annualized costs for Model Plants 2a and 3a as approximately \$186,800 and \$173,000, respectively. The capital costs of increasing the destruction efficiency from 90 to 95 percent, including the associated PTE and monitoring, reporting, and recordkeeping, were approximately \$531,000 and \$473,000 for Model Plants 2a and 3a, respectively.

6.3.5 Monitoring, Reporting, and Recordkeeping

There will be monitoring, reporting, and recordkeeping requirements for all affected POWC facilities, and therefore, for all of the model plants. In addition, the model plants with capture and control devices will require parameter monitoring devices for the capture and control systems, such as pressure and/or temperature monitors. Because such monitoring devices are typically included in

the cost of the control device, no additional capital costs were included here.

The annual monitoring, reporting, and recordkeeping costs for each of the model plants are presented in Table 6-7. The model plant total annual monitoring, reporting, and recordkeeping costs were \$14,322 for all model plants except for 1c. This model plant was the only one using all compliant coatings, resulting in an increased MR&R burden. The total annual MR&R costs for Model Plant 1c were \$17,231. These costs reflect the requirements specified in the proposed regulation and for which detailed labor hour and cost estimates were developed in the Standard Form 83-I Supporting Statement.⁷⁴

Table 6-7. Capital and Annual Operating Costs Associated with Monitoring, Recording, and Recordkeeping (MR&R) Requirements for the POWC Model Plants

Model Plant	MR&R Annual Operating Cost
1a	\$14,322
1b	\$14,322
1c	\$17,231
2a	\$14,322
2b	\$14,322
3a	\$14,322
3b	\$14,322
4	\$14,322
5	\$14,322

Assumptions:

- 1) All costs 1998 dollars.
- 2) Annual operating costs are detailed in the Standard Form 83-I Supporting Statement.⁷⁵

6.4 TOTAL COSTS AND COST EFFECTIVENESS - EXISTING SOURCES

The total capital investment (capital cost) for each capture and control approach for the nine model plants with Control Option 1 is summarized in Table 6-8. Depending on the capture and control approach taken, these capital costs include the costs of new thermal oxidizers or improvements to existing thermal oxidizers, and PTEs. Because Model Plant 1c uses all compliant coatings and Model Plant 5 is already achieving 95 percent OCE through the use of controls, there were no capital costs for these model plants. The total capital costs for the remaining model plants ranged from approximately \$147,000 to \$6.8 million.

The total annual costs of the capture and control approach to Control Option 1 for the nine model plants are presented in Table 6-9. These total annual costs include capital recovery costs and operating costs such as labor, fuel, and electricity, as well as MR&R costs. The total annual costs for the model plants ranged from approximately \$12,000 to \$1.9 million.

The cost effectiveness of the capture and control approaches for the nine model plants are presented in Table 6-10. The amount of HAP controlled represents the additional HAP controlled from implementing the capture and control approach to implement Control Option 1 in the model plants. For instance, for Model Plants 1a and 1b, which have no control, the HAP controlled represents 95 percent of the uncontrolled emissions. Model Plants 2b, 3b, and 4, however, all have existing capture and control systems. The HAP controlled for these model plants represents the additional HAP that is controlled by increasing the capture efficiency to 100 percent by

Table 6-8. Total Model Plant Capital Costs for Complying with Control Option 1

Model Plant	Approach for Capture and Control ^a	Average Number of Coating Lines	Average Number of Coating Stations	Coating Use, tpy	Uncontrolled Coating Line HAP Emissions, tpy	Total Model Plant Capital Costs ^b
1a	PTE and new control device	2	5	2,108	99	\$2,479,820
1b	PTE and new control device	12	9	7,521	1,765	\$6,780,733
1c	no change	3	17	6,597	48	\$0
2a	PTE and increase T.O. efficiency	5	11	8,607	276	\$531,481
2b	PTE	31	154	369,929	2,522	\$1,686,000
3a	PTE and increase T.O. efficiency	3	8	7,518	915	\$473,044
3b	PTE	8	15	14,516	6,890	\$290,000
4	PTE	4	12	3,431	990	\$147,000
5	no change	5	19	5,498	800	\$0

^a PTE = permanent total enclosure

T.O. = thermal oxidizer

^b Includes MR&R for all model plants.

Table 6-9. Total Model Plant Annual Costs for Complying with Control Option 1

Model Plant	Approach for Capture and Control ^a	Average Number of Coating Lines	Average Number of Coating Stations	Coating Use, tpy	Uncontrolled Coating Line HAP Emissions, tpy	Total Annual Model Plant Costs ^b
1a	PTE and new control device	2	5	2,108	99	\$725,422
1b	PTE and new control device	12	9	7,521	1,765	\$1,935,616
1c	no change	3	17	6,597	48	\$17,231
2a	PTE and increase T.O. efficiency	5	11	8,607	276	\$185,988
2b	PTE	31	154	369,929	2,522	\$885,113
3a	PTE and increase T.O. efficiency	3	8	7,518	915	\$173,077
3b	PTE	8	15	14,516	6,890	\$132,194
4	PTE	4	12	3,431	990	\$73,263
5	no change	5	19	5,498	800	\$11,827

^a PTE = permanent total enclosure; T.O. = thermal oxidizer

^b Includes MR&R for all model plants.

Table 6-10. Cost Effectiveness of Capture and Control Approaches to Control Option 1 for the POWC Model Plants

Model Plant	Approach for Capture and Control ^a	HAP Reduction, tpy	Annual Cost, 1998\$	Cost Effectiveness, \$/ton
1a	PTE and new control device	94	\$725,422	7,717
1b	PTE and new control device	1,677	\$1,935,616	1,154
1c	Compliant coatings/no change	0	\$17,231	N/A
2a	PTE and increase T.O. efficiency	124	\$185,988	1,500
2b	PTE	1,135	\$885,113	780
3a	PTE and increase T.O. efficiency	137	\$173,077	1,263
3b	PTE	1,034	\$132,194	128
4	PTE	50	\$73,263	1,465
5	no change	0	\$11,827	N/A

^a PTE = permanent total enclosure
T.O. = thermal oxidizer

adding a PTE. The cost effectiveness for the nine POWC model plants ranged from approximately \$130 to \$7,700 per ton of incrementally controlled HAP.

6.5 MODEL PLANT CAPITAL AND ANNUAL COSTS - NEW SOURCES

Based on projected growth rates for the four major POWC industry SIC codes, it was estimated that 32 new major source POWC facilities will be built in the five years following promulgation of the regulation.⁷⁶ For costing purposes, Model Plant 4 was chosen as being the most representative of the level of control these new facilities will use absent any new regulation. Thus, the baseline level of control for the new facilities was assumed to be a PTE operating at 100 percent efficiency and a thermal oxidizer operating at 95 percent destruction efficiency.

In order to estimate the cost for new facilities to upgrade from the baseline level of control to the new source MACT floor level of control of 98 percent OCE, it was assumed that the facility would make capital improvements to the existing thermal oxidizer to increase its destruction efficiency to 98 percent. The costing methodology presented in Section 6.3 was used for the annual costs of operating the PTE. The improvements in the operation of the thermal oxidizer were assumed to require 10 percent of the capital cost of a new thermal oxidizer. The estimated annual cost for the operation of the thermal oxidizer was based on the increased cost of operation at 1800EF versus 1600EF. Total annual costs also include MR&R costs.⁷⁷

The new source annual and capital costs were estimated to be approximately \$5.2 million and \$12 million, respectively. These costs are summarized in Table 6-11.

Table 6-11. Annual and Capital Costs of Achieving New Source MACT Floor Level of Control

POWC Costs	Facility Costs	Number of New Facilities	Total Annual Cost
Annual Costs Associated with...			
Operation of Permanent Total Enclosure (PTE)	\$61,437	32	\$1,965,984
Monitoring, Reporting, and Recordkeeping (MR&R) Requirements	\$11,827	32	\$378,464
Capital Improvements and Operation of New Thermal Oxidizers (TO) ^a	\$89,725	32	\$2,871,200
Total Annual Cost of Complying with 98 Percent OCE	\$162,989	32	\$5,215,648
Capital Costs Associated with...			
Purchase of Permanent Total Enclosure (PTE)	\$0	32	\$0
Capital Improvements to New Thermal Oxidizers (TO) Operating at 1800 degrees F	\$376,753	32	\$12,056,096
Equipment for Monitoring, Reporting, and Recordkeeping (MR&R) Requirements of POWC Rule	\$0	32	\$0
Total Capital Investment for Complying with 98 Percent OCE	\$376,753	32	\$12,056,096

^a Annual Costs of Capital Improvements and Operation of New Thermal Oxidizers include: 10 percent of the capital costs of purchasing a new TO operating at 1800 degrees F plus the increase in electricity and natural gas costs from 1600 to 1800 degrees F.

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