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Assessment of VOC Emissions from Fiberglass Boat Manufacturing

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ASSESSMENT OF VOC EMISSIONS FROM FIBERGLASS BOAT MANUFACTURING

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ABSTRACT

This report presents an assessment of VOC emissions from fiberglass boat manufacturing. First, a description of the industry structure is presented. This includes estimates of the number of facilities, their size, and geographic distribution. The fiberglass boat manufacturing process is then described along with the sources and types of VOC emissions. Model plants representative of typical facilities are also described. Estimates of VOC emissions are presented on a per plant and on a national basis. VOC emissions from this industry consist mainly of styrene emission from gel coating and lamination, and acetone or other solvent emissions from clean-up activities. Finally, an evaluation of potential VOC control technologies is made for this industry. This evaluation includes a discussion of technical feasibility. Limited cost data are also provided.

As used in this report, "fiberglass" means fibrous glass or fiberglass-reinforced plastic. The term does not necessarily mean Fiberglas™, trademark of Owens/Corning Fiberglas Corporation, Toledo, Ohio.

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CONVERSION OF ENGLISH UNITS TO SI UNITS

English Unit	Multiply by	To Obtain
Tons	0.907	Metric tons
Pounds	0.454	Kilograms
feet	0.304	m
cfm	28.314	1/min

ACKNOWLEDGEMENTS

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SECTION 1

INTRODUCTION

The purpose of this study was to conduct a survey of the fiberglass marine craft production industry to define the nature and scope of volatile organic compound (VOC) emissions from this source. The study includes total industry VOC emissions and the geographic distribution of the industry. Emissions from different industry segments, specific processes identified in the industry, industry structure (production rate, employment), and economic data (such as cash flows) were also determined. This study also includes an evaluation of potential VOC control options. Although this report is directed primarily toward boat manufacturing, the resulting technologies identified may also be applicable to other molded fiberglass operations. Phase 1 of this study was conducted in the spring of 1989. Phase 2, which included additional information gathering on emission controls, was conducted during September and October 1989.

Typically, the modern marine pleasure craft is manufactured using a molded fiberglass structure. Previous studies indicate that over 22,000 tons of VOC per year are emitted from fiberglass boat manufacturing operations in the United States. Significant concentrations of boat manufacturing facilities exist in the Great Lakes area, along the coastal areas of the country (i.e., California, Texas, Florida and South Carolina), and near recreational rivers and lakes, such as those located in Tennessee. As a result, fiberglass boat manufacturing may potentially impact local air quality.

SECTION 2

CONCLUSIONS AND RECOMMENDATIONS

The major findings from this study are presented below. The conclusions can be categorized in four groups: 1) industry characterization, 2) process emissions, 3) emission reductions through process or material changes, and 4) emission reductions through add-on controls. In general, substitution of lower VOC-containing materials is the most promising method of reducing VOC emissions. Add-on controls for reducing VOC emissions have not generally been demonstrated for this industry. A combination of the control techniques presented below may be used for even greater emission reduction.

CONCLUSIONS

- Industry Characterization:
  - The distribution of fiberglass boat manufacturing facilities is not limited to coastal States. Boat manufacturing facilities are located in 36 States.
  - There appears to be significant geographical concentrations of boat manufacturing facilities in the following coastal areas: Puget Sound, Washington; Miami and Tampa Bay, Florida; and Los Angeles, California. There is also a significant concentration of manufacturing facilities in central Tennessee. Boat manufacturing facilities are fairly evenly distributed between inland and coastal areas in coastal States.
  - The majority of national emissions are from medium size plants employing between 50 and 100 workers and producing boats less than 30 feet long.

- Process Emissions

  - Total National VOC emissions from fiberglass boat manufacturing are estimated to be 20,150 tons per year. Approximately 64 percent of these emissions are styrene; resulting from gel coating and lamination, the remainder is acetone or some other solvent used during clean-up.

  - The major emission sources are exhausts from gel coat spray booths, room exhausts from the lamination area, and evaporation of acetone or other solvents during clean-up.

  - Fiberglass boat manufacturing companies typically induce ventilation to meet the 100 ppmv OSHA styrene limit established for these operations. As a result, exhaust streams from individual plants are typically characterized by high flow rates and low VOC concentrations.

- Emission reductions through process or material changes:

  - Water/detergent emulsions can be used to replace approximately 50 percent of the solvent used for clean-up. This would be expected to reduce clean-up emissions by approximately 50 percent. These cleaners are successfully being used commercially in boat plants for resin clean-up and their use has been required as a permit restriction to reduce VOC emissions from fiberglass boat plants in some recent Best Available Control Technology (BACT) decisions. However, based on industry experience, these detergent emulsions appear to be inadequate for gel coat clean-up or cured resin.

  - Alternate cleaning compounds containing dibasic esters (DBE) are currently being tested at a number of fiberglass boat plants. These cleaners show the potential to replace acetone completely for resin and gel coat clean-up. Due to the much lower vapor pressure of dibasic esters, these substitutes can provide dramatic VOC emission reductions.

  - Low styrene resins are currently available and being used in the industry. Styrene emissions can be reduced by approximately 14 percent using a 35 percent styrene by weight resin. There are limits to the use of low styrene resins in the fiberglass boat manufacturing industry, however very few boat companies have been able to reduce styrene content below 35 percent by weight without sacrificing some of the structural integrity of the boat.

  - While vapor-suppressed resins show the greatest potential for styrene emission reductions, they are currently not being used by the fiberglass boat manufacturing industry due to the high cost of the resin and problems in secondary bonding which reduces product strength. Potential styrene emission reductions range from 20 to 35 percent. In order for these resins to be widely applied, problems with bonding between successive layers of resin will need to be resolved. Resin manufacturers are seeking solutions to this problem.

-- Work practice controls, such as limiting the amount of clean-up solvent issued to employees performing lamination, and the use of gloves and covered containers, can reduce VOC emissions by an estimated 22 percent. Additional VOC reductions can be achieved through reclamation and recycle of waste acetone.

-- Properly operated air-assisted airless spray guns have the potential to reduce emissions from application of gel coat and resin by 50 and 33 percent, respectively. This could reduce total styrene emissions by approximately 9 percent.

- Emission reductions through Add-on controls:

-- Of the add-on controls evaluated in this study, incineration is the only demonstrated and readily available technology for controlling VOC emissions from fiberglass manufacturing facilities. Although incineration is not being used in a boat manufacturing facility to date, it has been installed as a means of VOC control in a fiberglass tub and shower facility. Incineration can reduce VOC emissions by 90 percent or more; however, the cost per ton of VOC removed can be expensive (e.g., $15,000/ton) due to the high exhaust flow rates and low VOC concentrations characteristic of this industry.

-- There are no known applications of carbon adsorption to the fiberglass boat manufacturing industry. Use of carbon adsorption in this industry may be restricted due to the potential for styrene to polymerize on the carbon and deactivate the bed, and due to the vast difference in the capacity for carbon to absorb styrene versus acetone. The adsorptive capacity of styrene is 30 percent, while the capacity for acetone is only 1 to 2 percent, thus making the removal of acetone the limiting design criteria.

-- There are no known applications of chemical scrubbers to the fiberglass boat manufacturing industry. However, there are two systems, Chemtact™ and Styrex™ that could theoretically be used for removing styrene from exhaust air. Both systems require further testing and analysis to demonstrate commercial viability for this industry.

RECOMMENDATIONS

The following recommendations are made for additional study of the control technologies described in this report.

Material Substitutions

It appears, based on current information, that the control technology offering the greatest potential for VOC emission reductions at low costs are the substitution of lower VOC-containing materials. These include vapor-suppressed resins, low styrene resins, water-based emulsions for clean-up, and dibasic ester (DBE) compounds for clean-up. Further study to determine the applicability and limitations of using these materials for fiberglass boat manufacturing is warranted. The following recommendations for additional investigation should be undertaken to define their performance and economic viability for future application to this industry:

- Perform reformulation and laboratory testing of vapor-suppressed resins to determine if addition of adhesion promoters can effectively eliminate secondary bonding problems and improve structural performance for boat fabrication.
- Perform additional product strength testing of laboratory samples and/or prototype boats made with low styrene resins to determine the effect on product quality of reducing the styrene content in resins.
- Contact additional formulators of water-based emulsion cleaners and with boat manufacturers using these cleaners to clarify cleaning performance, overall costs, worker safety issues, and waste disposal issues.
- Investigate the feasibility of reformulating water-based emulsions to make them suitable cleaners for gel coat clean-up.
- Investigate the applicability of dibasic ester compounds for clean-up in boat manufacturing plants and to quantify VOC emissions associated with the use of these cleaners. Two boat plants were identified during this study that have recently starting using DBE cleaners in their production. The performance, overall costs, worker safety issues, and waste disposal issues faced by these plants should be evaluated further.

Add-on Controls

There are currently three control devices that have been reported to have potential for controlling VOC and styrene emissions from fiberglass boat manufacturing facilities. However, they have not been commercially demonstrated in the U.S. They are the Styrex™ scrubber, the Chemtact™ scrubber, and the polyade polymer system. Numerous technical issues still require resolution before these technologies can be considered demonstrated for fiberglass emissions control. Technical issues and data required for the styrex and chemtect technologies are outlined below.

- Styrex™
    - -- Develop equilibrium data and perform a theoretical design evaluation to assess the limitations of these system;
    - -- Determine the efficiency of the system at low inlet concentrations (i.e., 1-80 ppmv VOC);
    - -- Determine the feasibility of continuous regeneration and recycle of the Styrex™ using a bench top or pilot unit;
    - -- Perform a full economic analysis of a commercial unit including waste disposal costs.
- Chemtact™
    - -- Determine through laboratory testing, if sodium hypochlorite oxidizes acetone and styrene and if so, what are the potential reaction products and by-products;
    - -- Evaluate the efficiency of the sodium hypochlorite oxidation process through examination of the liquid effluent and outlet air ducts of existing installations; and at low inlet concentrations of styrene.

The Polyade™ technology has been applied in Europe. However, it still remains to be applied in the United States fiberglass boat industry. However, evaluations are still required to define the technical and economic viability of the system in the U.S. industrial environment.

SECTION 3

INDUSTRY STRUCTURE

This section contains industry distribution and economic information for the total boat building and repair industry, and for the fiberglass boat production segment of this industry.

INDUSTRY SIZE

The fiberglass reinforced plastic (FRP) boat manufacturing industry represents a segment of SIC code 3732, Boat Building and Repairing. Currently, 1,822 facilities comprise the boat building and repair industry as a whole, although only 214 of these establishments employ 50 or more people. The total estimated number of employees is approximately 47,000. The fiberglass boat manufacturing segment of the industry is composed of 695 small boat facilities producing boats larger than 30 feet in length. Table 1 shows the size distribution (the number of facilities and employees per employment size class) for the total boat building and repair industry in 1985 and for the fiberglass boat manufacturing segment alone in 1987.

MAJOR MANUFACTURERS AND GEOGRAPHIC DISTRIBUTION

Although most fiberglass boat manufacturers produce only six to seven individual models, a few large establishments produce more. The list of major fiberglass boat manufacturers presented in Table 2 indicates the facilities which produce 14 or more individual models. Another means of determining major boat manufacturers is to identify those with the highest total tangible assets (Table 3). Only 3 manufacturers (Wellcraft, Glasply, and Sea Ray) are found on both lists.

TABLE 1. NUMBER OF ESTABLISHMENTS IN THE BOAT BUILDING AND REPAIRING INDUSTRY

Establishment Employment Size Class	Total Industry, 1985[a]		Fiberglass Boat Plants, 1987[b]			
			Large Boats[c]		Small Boats[d]	
	Number of Establishments	Number of Employees	Number of Establishments	Number of Employees	Number of Establishments	Number of Employees
1 to 4	835	1,386				
5 to 9	335	2,263	65	455	350	2,450
10 to 19	242	3,251				
20 to 49	196	5,895	120	8,760	315	25,830
50 to 99	94	6,461				
100 to 249	85	13,253				
250 to 499	26	9,075	10	2,850	30	4,920
500 to 999	9	5,895				
1,000 or More	0	0				
TOTAL	1,822	47,479	195	12,065	695	33,200

[a] Reference 1.

[b] Reference 2.

[c] Boats over 30 feet in length.

[d] Boats less than 30 feet in length.

TABLE 2. MAJOR FIBERGLASS BOAT MANUFACTURERS[a]
(Based on number of total individual models produced)

Name	Number of Models	Location
Wellcraft	22	Sarasota, FL
Chaparral	21	Nashville, GA
Chris Craft	21	Brandenton, FL
Sun Runner	18	Spokane, WA
Baja	17	Bucyrus, OH
Century	17	Panama City, FL
Checkmate	17	Bucyrus, OH
Sea Ray	17	Knoxville, TN
Star Craft	16	Goshen, IN
Sylvan	16	New Paris, IN
Marlin	15	White City, OR
Regal	15	Orlando, FL
Sawyer	15	Oscada, MI
Glasply	15	Marysville, WA
Glastron	14	New Braunfels, TX
Larson	14	Little Falls, MN
Thompson	14	St. Charles, MI
VIP	14	Vivian, LA

[a] References 3-6.

TABLE 3. MAJOR FIBERGLASS BOAT MANUFACTURERS[a,b]
(Based on minimum total tangible assets)

Name	Assets (in millions)	Location
Bertram	50	Miami, FL
Helms	50	Irmo, SC
Trojan	50	Lancaster, PA
Wellcraft	25	Sarasota, FL
Galaxy	10	Columbia, SC
Glasply	10	Marysville, WA
Sea Ray	10	Knoxville, TN
Carver	5	Pulaski, WI
Cruisers	5	Oconto, WI
Glass Master	5	Lexington, SC
Hinkley	5	Southwest Harbor, ME
Irwin	5	Clearwater, FL
Morgan	5	Largo, MA
O'Day (Banga-Ponta)	5	Fall River, MA
Magnum	5	N. Miami Beach, FL
Ranger	5	Flippin, AR

[a] Reference 7.

[b] Some large companies do not appear in this table because they did not report their assets in published literature or because they are part of a much larger corporation, (e.g., Bayliner, Grady White, Hatteras Yachts).

The geographic distribution of the industry by number of facilities in each State is shown in Table 4. Of the 48 continental United States, 14 do not contain any fiberglass boat manufacturing establishments according to the references used.

As shown in Table 4, the following States have 10 or more boat manufacturing facilities: California, Florida, Illinois, Indiana, Michigan, North Carolina, South Carolina, Tennessee, Texas, and Washington. For the States listed above, the geographic distribution by State is presented in Figure 1. Points which represent more than one establishment in a given city are assigned a numerical value.

ECONOMIC VIABILITY OF INDUSTRY

Total value shipments for the entire Boat Building SIC presented in Table 5, have shown a 13.6 percent average increase since 1982, increasing from 2 billion dollars in 1982 to 3.6 billion dollars in 1986. While the manufacturing of less popular types of boats, such as canoes, rowboats, and "boats not elsewhere classified" show unstable growth patterns, value shipments for outboard motorboats, and inboard-outdrive boats, which together make up the majority of the industry, show steady increases from 1982 to 1986. Value shipments for Boat Repairs were excluded in order to represent the boat production industry alone.

Most boat manufacturing facilities tend to have a small number of employees (less than 50). Also, boat manufacturing is characterized as a low technology labor intensive industry. Data on the financial status of the industry is only available for boat manufacturing in general. It is assumed that since fiberglass boat manufacturing makes up such a large percentage of all boat building, the data shown are representative. Major financial parameters for both commercial and industrial dry cleaning facilities, respectively, are also shown in Table 6 for comparison. Dry cleaning facilities were selected for this comparison because they are also a low

TABLE 4. GEOGRAPHIC DISTRIBUTION OF THE INDUSTRY BY NUMBER OF FACILITIES[a]

Alabama	4	Montana	-
Alaska	-	Nebraska	1
Arizona	4	Nevada	-
Arkansas	9	New Hampshire	-
California	23	New Jersey	5
Colorada	-	New Mexico	-
Connecticut	3	New York	3
Delaware	-	North Carolina	10
Florida	77	North Dakota	-
Georgia	8	Ohio	5
Hawaii	-	Oklahoma	4
Idaho	-	Oregon	4
Illinois	12	Pennsylvania	2
Indiana	13	Rhode Island	7
Iowa	1	South Carolina	14
Kansas	4	South Dakota	-
Kentucky	3	Tennessee	40
Louisiana	9	Texas	21
Maine	7	Utah	1
Maryland	8	Vermont	-
Massachusetts	9	Virginia	1
Michigan	14	Washington	11
Minnesota	8	West Virginia	-
Mississippi	3	Wisconsin	6
Missouri	9	Wyoming	-

[a]Reference 8.

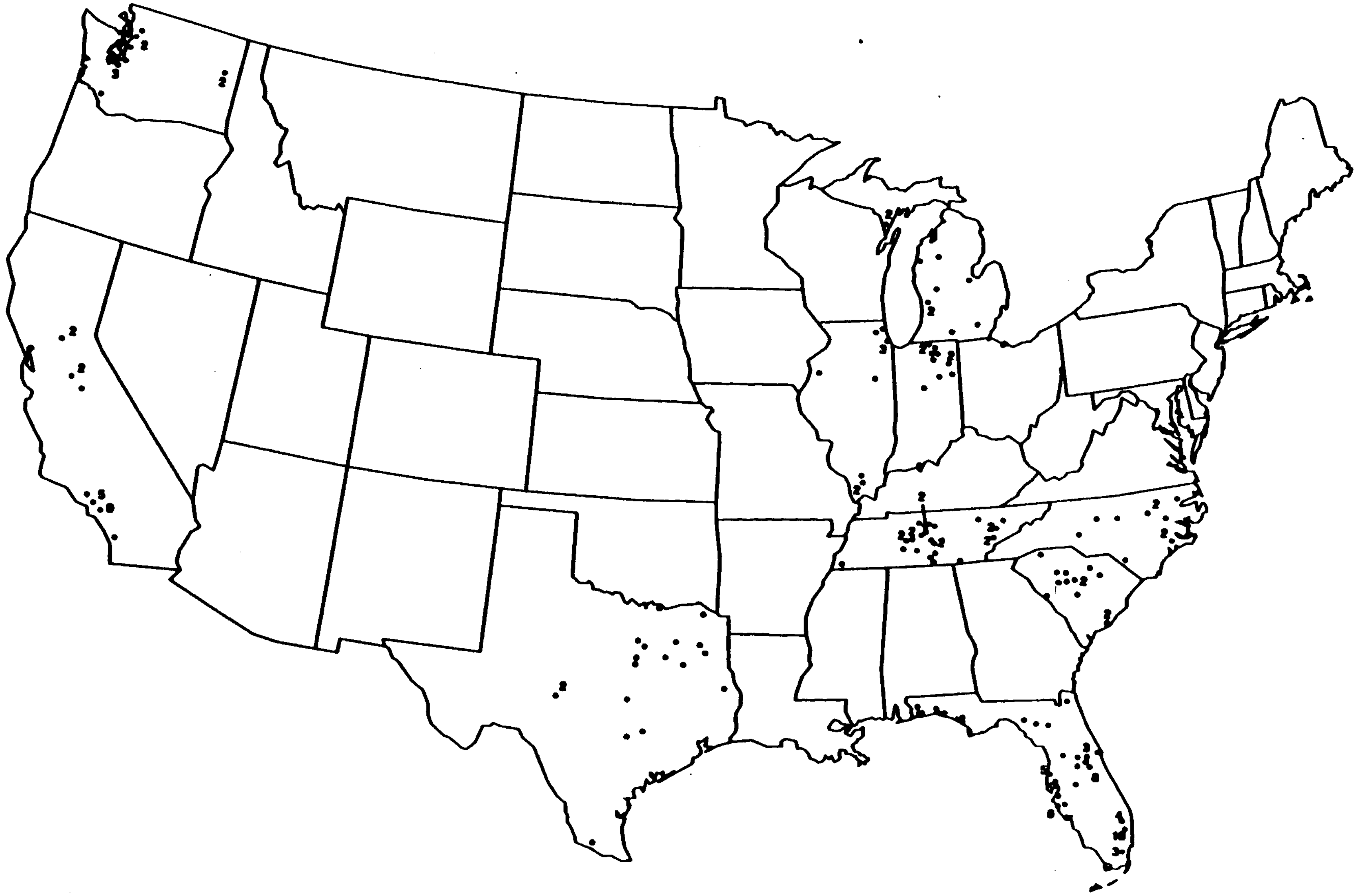

Figure 1. Geographic Distribution of Fiberglass Boat Manufacturing Facilities Plants for States with More Than Ten Facilities

TABLE 5. VALUE SHIPMENTS FOR PRODUCT CLASSES (1982-1986)[a]

Industry and Product Class Code	Description	Value of Product Shipments[b] (in millions of dollars) 1986 A	1985 B	1984 C	1983 D	1982 E
37322	Outboard Motorboats	759.3	650.5	657.1	449.1	345.0
37323	Inboard Motorboats	1022.1	779.6	748.8	580.8	522.3
37324	Inboard/Outdrive Boats	1156.2	912.3	691.6	530.6	459.9
37327	Boats n.e.c.	309.2	388.2	524.3	403.0	368.8
37320	Boat Building n.s.k.	391.2	330.2	399.5	302.3	293.2
3732	Total - Boat Building	3638.0	3060.8	3021.3	2265.8	1989.2

[a] Reference 9.

[b] 13.6 percent average annual increase

TABLE 6. FINANCIAL PARAMETERS FOR BOAT BUILDING AND REPAIRING VERSUS COMMERCIAL AND INDUSTRIAL DRY CLEANING[a]

	SIC 3732 Boat Building, Repairing (No Breakdown) 1987 (269 Establishments)		SIC 7216 Dry Cleaning, PLT EX Rug (No Breakdown) 1987 (619 Establishments)		SIC 7218 Industrial Launderer (No Breakdown) 1987 (96 Establishments)	
	$	%	$	%	$	%
Total Current Assets	253,780	60.8	54,360	34.6	396,061	50.8
Total Assets	417,401	100.0	157,109	100.0	779,648	100.0
Total Current Liabilities	142,401	100.0	35,978	22.9	240,911	30.9
Net Worth	200,770	48.1	82,482	52.5	389,824	50.0
Total Liabilities and Net Worth	417,401	100.0	157,109	100.0	779,648	100.0
Net Sales	956,739	100.0	309,863	100.0	1,400,000	100.0
Gross Profit	276,498	28.9	175,073	56.5	597,800	42.7
Net Profit after Tax	35,399	3.7	22,310	7.2	91,000	6.5
Working Capital	111,029	--	18,382	--	155,150	--

	SIC 3732 Boat Building, Repairing (No Breakdown) 1987 (269 Establishments)			SIC 7216 Dry Cleaning, PLT EX Rug (No Breakdown) 1987 (619 Establishments)			SIC 7218 Industrial Launderer (No Breakdown) 1987 (96 Establishments)		
	UQ[b]	MED[c]	LQ[d]	UQ[b]	MED[c]	LQ[d]	UQ[b]	MED[c]	LQ[d]
Ratios									
Solvency									
Quick Ratio (Times)	1.5	0.7	0.3	2.8	1.1	0.4	2.1	1.2	0.6
Current Ratio (Times)	3.8	1.9	1.2	4.1	1.7	0.7	3.4	1.9	1.0
Current Liabilities to Net Worth (percent)	18.1	56.4	148.8	8.9	26.2	75.5	23.5	51.1	106.3
Total Liabilities to Net Worth (percent)	29.6	74.7	242.1	17.0	57.9	158.5	37.7	82.4	182.3
Profitability									
Return on Sales (percent)	8.8	3.9	0.7	16.4	5.1	1.0	10.1	4.8	2.1
Return on Assets (percent)	14.8	8.2	1.5	25.4	7.1	0.8	13.1	7.5	3.3
Return on Net Worth (percent)	33.5	15.5	3.5	53.6	16.4	2.7	30.8	15.5	10.0

[a] Reference 10.
[b] UQ = upper quartile (75%)
[c] MED = median (50%)
[d] LQ = lower quartile (25%)

technology industry and a source that has been considered for regulation. Also, both dry cleaning and boat building industries are made up of relatively small facilities. Parameter definitions can be found in Appendix A.

MAJOR TRADE ASSOCIATIONS

Table 7 lists the names and addresses of the trade associations associated with fiberglass boat manufacturing.

TABLE 7. TRADE ASSOCIATIONS

Fiberglass Fabrication Association
732 Eighth Street S.E.
Suite 200
Washington, D.C. 20003

Society of the Plastics Industry, Composites Institute
355 Lexington Avenue
New York, NY 10017

American Boat Builders and Repairers Association
715 Boylston Street
Boston, MA 02116

National Marine Manufacturers Association
401 N. Michigan Avenue
Chicago, IL 60611

SECTION 4

FIBERGLASS BOAT PRODUCTION

This section describes the fiberglass reinforced plastic boat production process.

PROCESS OVERVIEW

Figure 2 presents an overview of the fiberglass boat production process. The most common production method is open contact molding.[11] The discussion in this section will be limited to this method. However, other molding methods are discussed in a later section.

The open contact molding method consists of laying up plies of resin impregnated fiberglass reinforcement on an open mold. The layers are built up to the desired thickness, then allowed to cure at room or elevated temperature. A male mold is convex leaving a smooth inner surface while a female mold is concave leaving a smooth outer surface. Although it is easier to lay up reinforcements on a male mold, a female mold is generally preferred since a smooth outer surface is more desirable for boat hulls and decks.[12]

As shown in Figure 2, the inner surface of the female mold is usually coated with a wax which ensures easy removal of the finished product from the mold after cure. Next, gel coat, a layer of resin without any reinforcing material, is sprayed into the empty mold to a precise thickness. Gel coat consists of unsaturated polyester resin, catalyst, and pigments, together forming the smooth outer surface of the final product. Gel coat spray systems often consist of separate resin and catalyst sources and an airless spray gun (similar to the type used in paint spraying) which mixes the two chemical

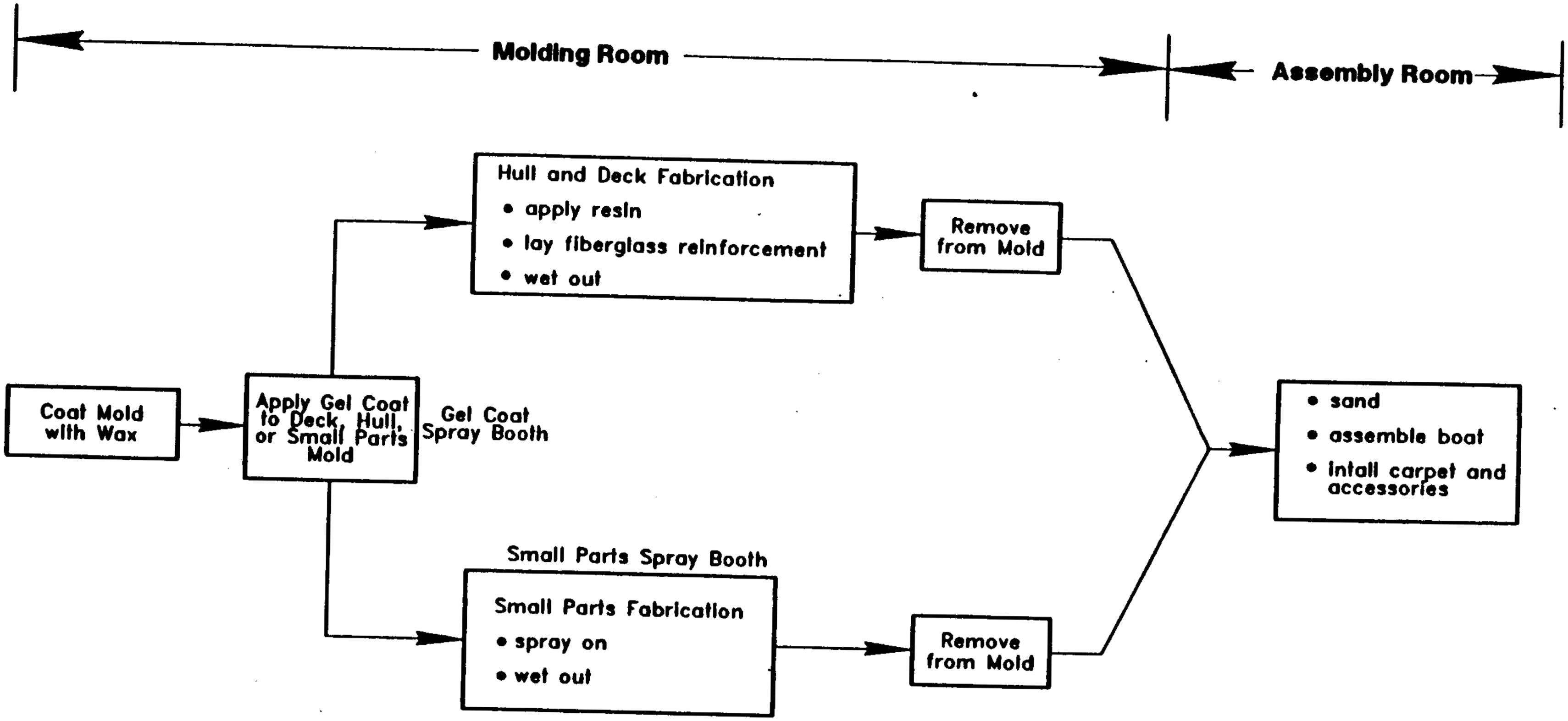

Figure 2. Fiberglass Boat Production Process

ingredients as they exit the gun. An initial clear layer of gel coat containing a UV inhibitor protects colors from wear and potential degradation from exposure to ultraviolet light. After the gel coat application, the mold is typically left to cure overnight. The first laminate of resin and fiberglass is applied using one of several lamination methods. The laminate can be applied by hand brushing or by spray-up operations. For a quality finish, the first layer of resin is applied and allowed to cure. Additional layers of laminate are then applied in succession to the desired thickness.

Structural reinforcements, such as wood, plastic, and metal can be added for extra strength. Plywood bonded with fiberglass may be added to the transom of the boat to concentrate strength in this highly stressed area.[13] Some manufacturers tie this into the stringer system constructed of kiln dried boards extending the length of the hull. Sometimes as many as six stringers are used to preserve the shape of the boat over time.[14] The entire system is then encapsulated with resin and fiberglass for additional strength. To comply with Coast Guard regulations governing certain flotation specifications, hollow spaces between the stringers and along the sides of the hull are filled with closed-cell urethane foam.

Figure 3 shows a representative process layout. As previously mentioned, gel coat application is usually performed in a ventilated spraybooth. However, for small facilities it is sometimes performed in the open molding area. The next portion of the production process takes place in the molding room. In some facilities, this room is completely open; in others, it may have a series of enclosures. The molding room is also ventilated to reduce styrene vapor exposure. This ventilation may be as simple as opening the doors and using roof exhaust fans, or could consist of push-pull ventilation systems with floor sweeps and other intakes designed to capture the heavy styrene vapors as efficiently as possible.[15-17]

Regardless of the specific design, one common characteristic is that the ventilation systems are typically designed to move large amounts of air to keep styrene levels in the work place below a 100 ppmv permissible exposure

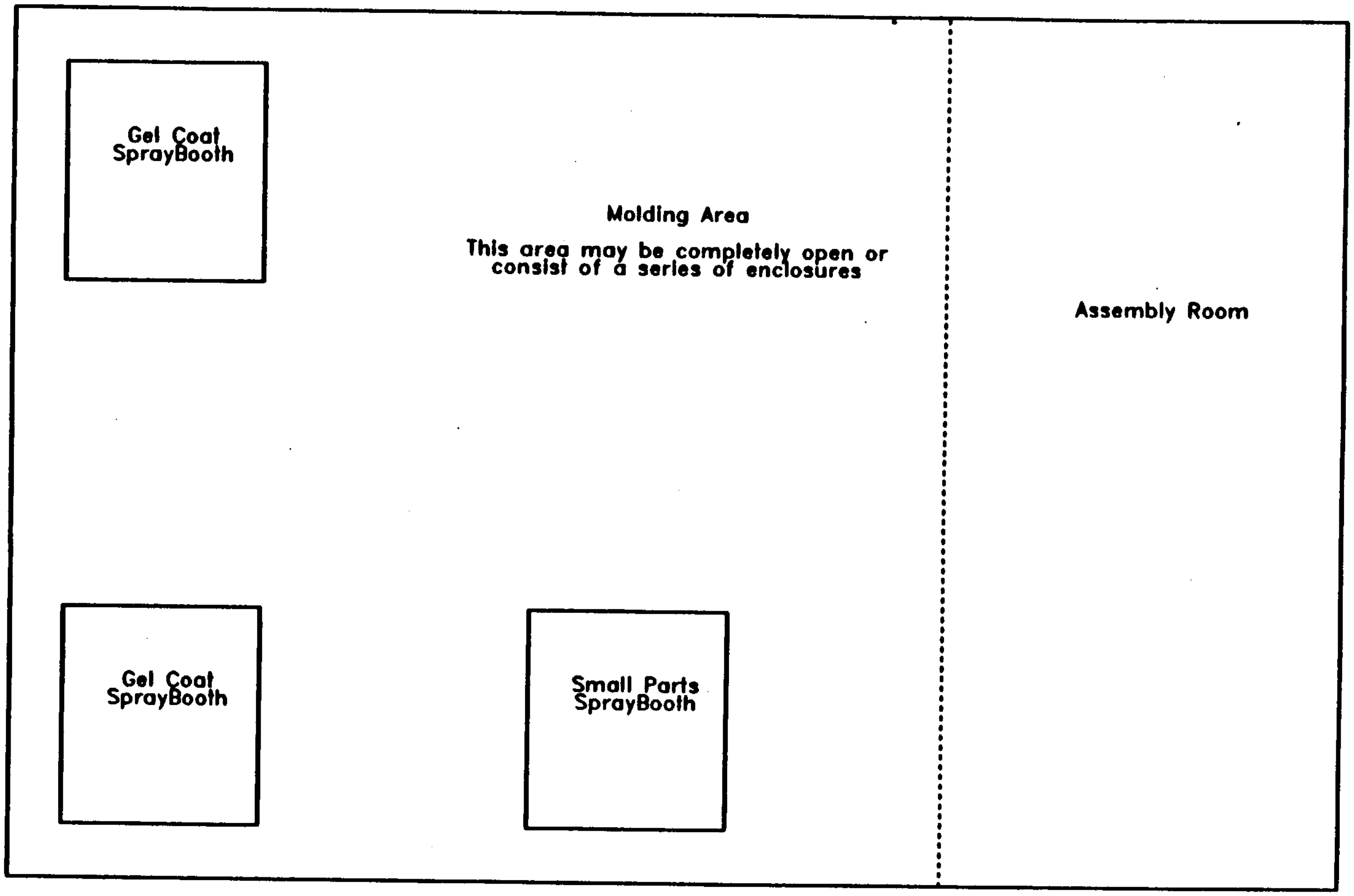

Figure 3. Representative Plant Layout

limit (PEL) as required by Occupational Safety and Health Administration (OSHA) regulations.[18] Small parts may also be produced in the molding area, usually in a spray booth.

After the parts are removed from the mold they are taken to the assembly room where they are sanded and assembled. In addition, carpet and accessories are installed to produce the finished product.

After the lamination process is complete, the parts are taken to the assembly room. This room may be separated from the molding area. Separating this area serves two purposes. First, it avoids exposing workers in the assembly area to styrene vapors generated during lamination. Second, it reduces the amount of air volume the lamination area ventilation system is required to move. This can be especially important in cold climates where the makeup air must be heated in order to maintain the temperature in the molding area within the range necessary for proper resin curing.

LAMINATES AND LAMINATION METHODS

A laminate consists of layers of fiberglass reinforcing material bonded together with resin. It is called fiberglass reinforced plastic (FRP), or simply fiberglass.

Although epoxy, phenolic, and melamine resins are available, polyester resins are used almost exclusively in fiberglass boat manufacturing because of their cost advantage and versatility.[19] Table 8 presents the typical components of polyester resins. Most polyester resins used in the boat industry contain styrene monomer as the linking agent. The typical styrene content ranges from 40 to 50 percent for resins and 35 to 42 percent for gel coat.[20]

TABLE 8. TYPICAL COMPONENTS OF RESINS[a]

To Form the Unsaturated Polyester

Unsaturated Acids	Saturated Acids	Polyfunctional Alcohols
Maleic anhydride	Phthalic anhydride	Propylene glycol
Fumaric acid	Isophthalic acid	Ethylene glycol
	Adipic acid	Diethylene glycol
	Terephthalic acid	Dipropylene glycol
		Neopentyl glycol
		Pentaerythritol

Monomers
Styrene
Methyl methacrylate
Vinyl toluene
Vinyl acetate
Diallyl phthalate
Acrylamide
2-ethyl hexylacrylate

---

[a] Reference 21.

In order to be used in the fabrication of products, the liquid resin must be mixed with an initiator to promote polymerization. Initiator concentrations generally range from 1 to 2 percent by original weight of resin. Within certain limits, the higher the catalyst concentration, the faster the cross-linking reaction proceeds.[22] Common initiators are organic peroxides, typically methyl ethyl ketone peroxide or benzoyl peroxide. Table 9 presents a variety of initiators commercially available. Resins may contain inhibitors to avoid self curing during resin storage, and promoters to allow polymerization to occur at lower temperatures.

Table 10 shows the different types of fiberglass reinforcing material used in boat manufacturing. The part being formed and the type of molding method determines the type of reinforcement used. All the reinforcements shown may be used in the contact molding method except preforms. The other molding methods shown are discussed in the next section.

There are three methods used to produce laminates in open contact molding: machine lay-up, hand lay-up, and spray lay-up. Machine lay-up involves the simultaneous mechanical application of fiberglass reinforcement material and resin and is generally reserved for large hull boats, such as sailboats. For such large surfaces, machine lay-up provides more even application of the layers than hand or spray lay-up. The laminate may require hand rolling to remove air pockets or other imperfections.

In the hand lay-up method, a thin coat of resin is brushed or sprayed on the tacky surface of the gel coat. Fiberglass reinforcement (usually mat or woven roving) is placed into the mold, over the wet resin. Additional resin is usually applied over the fiberglass to complete the "wet out" of laminate. The laminate is then rolled by hand to remove air pockets and other imperfections. Generally, the ratio of resin to glass is 60 to 40 by weight.[23]

After the first layer of resin gels, alternate layers of resin and reinforcement materials are added. For each successive layer, the resin is

TABLE 9. EXAMPLES OF INITIATORS USED WITH POLYESTER RESIN[a]

Chemical Name	Form
Benzoyl Peroxide	Wet Granules, Paste, Suspension
Methyl Ethyl Ketone Peroxide	Liquid
2,5-Dimethyl-2,5-bis (2-Ethyl-hexanoyl-peroxy) Hexane	Liquid
t-Amy Peroxy 2-Ethyl Hexanoate	Solution
t-Butyl Peroxy 2-Ethyl Hexanoate	Liquid/Solution
t-Butyl Peroxy Maleic Acid	Paste
1,1-bis(t-Butyl Peroxy) Cyclohexane	Powder
Cyclic Peroxyketal	Liquid
Di Peroxydicarbonate	Wet Granules, Powder
Lauroyl Peroxide	Flakes, Wet Granules, Paste, Emulsion, Powder

[a] Reference 24.

Type[b]	
Rovings	
Unidirectional	Great wrap to ea direc
Woven	
	Rovin weave, the w
Chopped Fibers	
Mat	Random togeth or mec togeth
Preforms	Random deposi screen with r
Continuous Strands	Contin choppe using Filler for mo
Cloth	
Weave	Plain slight strand directi
Unidirectional	Crowfoo greater warp.
Combinations	
Cloth and Mat	Fibergl mechani cloth.
Rovings and Mat	Fibergl woven r

[a] Reference 25.
[b] All reinforcements to have

SECTION 5

PROCESS EMISSIONS

This section discusses the sources of VOC emissions from the fi boat production process. Estimates of emission rates are provided i plants and on a national basis.

EMISSION SOURCES

There are four areas in the fiberglass boat production process may be emitted to the atmosphere. These are resin storage, the proc area, the assembly area, and waste disposal.

Resin Storage

Most facilities purchase resin in bulk and store the resin outc temperature controlled tank. The resin is often transferred to 55 g drums for use in spray systems.[33] If purchased in bulk, some volati of styrene occurs during storage and transfer. No data are availabl quantify these emissions; however, emissions can be estimated using for storage of organic liquids presented in EPA's AP-42.[34] Typicall emissions from this source are relatively small in comparison to lam gel coating, and clean-up emissions.

Lamination Area

There are two sources of emissions in the lamination area. The styrene lost during gel coat and resin application and from resin su during curing. No appreciable emissions of other components of the applied by a resin gun or brushed on by hand and each layer is wetted out to assure complete contact between the resin and reinforcement. Each layer is rolled out to remove air bubbles which could ultimately reduce product strength. The lamination procedure is repeated until the desired thickness is achieved. Ordinarily, stress areas get more layers of laminate.

Catalyst injection resin guns are the most common type of resin guns used in hand lay-up. These mix accelerated resin (resin containing a promoter) and a catalyst (to initiate curing) in the proper proportion inside the spray gun head and then spray the mixture through a single spray nozzle.[26] Alternatively, catalyst can be injected at full strength directly into the resin.

Spray lay-up is the most common method of small parts production and is an alternative to hand lay-up for hull and deck fabrication. The spray method employs a chopper gun which is capable of simultaneously depositing chopped strand fiberglass and catalyzed resin on the mold. Rollers are used, as in hand lay-up, to remove entrapped air.

The laminates in spray lay-up generally have a lower glass to resin ratio than laminates produced in hand lay-up.[27] Because the strength properties are directly proportional to the glass to resin ratio, spray lay-up processes sometimes yield a product with a lower strength for the same amount of glass. This is generally compensated by using more glass and/or additional reinforcements. Hand lay-up is more time consuming; so a common practice is to combine the two methods, using spray lay-up more for those parts of the boat that do not need much strength and for small parts.

ALTERNATIVE MOLDING METHODS

There are a number of alternative closed molding methods which can be used in manufacturing fiberglass products. Two of these which have been experimented within the fiberglass boat manufacturing industry are resin transfer molding and bag molding. Since there are no exposed resin surfaces

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Bag Molding

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Lamination Area

There are two sources of emissions in the lamination area. The
styrene lost during gel coat and resin application and from resin s
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and/or spray techniques. Vacuum bag molding applies pressure against the lay-up by drawing a vacuum under a cellophane, vinyl or nylon bag which covers the laminate. Pressure bag molding forces the bag against the laminate using compressed air or steam. When the bagged assembly is placed in an autoclave and heated under pressure, the product is given a higher density and allows use of a higher fiberglass to resin ratio.[32]

CLEANUP

Cleanup of hands, tools, and spray guns is a very important part of the production of fiberglass boats. Tools such as brushes, rollers, and squeegies are typically cleaned with a solvent after applying resin. Also, spray guns must be flushed with a solvent after each use and thoroughly cleaned daily. This cleaning prevents resin from curing on the tools and guns and making them unusable. In addition, periodic hand cleaning is also necessary for employee comfort. While employees are encouraged to wear gloves when handling resin, they do not always wear them for the entire shift.

The cleaning solvent most commonly used is acetone. Although, alternative ketones, which are less volatile, such as methyl ethyl ketone are occasionally used. The following discussion presents typical acetone usage practices; however, these practices would be similar for other cleaning solvents. Acetone is usually available for each employee in containers at their work station. Also, internal mix resin guns have a clean acetone feed line to flush the internal parts after each use. Acetone for hand cleaning must be relatively clean to avoid hand irritation, therefore, a method is generally adopted in which clean acetone is first used for hand cleaning. When the acetone becomes too contaminated for hand cleaning, it is used for tool cleaning until it is no longer effective for cleaning tools. Then the dirty acetone is transferred to a container for soaking the resin gun between applications. Finally, when the acetone becomes too contaminated for any further use, it is transferred to a solvent recovery or disposal area. Each employee usually has his own set of hand and tool cleaning containers in the molding room and spray gun containers are available for each spray gun. The containers used may be open top or covered or self closing lids.

SECTION 5

PROCESS EMISSIONS

This section discusses the sources of VOC emissions from the fiberglass boat production process. Estimates of emission rates are provided for typical plants and on a national basis.

EMISSION SOURCES

There are four areas in the fiberglass boat production process where VOC may be emitted to the atmosphere. These are resin storage, the production area, the assembly area, and waste disposal.

Resin Storage

Most facilities purchase resin in bulk and store the resin outdoors in a temperature controlled tank. The resin is often transferred to 55 gallon drums for use in spray systems.[33] If purchased in bulk, some volatilization of styrene occurs during storage and transfer. No data are available to quantify these emissions; however, emissions can be estimated using equations for storage of organic liquids presented in EPA's AP-42.[34] Typically, emissions from this source are relatively small in comparison to lamination, gel coating, and clean-up emissions.

Lamination Area

There are two sources of emissions in the lamination area. The first is styrene lost during gel coat and resin application and from resin surfaces during curing. No appreciable emissions of other components of the resin occur due to their low concentration and/or low volatility. The second source of emissions is solvents (usually acetone) used for cleanup of hands, tools, molds, and spraying equipment.

Styrene Emissions--

Styrene emissions occur during the lamination of the deck, hull, and small parts due to evaporation from the resin or gel coat overspray and vaporization from the applied resin or gel coat before polymerization occurs. Both of these sources of styrene emissions are discussed below.

As previously mentioned, gel coat is always applied by spraying, whereas the resin can be applied by either spraying or brushing. When spraying the resin or gel coat, approximately 10 percent of the styrene is lost in overspray. If the resin is brushed on, only one percent of the styrene is lost during application. The overspray is made up of small particles; therefore, there is more surface area for styrene evaporation. Because of this, it would be expected that total styrene emissions from spraying would be greater than those from brush application. This is true, although, not all of the styrene in overspray is lost because overspray also polymerizes. An additional eight percent is lost during curing.[35]

Styrene emissions also occur during the curing of the resin or gel coat. It is estimated that about eight percent of the styrene monomer in the applied resin or gel coat evaporates before polymerization is complete.[36]

Table 11 presents emission factors for uncontrolled polyester resin product fabrication. The ranges represent the sensitivity of emission to process parameters. Table 11 also shows that the overall emission factor for spray lay-up is higher than that for hand lay-up. This is due to the volatilization of styrene from overspray. Table 12 presents a list of the parameters which affect emissions. Increases in any of these factors will increase emissions.

TABLE 11. EMISSION FACTORS FOR UNCONTROLLED POLYESTER RESIN PRODUCT FABRICATION PROCESSES[a]

Processes	Emission Factor, lb styrene emitter per[b] 100 lb of styrene used: Resin	Gel Coat
Hand lay-up	5 - 10	26 - 35
Spray lay-up	9 - 13	26 - 35
Closed Molding	1 - 3	N/A

[a] The ranges represent the variability of processes and sensitivity of emissions to process parameters.
[b] AP-42 factors.

TABLE 12. FACTORS AFFECTING STYRENE EMISSIONS FROM LAMINATION[a]

Factors	Affect on Emissions
Resin Temperatures	Emissions increase as temperature rises
Air Temperatures	Emissions increase as temperature rises
Spray Gun Pressure/Equipment Atomization	Greater pressure increases the atomization which increases the overspray
Air Velocity in Lamination Area	Greater air flow may increase evaporation resulting in increased emissions and decreased concentration
Mold Surface Area	Greater surface area allows more vaporization in terms of total mass
Resin/Gel Coat Styrene Content	Increased emissions from increased styrene monomer content

[a] Reference 37.

Acetone Emissions--

Cleaning solvent emissions can account for over 36 percent of the total plant VOC emissions.[38] Acetone is the primary cleaning solvent used in the industry. As discussed earlier, tool and spray gun cleaning is usually required after applying each batch of resin. Also, employees must clean their hands periodically. When hands, tools, and spray guns are removed from the acetone, a good deal of liquid is carried out. This liquid readily vaporizes due to the high vapor pressure of acetone and the large surface area per volume of acetone. Additionally, spray guns are normally flushed with acetone after each resin application. When spray guns are flushed, some of the atomized acetone vaporizes. In addition to emissions that occur during cleaning operations, acetone also evaporates from any uncovered acetone containers in the molding room.

The major factors affecting emissions are the number of lamination employees, use of covers on acetone containers, use of hand protection, employee work habits, and resin gel time (i.e., application/cleaning cycle). The number of lamination employees directly affects total acetone emissions since each employee must clean his hands, tools, and spray gun (if used). Also, common practice is for each employee to have his own set of acetone containers which increases the surface area available for acetone evaporation. Containers with self-closing lids can be used to reduce evaporation between cleanups.

The use of hand protection reduces the number of times the employees must clean their hands. The two types of hand protection available are gloves and barrier creams. Usually employees must clean their hands after every resin application (every 20 to 30 minutes). The use of gloves can reduce the number of cleanups to as low as four times daily.[39]

Employee work habits can reduce emissions by reducing the amount of resin which must be removed from hands and arms. Some employees only get a minimal amount of resin on their hands and body while other employees may get considerably more on themselves. Employee work habits are mainly influenced by initial training and supervision.[40] Another factor which can affect the amount of resin which employees get on their hands and arms is the complexity of the mold. The more complex the mold the more difficult it is for employees to keep clean.

The gel time of the resin affects emissions because it determines the number of times that hands, tools, and spray guns must be cleaned in a given period of time. Shorter gel times mean more frequent resin applications and cleanings. Resin gel times can vary from 10 to 30 minutes. However, most resin gel times are about 15 minutes.[41] If hand protection is used, resin gel time should not affect the frequency of hand cleanup as much as when no hand protection is used.

Other factors which affect acetone emissions are the vapor space above the liquid level of acetone in the containers, air velocity across the containers, and room temperature. Increasing any of these factors will increase acetone evaporation. These factors are generally determined by the amount of acetone issued per employee, room air ventilation required for worker safety, and temperature required for resin curing. The amount of acetone issued can be reduced if gloves are used to reduce hand cleanup and covered containers are used to reduce acetone evaporation. Issuing only a specified amount of acetone to each lamination employee per day for cleanup reinforces good work habits and contributes to efficient acetone use. Reducing the room air ventilation is not feasible to reduce evaporation because this would expose employees to higher concentrations of styrene vapors. The temperature required for proper resin curing is determined by the resin manufacturer and cannot be easily changed.

The resin application method (spray gun versus brush application) is not one of the controlling factors affecting acetone emissions for the following reasons:

- All resin application methods require use of hand tools, such as rollers and squeegies, and hand contact with the resin.

- Brushes are generally used to smooth out resin applied with a resin gun. Brushes used for resin application rather than for simple smoothing may require more thorough cleaning, however, the amount of acetone needed for thorough brush cleaning and resin gun cleaning is not appreciably different.

Other Pollutants--

There are other pollutants which may be found in the lamination area. These include components of the polyurethane foams used for buoyancy and chemicals used to clean the molds after use. However, the contribution of these pollutants is very small compared to styrene and acetone.

Assembly Area

The major source of emissions in the assembly area is evaporation of solvent from glues used in carpet application. The specific amount of emissions are very site-specific but are usually small compared to styrene emissions. Glues typically contain 1,1,1-trichloroethane (TCA) or a mixture of TCA and Stoddard solvent, a petroleum distillate used in dry cleaning. Though TCA is not considered a VOC, it is considered a toxic air pollutant. Emissions may also include solvents from paints, but these emissions are not considered to be significant since paint is only used for touch up at the end of the manufacturing process.

Waste Disposal

The major source of emissions from waste disposal is evaporation of used acetone from cleanup. Approximately 40 percent of the acetone used in cleanup is recovered as waste.[42] Previous practice was to allow the acetone in the waste to evaporate on-site and dispose of the solids. However, many facilities now reclaim the acetone on-site using batch stills, or ship the waste to a recycler for acetone reclamation.

VOC EMISSION RATES FROM BOAT MANUFACTURING

This section presents VOC emission estimates on a plant and national level. Total VOC emissions at any particular boat manufacturing facility will vary significantly based on the facility size, number, and type of boats produced. However, the emission estimates presented here can provide some guidelines on emissions as a function of plant sales and number of employees.

Model Plants

Tables 13 and 14 present data for six model plants. These models are based on economic models developed as part of a study performed for the Society of the Plastics Industry (SPI).[43] Table 13 presents data for three sizes of plants producing small boats (<30 feet). Table 14 presents data for plants producing large boats (>30 feet).

The estimates for annual sales, number of employees, and plant exhaust flow rates were taken directly from the economic models. The resin use was estimated based on total 1987 industry use of polyester resin provided by SPI, the number of each model plant, and resin cost per plant from the economic study. Gel coat use is assumed to be one seventh of resin use.[44] Emissions of styrene are calculated based on the emission factors shown in Table 11 assuming a 50/50 split of resin use between hand lay-up versus spray lay-up. Acetone emissions are assumed to be 36 percent of total plant VOC emissions.

Also shown are calculated average VOC concentrations in the plant exhausts. These average concentrations were calculated based on 2,000 hours per year of plant operation and annual VOC emissions. The concentrations shown are very low compared to other VOC sources currently being controlled or considered for control. This is to be expected due to the requirement to maintain low styrene vapor concentrations in the work place.

The plant exhaust flow rates shown for the model plants were developed based on a potential regulatory requirement to reduce styrene exposure to

TABLE 13. MODEL PLANTS - SMALL BOATS (<30 FEET)

Plant Size	Small[h]	Medium[h]	Large[h]
Annual Sales, $/yr[a]	385,000	8,500,000	23,750,000
Total Number of Employees[a]	7	82	164
Raw Materials use, lb/yr			
Resin[b]	45,800	902,300	1,790,400
Gel Coat[c]	6,540	128,900	255,800
Acetone[d]	2,360	46,530	92,350
Emissions, lb/yr			
Styrene[e]	2,520	49,650	98,520
Acetone[f]	1,420	27,920	55,410
Total VOC[g]	3,940	77,570	153,930
Total Plant[a] Exhaust Flow, acfm	69,750	124,650	303,300
Average Exhaust VOC concentration, ppm	2	24	20

[a] Data taken directly from Reference 45.

[b] Calculated based on estimated national 1987 resin use in the marine manufacturing industry from Reference 46, and the total number of model plants and resin cost per plant from Reference 47.

[c] Assumes a resin to gel coat ratio of 7/1.

[d] Calculated based on the assumption that 60 percent of the acetone used is emitted.

[e] Based on the emission factors in Table 10, typical resin and gel coat contents from Section 3, and assuming a 50/50 ratio of hand lay-up to spray lay-up.

[f] Assumes acetone emissions are 36 percent of total VOC emissions.

[g] Does not include emissions from resin storage or glues. These emissions are assumed to be negligible compared to other sources.

[h] For those more familiar with metric units refer to metric conversion table page ix in front of report.

the resin with a less volatile monomer, such as p-methyl styrene; an a resin containing a vapor suppressant. High transfer efficiency sp are applicable to both resin and gel coat application. However, the substitute resins will not affect emissions attributable to the gel comparison of the three different types of reins which can be used i conventional resins to reduce styrene emissions is presented in Tabl Each of these methods is described in further detail below.

High Transfer Efficiency Spray Guns--

As discussed in Sections 3 and 4, airless spray guns can be use both gel coat and resin. Airless spray guns mix the resin or gel co catalyst at the spray gun tip. Gel coat is almost always applied wi gun, while resin can be applied to the fiberglass reinforcing materi either spray guns or brushes.

Air Assisted Containment (AAC) airless spray guns use an air st contain the mixed resin and catalyst. This air stream reduces overs which makes application more efficient, thus reducing styrene emiss one test, it was reported that the average transfer efficiency for a spray gun spraying gel coat was 90 percent, compared to an average t efficiency of 81 percent for conventional airless spray guns tested same conditions.[53] In tests spraying resin, the reported transfer efficiencies were 96 percent for the AAC gun versus 94 percent for t spray gun.[54] Comparing these transfer efficiencies would imply that guns would reduce styrene emissions due to overspray by 42 percent f coat application and 33 percent for spray up resin application. For plants presented in Section 5, this technique provides an overall re nine percent in total plant styrene emissions. It should be noted t transfer efficiency for an airless spray gun is highly dependent upo proficiency and may vary from the values reported in this study.

Detailed costs for an air assisted airless spray system were not developed as part of this study. One manufacturer stated that reduci

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Pla

Annual Sale

Total Numbe

Raw Materia

Resin[b]
Gel Coat[c]
Acetone[d]

Emissions,

Styrene[e]
Acetone[f]
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50 ppmv. In the most recent rulemaking, OSHA has exempted the fiberglass boat manufacturing industry from using engineering and work practice controls (e.g., ventilation systems, process enclosure, or use of suppressed styrene resins) to meet the new 50 ppmv standard due to the difficulty and cost involved.[51] However, the plant exhaust flow rates and concentrations shown are still believed to be typical for this industry.

No emissions are shown for disposal of spent acetone. In most cases waste acetone is either recycled using a batch still or sent off-site for reclamation, minimizing the amount emitted from disposal.

National Emissions

National VOC emissions from boat manufacturing are shown in Table 15. These estimates were derived from the number of plants in each size category and emissions per plant. Small plants make up 47 percent of the total population but only 4 percent of the total emissions. Medium size plants make up 49 percent of the facilities and 78 percent of the total emissions.

The geographic distribution of boat manufacturing facilities and, therefore, emissions were previously shown in Figure 1 for the States having more than ten facilities. A high concentration of boat manufacturing facilities occurs in Florida, near Miami and Tampa Bay, in Los Angeles, California, and in central Tennessee.

TABLE 15

Small Boats

Small Plant

Medium Plar

Large Plant

Large Boats

Small Plant

Medium Plar

Large Plant

TOTAL

[a]Reference 52

[b]See metric c

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the resin with a less volatile monomer, such as p-methyl styrene; a a resin containing a vapor suppressant. High transfer efficiency s are applicable to both resin and gel coat application. However, th substitute resins will not affect emissions attributable to the gel comparison of the three different types of reins which can be used : conventional resins to reduce styrene emissions is presented in Tab Each of these methods is described in further detail below.

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As discussed in Sections 3 and 4, airless spray guns can be use both gel coat and resin. Airless spray guns mix the resin or gel cc catalyst at the spray gun tip. Gel coat is almost always applied wi gun, while resin can be applied to the fiberglass reinforcing materi either spray guns or brushes.

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Detailed costs for an air assisted airless spray system were not developed as part of this study. One manufacturer stated that reduci

SECTION 6

EMISSION CONTROL TECHNIQUES

This chapter discusses emission control techniques which have the potential to reduce VOC emissions from fiberglass boat manufacturing. This includes both demonstrated control techniques and techniques which have not been demonstrated, but which could potentially be used. These control technologies are divided into two general categories. The first are process changes designed to reduce the release of pollutants into the air. These include improved work practices and raw material substitution. The second is add-on controls. The discussion of add-on controls includes both demonstrated control technologies and concepts which have not been fully demonstrated. In the case of undemonstrated technologies, the key technical uncertainties are identified and discussed.

PROCESS CHANGES

This section discusses changes in the boat production process which can potentially be used to reduce the atmospheric releases of VOC. In addition to reducing emissions, these types of controls offer the added benefit of reducing worker exposure to acetone and styrene. The discussion is divided into two sections: process controls for styrene, and process controls for acetone.

Process Controls for Styrene Emissions

Four methods were identified for reducing styrene emissions through process changes. These are: 1) using high transfer efficiency spray guns; 2) reducing the styrene content of the resin; 3) substituting styrene monomer in the resin with a less volatile monomer, such as p-methyl styrene; and 4) using a resin containing a vapor suppressant. High transfer efficiency spray guns are applicable to both resin and gel coat application. However, the use of substitute resins will not affect emissions attributable to the gel coat. A comparison of the three different types of reins which can be used in place of conventional resins to reduce styrene emissions is presented in Table 16. Each of these methods is described in further detail below.

High Transfer Efficiency Spray Guns--

As discussed in Sections 3 and 4, airless spray guns can be used to apply both gel coat and resin. Airless spray guns mix the resin or gel coat and catalyst at the spray gun tip. Gel coat is almost always applied with a spray gun,. while resin can be applied to the fiberglass reinforcing materials with either spray guns or brushes.

Air Assisted Containment (AAC) airless spray guns use an air stream to contain the mixed resin and catalyst. This air stream reduces overspray which makes application more efficient, thus reducing styrene emissions. In one test, it was reported that the average transfer efficiency for an AAC spray gun spraying gel coat was 90 percent, compared to an average transfer efficiency of 81 percent for conventional airless spray guns tested under the same conditions.[53] In tests spraying resin, the reported transfer efficiencies were 96 percent for the AAC gun versus 94 percent for the airless spray gun.[54] Comparing these transfer efficiencies would imply that AAC spray guns would reduce styrene emissions due to overspray by 42 percent for gel coat application and 33 percent for spray up resin application. For the model plants presented in Section 5, this technique provides an overall reduction of nine percent in total plant styrene emissions. It should be noted that the transfer efficiency for an airless spray gun is highly dependent upon operator proficiency and may vary from the values reported in this study.

Detailed costs for an air assisted airless spray system were not developed as part of this study. One manufacturer stated that reducing

TABLE 16. COMPARISON OF RESINS WHICH REDUCE STYRENE EMISSIONS

	Low Styrene Resins	Low VP Monomer	Vapor Suppressed Resins
Potential Emission Reductions	14 %	16% (Styrene emissions may be replaced with other VOC emissions.)	20 - 35 %
Working Properties	More viscous than conventional resins, difficult to apply even layers.	Similar to conventional resins.	Requires extra step in manufacturing process to prepare each surface between layers.
Strength Characteristics of Laminate	May create weaker laminate structure due to air entrapment.	Similar to conventional resins.	Poor secondary bonding between layers creates weak laminate structure.
Costs	Similar to conventional resins.	Two times the cost of conventional resin.	Resin cost is 5-10% more than conventional resin, plus increased labor costs to prepare laminate surface between layers.
Currently Demonstrated	Many plants are able to use resins down to ~38% styrene. Very few are able to use 35% styrene content resins.	Many plants currently testing resins with low VP monomer.	A few plants using this for small boats which do not require high strength characteristics.

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TABLE 17. COMPARISON OF PROPERTIES OF LAMINATES MADE WIT
LOW STYRENE RESINS VERSUS CONVENTIONAL RESINS[a]

Property	35 Percent Styrene Content Resin[b]	42 Perc Conte
Viscosity (Brookfield #2 @ 20 rpm)	750 ± 150 cps	600 ±
Barcol Hardness (934-1)	37 ± 2	4
Flexural Strength (psi)	10,000 ± 1,000	13,50
Flexural Modulus (psi)	560,000 ± 20,000	500,00
Tensile Strength (psi)	7,000 ± 1,000	8,000
Percent Elongation @ Break	1.0 ± 0.2 percent	1.2 ± 0

[a] Typical properties were extracted directly from Technical Data Shee each product provided by the supplier.

[b] Altek® 80-600 LE Series Resin manufactured by Alpha Resins Corporat

[c] Altek® 526-750 Resin manufactured by Alpha Resins Corporation.

The cost of low styrene resins is approximately the same as conventional resins.[57]

There are limitations on the use of low styrene resins for fiberglass boat manufacturing.[58] Low styrene resins are more viscous than conventional resins, particularly at lower temperatures. The high viscosity makes the low styrene resins harder to work with and application of a smooth, even layer of resin in the lamination process is dependent on the skill level of the operator. Spray-up operations, in which the resin and fiberglass layers are applied to the mold with spray and chopper guns, respectively, are particularly affected by resin viscosity. Application of uneven layers results in varying curing. If a second layer is applied before the first layer is evenly cured then air entrapment or bubbles can occur which reduces the strength of the laminate structure. Fiberglass boats typically have 4-6 layers of laminate consisting of layers of chopped glass and roving depending on the boat size and performance specifications. Producing boats with weaker laminate structures could result in serious product liability issues, particularly for high performance speed boats. Consequently, the boat manufacturing industry has been cautious to substitute low styrene resins in their production. Table 17 includes a comparison of typical properties of resins and laminates made with 35 percent styrene monomer resins and 42 percent styrene monomer resins.

A number of boat plants have reduced the styrene content in their resins to 38-40 percent styrene with satisfactory results.[59] Some boat plants are using two different content resins: low styrene (35-36 percent) resins for manufacturing boat decks and small parts such as seats and bait boxes, and conventional resins (40-45 percent styrene) for boat hulls which require superior strength characteristics.

The date for boat plants in the SCAQM district to comply with Rule 1162 was July 1, 1988. Very few boat manufacturers have been able to successfully comply with this rule by reducing the styrene content in their resins to 35 percent. The effect of this rule has been for fiberglass boat

TABLE 17. COMPARISON OF PROPERTIES OF LAMINATES MADE WITH LOW STYRENE RESINS VERSUS CONVENTIONAL RESINS[a]

Property	35 Percent Styrene Content Resin[b]	42 Percent Styrene Content Resin[c]
Viscosity (Brookfield #2 @ 20 rpm)	750 ± 150 cps	600 ± 100 cps
Barcol Hardness (934-1)	37 ± 2	40 ± 5
Flexural Strength (psi)	10,000 ± 1,000	13,500 ± 1,000
Flexural Modulus (psi)	560,000 ± 20,000	500,000 ± 20,000
Tensile Strength (psi)	7,000 ± 1,000	8,000 ± 1,000
Percent Elongation @ Break	1.0 ± 0.2 percent	1.2 ± 0.3 percent

[a] Typical properties were extracted directly from Technical Data Sheets for each product provided by the supplier.

[b] Altek® 80-600 LE Series Resin manufactured by Alpha Resins Corporation.

[c] Altek® 526-750 Resin manufactured by Alpha Resins Corporation.

manufacturers to experiment with a combination of material changes, improved work practices, and additional controls. A number of boat plants have shut down in the area and relocated to other areas outside the SCAQM district.

Low Vapor Pressure Monomer Resins--

Styrene monomer can sometimes be replaced by a monomer that has a lower vapor pressure, such as p-methyl styrene. The main advantage of p-methyl styrene is that its vapor pressure is two to three times lower than that of styrene, depending on temperature, resulting in lower emissions. The p-methyl styrene monomer also requires less curing time. Styrene monomer emissions during curing can be reduced by 50 percent, but some of these styrene emissions are replaced by non-styrene VOC emissions.

It should be noted that emissions from overspray are not necessarily reduced by using p-methyl styrene resins. The emission reductions are a result of less evaporation of the volatile constituents in the resin due to shorter curing times and lower vapor pressures of the monomer. For conventional resins, AP-42 emission factors are based on 10 percent loss from overspray and 8 percent loss from evaporation during cureout. Emission reductions achievable from using low vapor pressure monomers in place of styrene monomer are dependent on the substitute monomer used and the amount of styrene replaced. For the model plants presented in Section 5, total plant styrene emissions could be reduced by 16 percent, and total plant VOC emissions by approximately 10 percent.

A major disadvantage to the use of p-methyl styrene-based resins is that p-methyl styrene monomer costs nearly twice as much as styrene monomer. Currently, there are very few chemical companies in the United States that manufacture p-methyl styrene, therefore limiting its availability. However, this would be expected to change if requirements imposed by regulatory actions resulted in a market for p-methyl styrene.

Fiberglass boat manufacturers have experimented with resins which contain other low vapor pressure monomers such as vinyl toluene and dicyclopentadiene (DCPD). Typically these compounds are substituted for 3 to 5 percent of the styrene in the resin. The styrene content in the resin may be reduced to 30 to 35 percent, however the total monomer content may still be over 40 percent. Vinyl toluene and DCPD have similar physical properties to p-methyl styrene, but may be more economically attractive and more readily available.

Vapor Suppressed Resins--

Vapor suppressed resins contain additives which reduce VOC emissions during resin curing. The most common vapor suppression additives are paraffins, which migrate to the surface of the resin layer and reduce the volatilization of free styrene during resin curing. Emissions reductions ranging from 30 to 50 percent can be achieved, relative to emissions from conventional resins. For the model plants shown in Section 5, this would reduce total plant styrene emissions by 20 to 35 percent.

In certain applications vapor suppressed resins can be substituted directly for conventional resins. They have been used successfully by spa manufacturers and reportedly used by some boat manufacturers who produce their entire product from one continuous resin application.[60,61,62] In general, however, most boat manufacturers have not been able to achieve satisfactory strength performance with vapor suppressed resins as a result of poor secondary (i.e., interlaminate) bonding.

When vapor suppressed resins are used, the air/resin interface is separated by a wax film which limits the diffusion of oxygen to the resin surface. Oxygen normally plays an important role in the curing process by forming weak surface bonds with the resin, thereby occupying potentially reactive surface sites as the bulk of the resin polymerizes. These weak resin surface/oxygen bonds are displaced when the next laminate layer is applied, which allows resin/resin bonds to form between layers. When paraffin-based suppressants are used, the lack of oxygen at the resin surface caused by the wax film allows the active surface sites to react with each other completely. This results in a fully cured surface not amenable to cross-linking with subsequent laminate layers.

Surface sanding and/or solvent wiping can be used as a means of alleviating the secondary bonding problems. The surface of each laminate layer must be prepared by sanding off the wax layer to create an improved surface for mechanical bonding. A typical mid-size fiberglass boat contains four to six laminate layers. The labor intensive step of sanding the wax layer between application of each laminate layer is estimated to add approximately four to eight hours of additional labor time per boat.[63]

Vapor suppressed resins have been commonly used in Sweden since 1982.[64] They have also been used at a few boat plants in the United States. The boat plants that have been successful with using vapor suppressed resins typically are manufacturing their boats from start to finish with no cureout allowed between laminate layers. Since insufficient time is allowed between application of layers for complete reaction of the resin surface, the laminate layers can effectively bond to each other as the boat is constructed. This process is adequate for small boats which do not require high strength characteristics such as flat water canoes and row boats.

A disadvantage to this "start-to-finish" approach is that the final product strength is less than the strengths achieved when total cureout between layers is allowed. Most boat manufacturers seek to maximize product strength due to the demanding use of the product and the high costs associated with product liability concerns. The need to maximize strength is particularly important in the case of high performance boats. As a result, at most high performance boat manufacturing facilities, individual laminate layers are allowed to cure before subsequent layers are applied. This manufacturing procedure results in significantly increased boat strength and improved overall product quality compared to the start-to-finish method. Thus, the need to build boats with complete laminate curing between layers limits the use of vapor suppressed resins in the fiberglass boat manufacturing industry. No data were available for a quantitative comparison of laminate strengths.

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TABLE 18. COMPARISON OF METHODS TO REDUCE VOC EMISSIONS FROM CLEAN-UP OPERATIONS

	Acetone Usage with Improved Work Practices	Use Water Based Emulsions	Use Dibasic Ester Solvent
Potential Emission Reductions	22 %	50 - 75 %	75 %
Applicability	--	Not adequate cleaner for hardened gel-coat or internal parts of equipment.	Potential to completely replace acetone.
Ease of Conversion	Resistance by workers.	Must install heating systems throughout plant and keep cleaner heated in a hot water bath.	--
Potential For Recycle/ Reclamation	High	High	High
Waste Disposal	Spent acetone is a hazardous waste.	Non-hazardous under RCRA. Can dump to sewer except in rural areas with limited WWT.	Non-hazardous under RCRA. Can be biotreated or incinerated.
Costs	--	Overall costs should be similar to acetone.	Overall costs should be similar to acetone.

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Disposal of used water-based emulsions is usually much easier and less costly than acetone disposal. The spent emulsion cleaner is collected in a drum or small settling tank and the sludges are allowed to settle out. The U.S. Environmental Protection Agency has determined that spent Res-Away™ is considered non-hazardous under the requirements of RCRA.[73] As such, the sludges can be dried and sent to a sanitary landfill. At some plants, the liquid portion is reused as make-up for the next batch of cleaner, however some of the liquid waste must be disposed. In most areas, the liquid waste has been accepted by local wastewater treatment plants. In rural areas or areas where wastewater does not undergo secondary treatment, boat plants have not been allowed to dispose of waste emulsion cleaner to the sewer due to its high pH and corrosivity. Another alternative is to dispose of it as a hazardous waste, which is very costly. Boat plants in this situation have not been able to use emulsion cleaners in place of acetone due to the high disposal costs.

One issue that boat plants are facing is employee health and safety when using the water-based emulsions. The product is typically purchased in concentrated form and is diluted with water to make the appropriate strength cleaning solution. The concentrated product is very alkaline with a pH of 11 to 12. While diluting with water brings the pH down, it is still very harsh and employees with sensitive skin have developed rashes and allergic reactions upon skin contact. Instructions from the manufacturer state that gloves should be worn when using these cleaners, however employees in the lamination area are often resistant to wearing gloves for entire eight hour work shifts due to the discomfort. An additional concern is that boat plants using both acetone and water-based emulsions have not identified gloves that are resistant to both compounds. Therefore, employees who work with both gel coat and lamination must use different gloves when using acetone to clean-up gel coat and when using water-based emulsions to clean-up resin.

The overall cost differences between the use of acetone and water-based emulsions have not been well quantified by the industry, partially because the water-based emulsions have not been used for a long enough period to have

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A number of boat plants were identified that are experimenting with this cleanup alternative, however during this study only a few small boat plants in California were identified that are actually using it in their production area. This alternate product for resin cleanup is very new on the market and the plants contacted had only been using it for a few months. Boat plants were not able to provide quantitative data on emission reductions or cost differences at this time.

Based on preliminary tests, it is estimated that by switching completely to a dibasic ester cleaning solution, a reduction in VOC emissions from cleanup activities of 75 percent over the use of acetone can be achieved.[78] There are still some VOC emissions from the cleanup activities but they are much lower because the dibasic esters have much lower vapor pressures than acetone (0.2 mm Hg at 20°C for DBE versus 266 mm Hg for acetone).

In terms of costs, the dibasic ester cleaner is currently two to three times more expensive to purchase than acetone. However, it lasts longer because it evaporates at a slower rate. Therefore, much less material is purchased over time. The product can be recycled by passing it through a distillation column to remove impurities. The sludges that accumulate are a liquid waste that are currently not considered hazardous under RCRA definitions. This liquid waste can be incinerated, and because of its high heat content, incineration can be a cost effective solution to waste disposal. Because the DBE is non-hazardous, the disposal costs are much less than disposal of waste acetone. One boat company estimated the incremental cost of switching from acetone usage to use of a dibasic ester cleaner is $150 per ton VOC removed per year.[79]

Waste Acetone Recycle/Reclamation--

Assuming 60 percent of the acetone used in clean-up at fiberglass boat plants is emitted in the lamination area, the remaining 40 percent is waste. If the waste acetone is allowed to evaporate, plant acetone emissions would increase by 67 percent. Two methods available to reduce these emissions are to recover acetone on-site using a batch still and to ship the waste to a commercial recycling operation.[80]

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TABLE 19. EXHAUST AIR VOC CONCENTRATIONS FOR THREE FIBERGLASS REINFORCED PLASTICS INDUSTRIES[a]

VOC Source	Minimum VOC Concentration, ppmv	Maximum Concentration, ppmv
Continuous Lamination[b]	2	1,100
Tank Coating	82	405
Synthetic Marble	10	22

[a] Reference 84.

[b] Continuous lamination consists of mechanical lamination of resin and reinforcing material on an in-line conveyor.

low VOC concentrations found in this industry is the concern for worker exposure to styrene and the 100 ppmv styrene exposure limits established by OSHA. The traditional method of meeting this exposure limit has been to simply move large volumes of fresh air through the work area. As a result, effective control from both a technical and cost effective perspective has been difficult to achieve in the fiberglass boat manufacturing industry.

Although there have been attempts in the fiberglass boat manufacturing industry to reduce exhaust air flow rates while maintaining compliance with OSHA regulations, it was not possible, in this study, to quantify the success of such efforts. Intuitively, confinement of the major VOC sources (e.g., gel coat and lay-up operations) to well-designed and well ventilated booths or bays would facilitate reduction in plant exhaust flows. However, based on the limited amount of information obtained on this issue, it appears that achievable flow reductions are relatively small. The only example of successful flow reduction that can be cited from the efforts of this study is a plant in Michigan.[85] This facility was designed with isolated bays for gel coat, lay-up, and finishing operations. To minimize flow, exhausts from the gel coat bays are recirculated back into other areas when gel coat is not being sprayed.

Based on a comparison of typical exhaust concentrations (1 to 24 ppmv) and the OSHA exposure limits for styrene (100 ppmv), the potential exists for more effective capture of VOC. Effective capture of the VOC emissions could offer two benefits. First, the VOC-laden exhaust stream is more amenable to add-on control techniques. Since, the removal efficiency of most control techniques drops considerably at very low VOC concentration (<20 ppmv), a higher degree of VOC control can be achieved. Additionally, the capital and operating costs of the add-on control are greatly reduced. A secondary benefit, especially in colder climates is the savings in space heating costs, since much lower volumes of fresh air would be moved through the building. This benefit has been the driving force for the limited flow reduction applications in the boat manufacturing industry.

Another factor which should be considered is that based on a resin/gel coat ratio of 7/1, gel coat application and curing produces approximately 30 percent of the styrene emissions. However, based on the model plant ventilation systems developed as part of a submission from the Society of the Plastics Industry made in response to recent OSHA rulemaking on styrene exposure, the gel coat spray booth exhaust may account for as little as 10 percent of the total plant exhaust.[86] Therefore, highly efficient controls applied to gel coat booths could potentially reduce emissions by approximately 27 percent. This would only be the case where gel coat operations are performed in a separate enclosed spray booth separate from lamination. This is most likely to occur in medium and large size plants manufacturing small boats (<30 feet).[87]

The remainder of this section discusses add-on control technologies which could be used in the boat manufacturing industry. The devices may be divided into three general groups: incineration, adsorption systems, and absorption systems (wet scrubbers). Of the add-on control technologies evaluated in this study, incineration is the only demonstrated and readily available technology for controlling VOC emissions from fiberglass manufacturing facilities. Information on the possible adsorption and absorption technologies is provided with a discussion of the potential advantages and disadvantages.

Where available, cost data are presented for these systems. The costs presented are order-of-magnitude cost estimates only. For illustrative purposes, costs are based on control of gel coat spray booths only for a medium size plant producing small boats. For illustration purposes, the combined gel coat spray exhaust flow rate is 14,400 acfm with a total average VOC concentration of 44 ppmv. This example was selected because it would be the most cost-effective portion of the exhaust to apply add-on controls due to its higher concentration relative to the total plant exhaust.

Incineration--

Two types of incinerators are available, thermal and catalytic. Both destroy the VOC through oxidation to carbon dioxide and water. In thermal incineration, the solvent-laden air is exposed to a high temperature of approximately 1,600°F (870°C) and are contained in a direct flame combustion chamber for a period of approximately 0.75 seconds. Catalytic incinerators use a catalyst bed to oxidize the organic vapors and operate at reduced temperatures of 750° to 1,000°F (400° to 540°C). Important incineration design factors are combustion chamber residence time, gas stream flow rate, operating temperature, and gas stream fuel value.

The heat content of exhausts from boat manufacturing is negligible due to the low VOC concentrations previously discussed. Therefore, supplemental fuel is needed to raise the exhaust to the required operating temperature. Heat recovery equipment is nearly always used with incinerators applied to low VOC concentration streams to reduce the amount of supplemental fuel required. The amount of heat recovery achievable can be up to 95 percent.[88] Heat recovery is accomplished by exchanging heat between the incinerator exhaust and the incoming air and/or stream to be treated.

Ceramic heat exchange media is sometimes used to achieve very high energy recovery (95 percent).[89] Other types of incinerators use metal air/air heat exchanges. Generally, the more energy efficient incinerators have lower operating costs but higher initial capital costs.

For the higher end of the range of VOC concentration levels encountered in fiberglass boat manufacturing (i.e., 20 to 80 ppmv), incinerators would be expected to achieve 90 to 95 percent VOC destruction or greater. Based on information provided in the Control Technologies for Hazardous Air Pollutants Handbook, thermal incinerators are capable of achieving at least 95 percent VOC destruction for streams with VOC contents above 20 ppmv and catalytic incinerators are capable of achieving 90 percent VOC destruction for inlet VOC concentrations above 50 ppmv.[90]

The costs of applying incineration to fiberglass boat manufacturing are high due to the large air volumes and low pollutant concentrations typically encountered. For this reason, incinerators have not been applied in this industry. As an example, the total capital cost of a thermal incinerator with a 70 percent efficient heat exchanger to control a 14,400 scfm vent stream would be over $500,000. Fuel costs alone would exceed $40,000/yr based on a natural gas price of $2.69 per million Btu. If the gel coat booths were controlled for a medium size plant producing small boats, the total annualized cost would be over $120,000 per year. The emission reduction would be 8 tons per year based on an estimated achievable destruction efficiency of 90 percent. This equates to a cost of approximately $15,000 per ton of VOC removal.

Gas Absorption--

As previously mentioned, gas absorption is not a proven technology for controlling VOC emissions from fiberglass boat manufacturing facilities. However, there are two systems currently under development that may be candidates for the fiberglass boat industry: the Styrex™ system and the Chemtact™ system. This section discusses the current technology on these systems along with a general discussion of the principles of gas absorption.

Gas absorption is a mass transfer operation in which one or more soluble components of a gas mixture are separated from the mixture by selective dissolution in a liquid. The absorbed components can be recovered from the liquid or solvent by stripping or desorption or other recovery techniques. A typical absorption system with stripping tower is shown in Figure 4.

Gas absorption equipment is designed to provide thorough contact between the gas and the liquid solvent. The rate of mass transfer between the two phases is primarily dependent on the surface area exposed. Additional factors that govern the absorption rate include the solubility of the gas in the particular solvent and the degree of chemical reaction. These factors; however, are generally independent of the equipment used. The types of equipment that are typically used for gas-liquid contact operations include

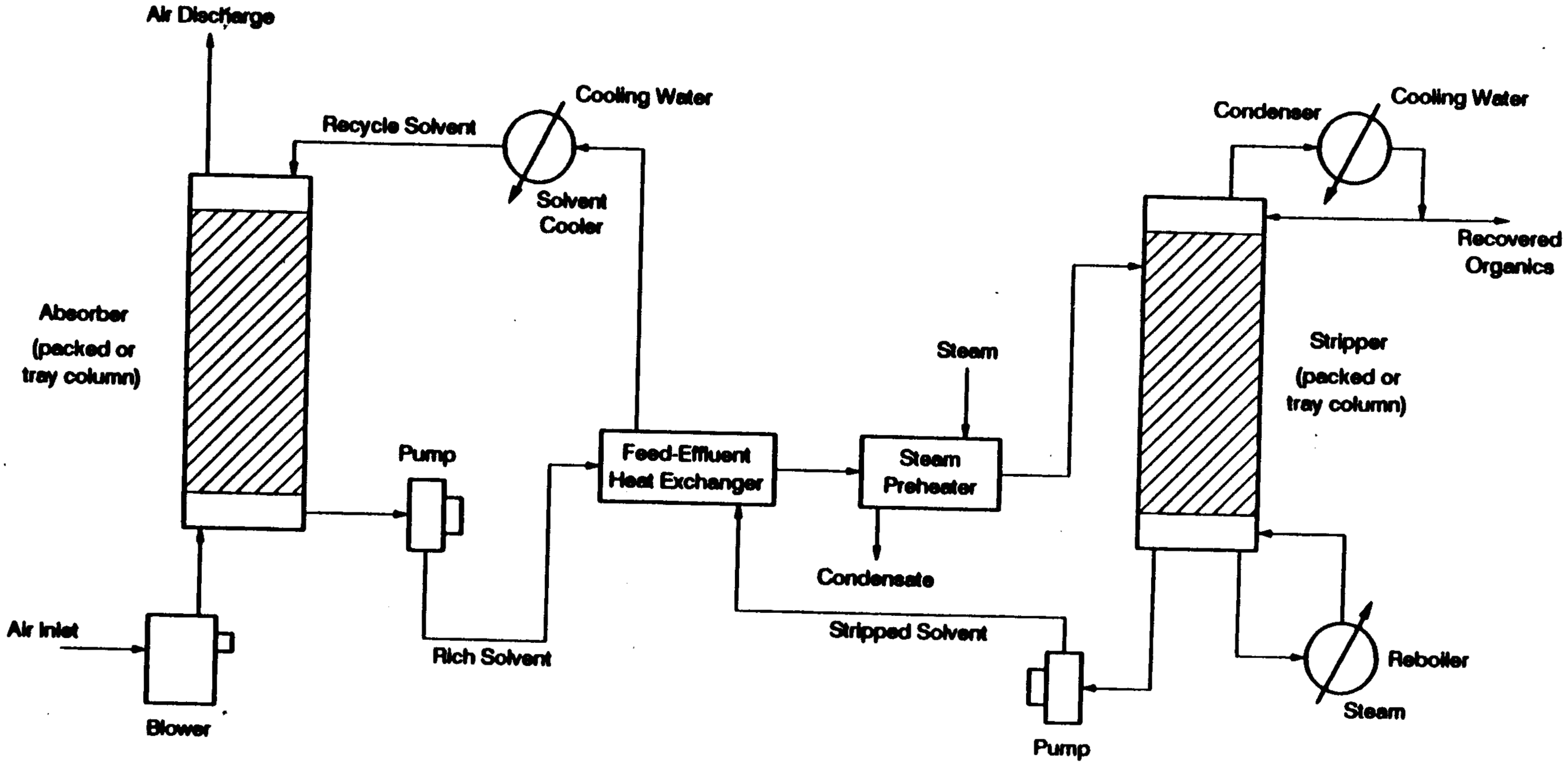


Figure 4. Absorption System with Stripping Tower and Solvent Recycle

packed towers, plate or tray towers, spray chambers, venturi scrubbers, and vessels with sparging equipment. The use of spray chambers, venturi scrubbers, and sparging is generally limited to the control of particulate matter and highly soluble gases requiring very few transfer units and are not frequently used for the control of VOC emissions in dilute concentrations.[91]

A common factor used to indicate the operating limits is the absorption factor. The absorption factor, A, is the ratio of the slope of the operating line to the equilibrium line, the two curves used in theoretical design of absorption systems. Values of A less than unity indicate that the fractional absorption of solute is definitely limited. If A is greater than 1, any degree of absorption is possible. For a given equilibrium system there will be a value of A for which the most economical absorption results. A rule of thumb is that the most economical A will be within the range of 1.25 to 2.0.[92]

As an emission control method, gas absorption is most widely used for the removal of water-soluble inorganic contaminants. Water can also be used for the removal of organic compounds with relatively high water solubilities. Other solvents, usually organic liquids with low vapor pressures, are used for organic compounds with low water solubility.[93] Some important aspects that should be considered in selecting absorption solvents are listed below:

1. The gas solubility should be relatively high as to enhance the rate of absorption and decrease the quantity of solvent required. Solvents chemically similar to the solute generally provide good solubility.

2. The solvent should have relatively low volatility so as to reduce solvent loss. This is particularly important in emission control applications as solvent losses may result in additional VOC emissions.

3. The solvent should be noncorrosive (if possible) to reduce construction costs of the equipment.

4. The solvent should be inexpensive and readily available.

5. The solvent should have relatively low viscosity for suitable mass-transfer rates and flooding characteristics.

6. Ideally the solvent should be non-toxic, nonflammable, chemically stable, and have a low freezing point.

The technical suitability of gas absorption as a VOC emission control method is generally dependent on the following factors:

1. Availability of a suitable solvent;
2. VOC removal efficiency required;
3. Recovery value or terminal disposal cost;
4. Capacity for handling vapors; and
5. VOC concentration in the inlet vapor (absorption is usually considered when the VOC concentration is above 200-300 ppmv).

For the fiberglass boat industry, use of gas absorption to control styrene and acetone emissions may be limited due to the typically low concentrations and the low water solubility of styrene. While acetone is infinitely soluble in water, styrene is only very slightly soluble, thus eliminating water as a suitable solvent. Identification of an appropriate solvent that can be regenerated or easily disposed of may be difficult.

The two absorption systems evaluated for their effectiveness in controlling styrene and acetone emissions are: the Styrex™ absorption system and the Chemtact™ scrubber. The Styrex™ system uses the proprietary liquid, Styrex™ as the absorbent, while Chemtact™ uses sodium hypochlorite. Neither system has been installed in a fiberglass boat manufacturing or related facility; however, available test data sugggest the potential for reducing styrene and/or acetone emissions. The following subsections detail the findings on the Styrex™ and Chemtact™ systems.

Styrex™--Styrex™ acts essentially like activated carbon, the differences being that rather than the microscopic physical interaction between the liquid and solid, which acts as an extensive condensation surface in activated carbon, Styrex™ exhibits unsaturated vacancies. These vacancies achieve the same effect as in activated carbon, but on a molecular level. Vapors are attracted to the unsaturation points by Van der Waals forces (weak interatomic forces) and trapped without chemical change. The entrapped gas may be removed, as with activated carbon, by heat stripping, steam stripping and distilling, or polymerization of the entrapped molecules into aggregates which are too large for the vacancies and thus form a precipitate. Polymerization may be accomplished by means of a catalyst or a photochemical reaction employing ultraviolet light.[94]

There are two units currently available that operated using the Styrex™ absorbent: the Blitz Roller™ and the ChemPro™ scrubber. The Blitz Roller™, illustrated in Figure 5, is portable in design and can be positioned inside a facility. The ChemPro scrubber is illustrated in Figure 6. The Blitz unit rolls on casters and can be moved from station to station.

Vapor-laden air is pulled in at the bottom of the nine-foot high unit and passed through two solid pack filter sections of Styrex™. Treated air is exhausted at the top of the unit. Styrex™ is pumped from a fresh supply drum and distributed over the upper filter, draining down over the lower filter to a spent chemical drum. The advantages of the Blitz Roller™ is its portability and size, enabling capture of styrene close to the source. The disadvantages are the potential disposal problems associated with the spent Styrex™, the added equipment cost if the unit needs to meet explosion-proof criteria, the potential maintenance problems resulting from resin overspray, and the need for skilled personnel to run the unit properly. The Blitz Roller™ is currently installed in one small plastics prototype facility for demonstration purposes. No performance test has been made on this unit; however, the workers have commented on the reduction in odor in the work place.[95]

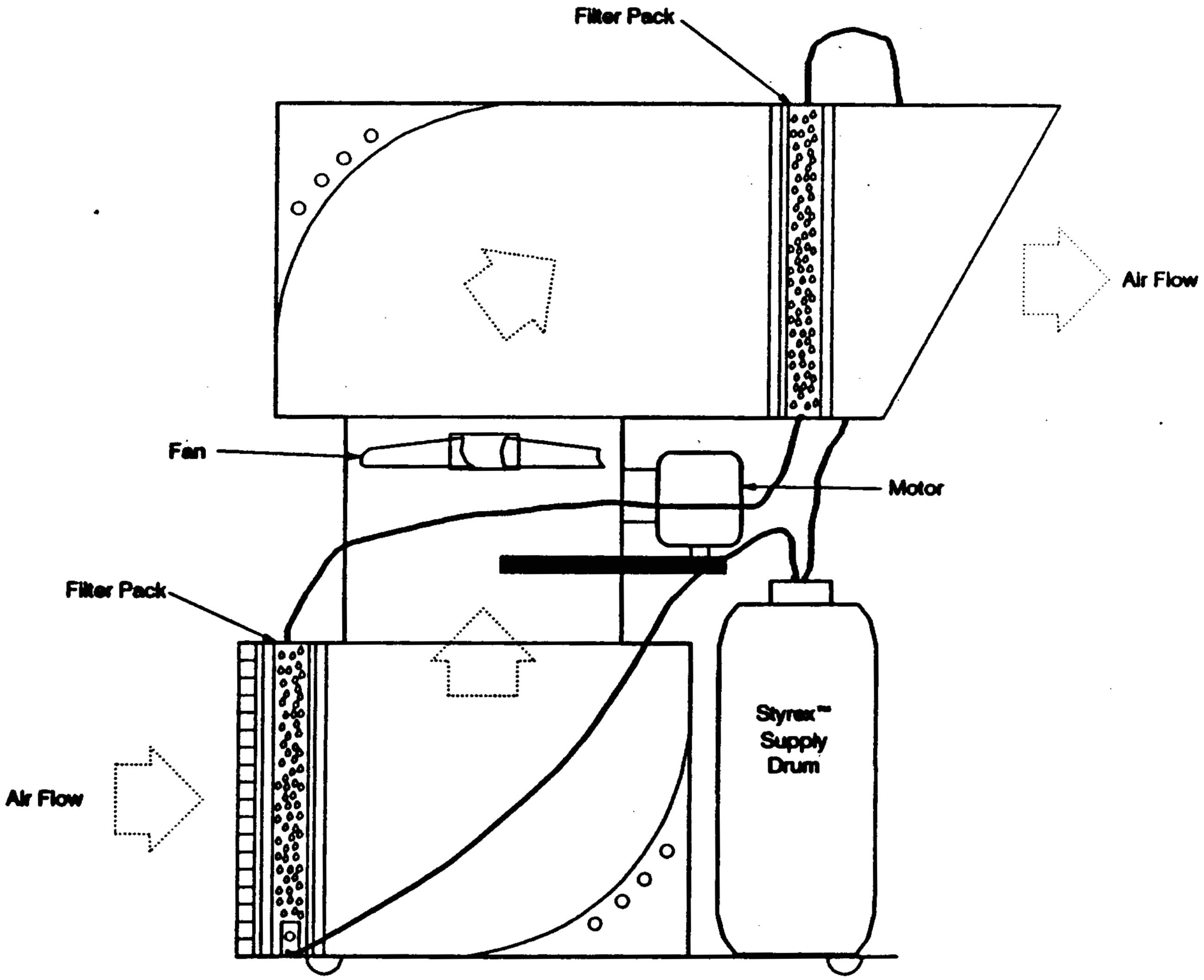


Figure 5. Cross-section Schematic of the Blitz Roller™

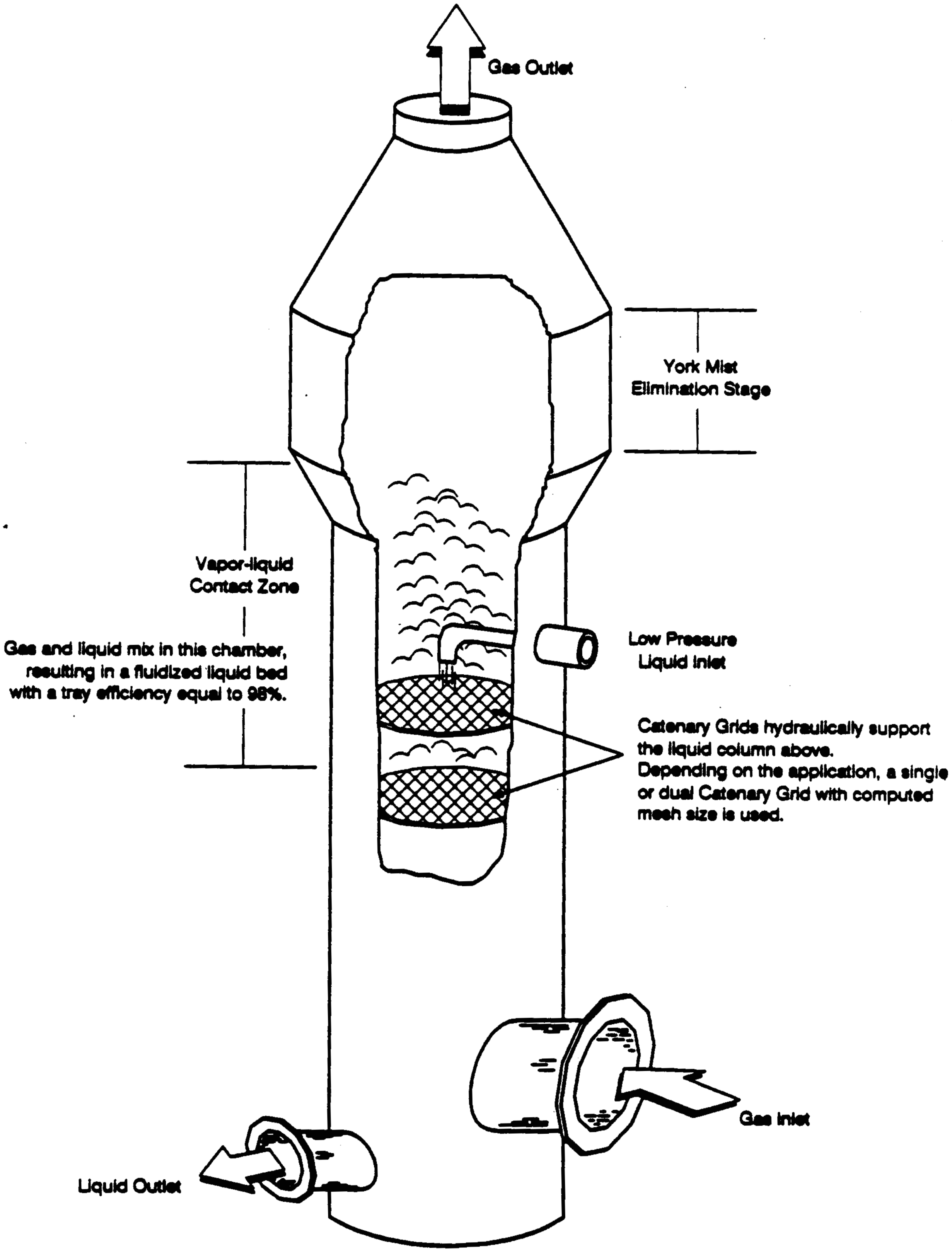


Figure 6. Chempro™ Scrubber with Catenary Grids

The ChemPro™ scrubber, illustrated in Figure 6, is an add-on unit that is tied into a facility's exhaust system. This system operates in the same manner as the Blitz Roller™, but is intended to handle higher flow rates. The ChemPro™ unit has not been installed in any facility to date.

Vendor efforts are currently underway to establish the commercial viability of the patented Styrex™ absorption system. Information on this system, therefore, is limited to experimental tests and pilot scale test runs. Two such tests were selected for an evaluation of the Styrex™ system capabilities.[96] The test results to date focus on the Styrex™ system's effect on styrene emissions. No test data are available regarding its effectiveness in reducing acetone emissions.

The first test to be discussed is a bench-top evaluation of the Styrex™ system, performed by the vendor in August 1985. The purpose of the evaluation was to determine the effectiveness of styrene control. The bench-top unit consisted of an air pump, three flow meters, a flask containing resin, a blender, a submersible pump, condensers, and an infrared (IR) analyzer. A schematic of this unit is shown in Figure 7.

Clean air was pumped through two parallel rotometers; one leading to a flask containing a polyester resin with approximately 50 percent styrene and the other by-passing the flask. The two streams were combined and passed through a final rotometer to determine the total air flow to the system. From the final rotometer, the airstream was directed to either the IR analyzer for concentration measurement or to the scrubber for treatment and subsequent analysis via a three-way valve.

The scrubber was a modified vita-mix blender. The airstream entered near the bottom, and after vigorous mixing with the Styrex™ liquid, exited out at the top. The Styrex™ liquid was recirculated through the blender by a pump positioned in a reservoir of Styrex™. The Styrex™ was not regenerated prior to recycle. A total of six runs were performed. As shown in Table 20, runs 1-4 evaluated the styrene removal efficiency versus time at three absorbent volumes: 1,500 ml, 2,150 ml, and 3,750 ml. Run 5 was performed to determine

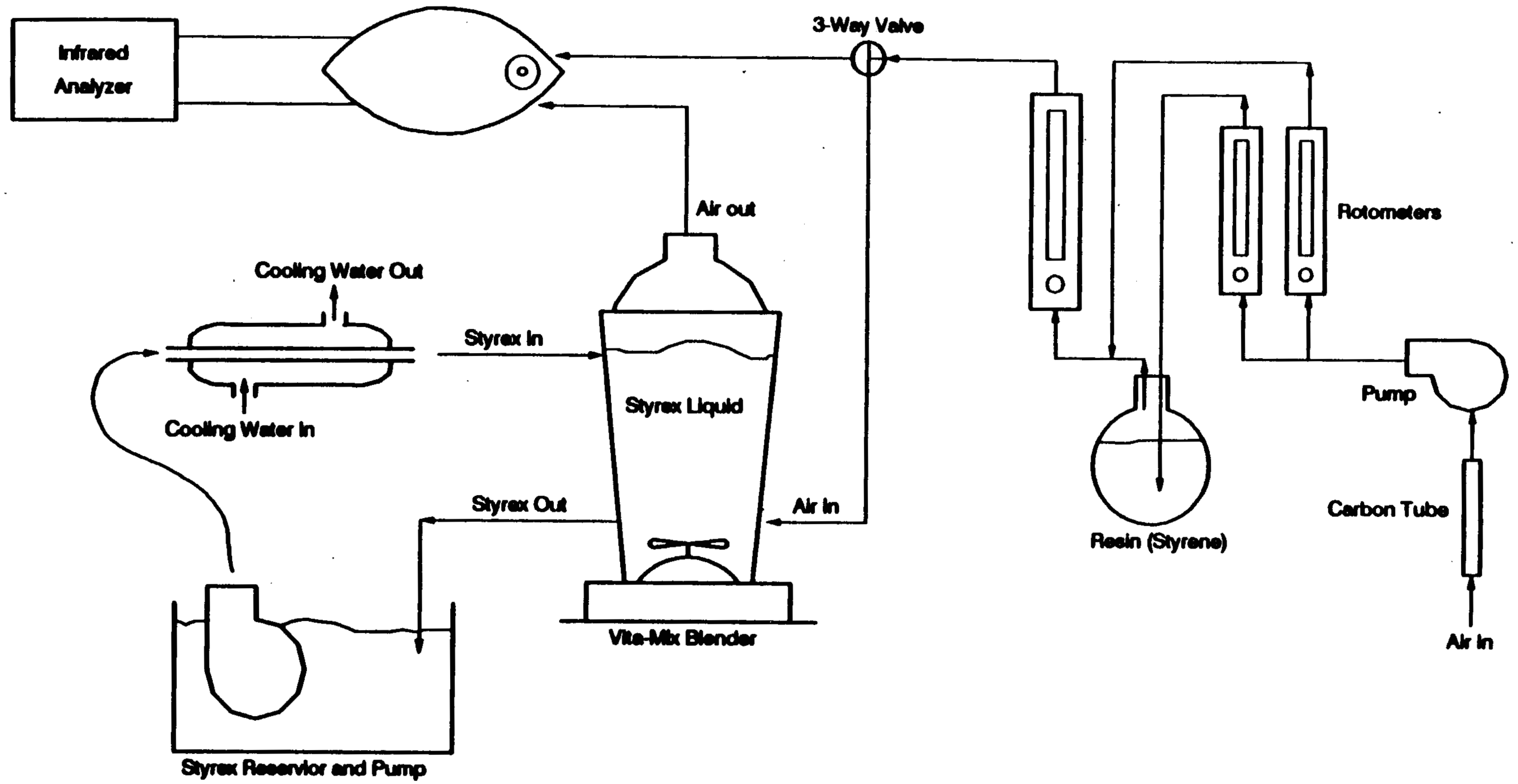


Figure 7. Styrex™ System Bench Top Pilot Unit

TABLE 20. SUMMARY OF RUNS PERFORMED IN THE BENCH-TOP EVALUATION OF THE STYREX™ SYSTEM

	Description		
Run No.	Average Styrex™ Volume in Blender and Reservoir (ml)	Recycle Rate (ml/min)	Inlet[d] Concentration (ppmv)
1	2,150	275	151 - 315
2	1,500	275[a]	165 - 279
3	3,750	275[b]	89 - 229
4	3,750	275	230 - 285
5	3,570[c]	275	Not Provided
6	Hydrocarbon emissions test		

[a] Decreased after 280 minutes; level not recorded.

[b] Increased to 500 ml/min after 410 minutes.

[c] Spent Styrex™ from Run 3 passed under ultraviolet light to test regeneration capabilities.

[d] Corresponding outlet concentrations for Runs 1-4 can be determined from Figure 8.

the regeneration capability of the Styrex™ and Run 6 was performed to evaluate the hydrocarbon emissions from the unit. The inlet styrene concentrations for all of the runs (presented in Table 20) were generally between 90 and 300 ppmv which is up to 10 times the average VOC concentration typical of the fiberglass boat manufacturing industry.

The outlet concentrations for Runs 1-4 can be calculated from Figure 8. As shown, the system demonstrated an initial styrene removal efficiency of 90 percent or greater, but decreased with time. Data were insufficient to determine the liquid to gas ratio for any theoretical comparisons. During Runs 2 and 3, the effect of recycle rate was evaluated. The recycle rate was decreased 280 minutes into Run 2 and was accompanied by a drop in efficiency as noted in Figure 8. During Run 3, the recycle rate was increased to 500 ml/minute (from an average 275 ml/min) and was accompanied by an increase in efficiency as noted in Figure 8.

In Run 5, spent Styrex™ from test 3 was passed under an ultraviolet liquid sterilizer with a wave length of 254 m. The regenerated Styrex™ was retested and showed an initial reduction of 95 percent, but dropped to ~75 percent in a tenth of the time. No test data was provided. During Run 6, a malfunction of the flame ionization detector used to determine the total hydrocarbon concentration levels was discovered, rendering the results unreliable. An estimation of the hydrocarbon contribution of the Styrex™ alone was later estimated at less than 4 ppmv. A breakdown of the speciated hydrocarbons was not provided.

The next series of tests were run at a glass fiber reinforced plastics fabrication facility. The tests were performed using the Model 1000 ChemPro™ stainless steel pilot unit, outfitted with two elements of the patented Catenary Grid, as shown in Figure 6. Styrex™ was fed only to the lower grid. Air volumes were adjusted to maintain a constant grid pressure drop between 4 and 4.5 inches of water. Approximately 100 gallons of Styrex™ was charged to the system. Two recirculation rates were evaluated: 5 and 9 gallons per minute (gpm). Due to low shop activity, the inlet of the unit was spiked with

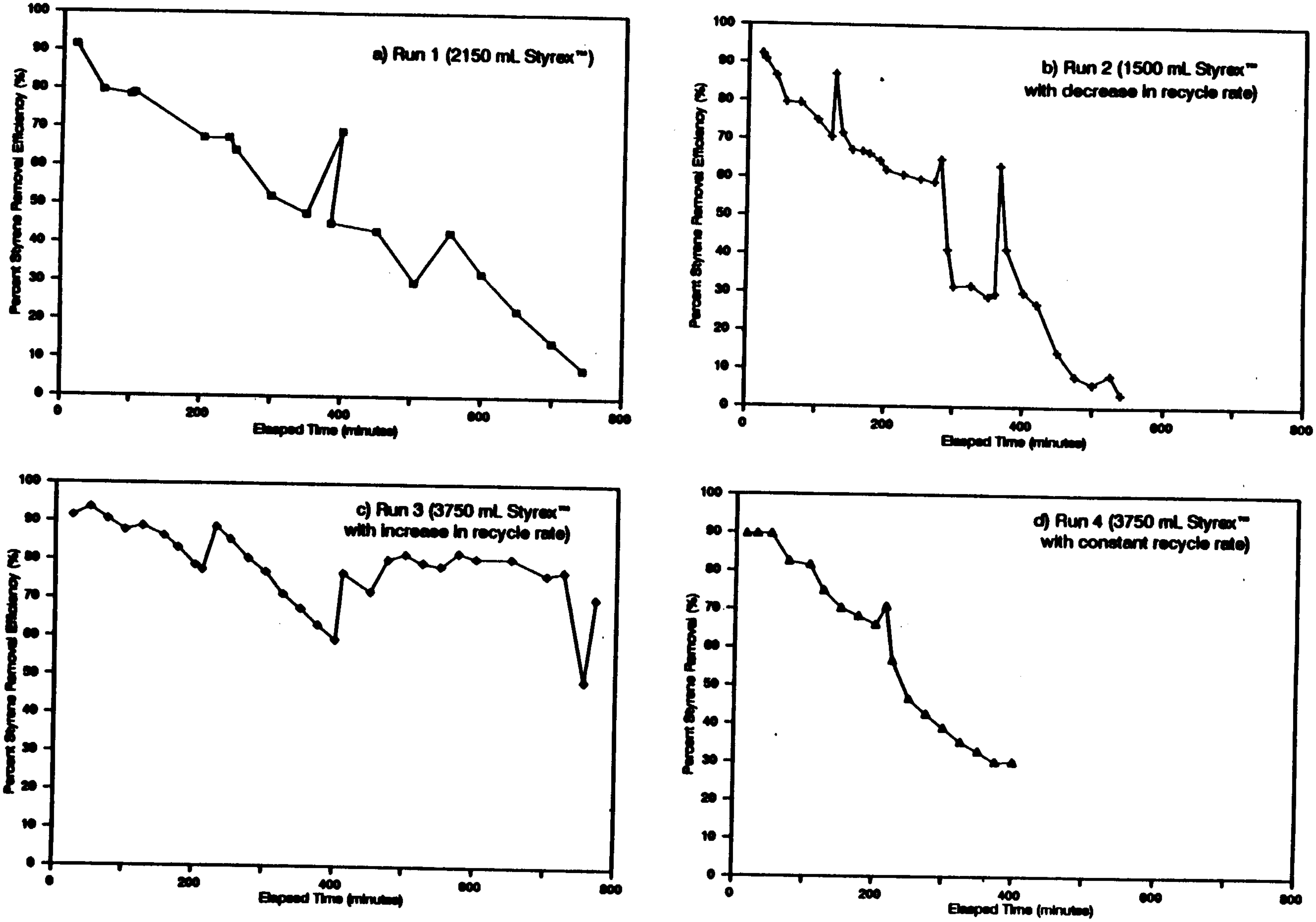


Figure 8. Results from Styrex™ System Bench-top Tests

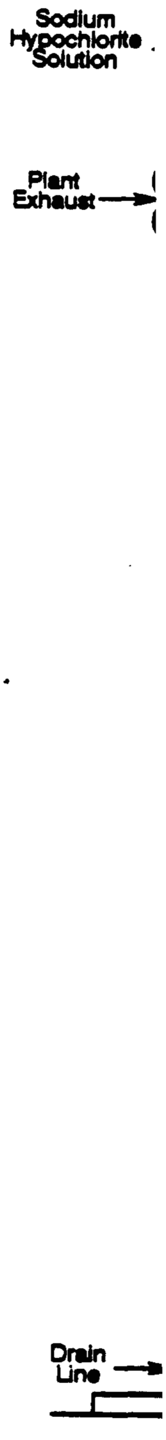
fumes from the evaporation of styrene monomer to raise the inlet concentration to approximately 100 ppmv. Concentration measurements were made using an MSA Samplair pump and MSA styrene-specific length-of-stain detector tubes.

At a recirculation rate of 9-10 gpm, the Styrex™ demonstrated an initial styrene removal efficiency of approximately 85 percent, but dropped to approximately 35 percent in 80 minutes. The inlet air flow rate was measured at 720 cfm which yields an L/G ratio (slope of the operating curve) of 13.9 gallons Styrex™/1000 cfm. The liquid residence time was 10 minutes. At a recirculation rate of 5 gpm, the Styrex™ demonstrated an initial efficiency of almost 90 percent, dropping to 30 percent in 80 minutes. The L/G ratio was 6.9 gallons/1000 cfm and the residence time was 20 minutes. Without styrene/styrex equilibrium data, it is difficult to assess these operating conditions.

Although some testing has been done to verify the capability of Styrex™ to absorb styrene, further work is required to assess the capability of Styrex™ systems control VOC emissions from to the fiberglass boat manufacturing industry. This should include:

1. Development of Styrex™/styrene equilibrium data and theoretical evaluation of the absorption potential;
2. Demonstration of continuous regeneration and recycle of the Styrex™;
3. Evaluation of the effect of Styrex™ on acetone, or vice versa;
4. Determination of the expected amount of waste generated from regeneration; and
5. Full economic analysis of a commercial unit including waste disposal costs.

Chemtact™ System--The Chemtact™ system is an air scrubber which uses a fine mist of sodium hypochlorite solution to absorb and oxidize airborne chemical contaminants. A schematic of the system is provided in Figure 9. The basic system includes a fiberglass reaction chamber, a nozzle for



Figure

Chemtact™ removal efficiency data were generated by analyzing air s the inlet and outlet air ducts. Therefore, the calculated efficien reflect the absorption of compounds from the gas phase into the liq and not the efficiency of the oxidation process which occurs in the phase. Testing of liquid effluent samples could be used to evaluat efficiency of the oxidation process. Such information may be impor larger facilities where waste water discharge rate from a Chemtact™ be significant. Effluent data could not be obtained for this evalu

The capital investment for a 14,400 acfm system is approximate $130,000. The operating costs are estimated to be $11,000/year inc cost of chemicals and electricity. These costs do not include inst ventilation duct work which would be required to capture and delive contaminated air to the Chemtact™ system. This cost also does not permits or waste disposal fee associated with the installation of s system.[101]

This system has been demonstrated to successfully remove odors rates ranging from 100 to 80,000 cfm. Treatment flow rates in exce 100,000 cfm have been obtained with the use of multiple units. As earlier, it may be possible to reduce the flow rate of air requirin significantly through the use of ventilation stations located at in work areas in the plant where the majority of VOC emissions occur. potentially reduce the size, and therefore the total cost of the tr system.

Adsorption--

The use of adsorption devices has not been demonstrated for co VOC emissions from fiberglass boat manufacturing facilities. The f discussion presents the fundamentals of adsorption and the technical limitations of applying adsorbers to the fiberglass boat industry.

Adsorption is a mass-transfer operation involving interaction b gaseous and solid phase components. The gas phase (adsorbate) is ca the solid phase (adsorbent) surface by physical or chemical adsorpti atomizing the sodium hypochlorite solution, inlet and outlet air ducts and a drain. An exhaust fan is used to draw contaminated air into the reaction chamber.

The primary operating feature of the Chemtact™ system is the spray nozzle located at the top of the chamber. The nozzle atomizes the sodium hypochlorite solution into droplets 10-12 microns in size. The sodium hypochlorite mist is sprayed from the top of the tower where it mixes with the contaminated air. The mass transfer process of gas absorption takes place at the interface between the liquid droplet and the surrounding gas phase. Chemical contaminants are absorbed through the interface and into the sodium hypochlorite droplet where oxidation takes place. Smaller droplets equate to an increase in the overall gas-liquid interface surface area. This provides for an increase in removal efficiency.[97]

There are approximately 120 Chemtact™ scrubbers in operation at paint plants, rendering plants, resin cookers, food processors, and waste water treatment plants. No Chemtact™ scrubbers are currently in operation or have been tested in a fiberglass manufacturing facility.[98]

Test data obtained from a Chemtact™ system in operation at a composting facility indicates a reduction in styrene concentration from 2.00 to 0.12 ppmv (94 percent removal) and a reduction in acetone concentration from 114 to 3.40 ppmv (97 percent reduction).[99] Similar removal efficiencies are given for other VOC compounds. These test data indicate the Chemtact™ system has the potential to achieve high VOC removal efficiencies. The composting facility test data does not include information on treatment flow rates or system configuration. Such engineering data would be essential for a more thorough assessment of the applicability Chemtact™ system to controlling emissions from fiberglass boat manufacturing plants.

Current Chemtact™ systems are able to discharge liquid waste directly to municipal sewage facilities, due to low concentrations of contaminants being treated.[100] Further evaluation of the liquid effluent is necessary to determine the efficiency of the sodium hypochlorite oxidation process.

Chemtact™ removal efficiency data were generated by analyzing air samples from the inlet and outlet air ducts. Therefore, the calculated efficiencies reflect the absorption of compounds from the gas phase into the liquid phase, and not the efficiency of the oxidation process which occurs in the liquid phase. Testing of liquid effluent samples could be used to evaluate the efficiency of the oxidation process. Such information may be important at larger facilities where waste water discharge rate from a Chemtact™ system may be significant. Effluent data could not be obtained for this evaluation.

The capital investment for a 14,400 acfm system is approximately $130,000. The operating costs are estimated to be $11,000/year including the cost of chemicals and electricity. These costs do not include installation of ventilation duct work which would be required to capture and deliver VOC contaminated air to the Chemtact™ system. This cost also does not include any permits or waste disposal fee associated with the installation of such a system.[101]

This system has been demonstrated to successfully remove odors at flow rates ranging from 100 to 80,000 cfm. Treatment flow rates in excess of 100,000 cfm have been obtained with the use of multiple units. As discussed earlier, it may be possible to reduce the flow rate of air requiring treatment significantly through the use of ventilation stations located at individual work areas in the plant where the majority of VOC emissions occur. This could potentially reduce the size, and therefore the total cost of the treatment system.

Adsorption--

The use of adsorption devices has not been demonstrated for controlling VOC emissions from fiberglass boat manufacturing facilities. The following discussion presents the fundamentals of adsorption and the technical limitations of applying adsorbers to the fiberglass boat industry.

Adsorption is a mass-transfer operation involving interaction between gaseous and solid phase components. The gas phase (adsorbate) is captured on the solid phase (adsorbent) surface by physical or chemical adsorption mechanisms. Physical adsorption is a mechanism that takes place when intermolecular (van der Waals) forces attract and hold the gas molecules to the solid surface. Chemisorption occurs when a chemical bond forms between the gas and solid phase molecules. A physically adsorbed molecule can readily be removed from the adsorbant (under suitable temperature and pressure conditions) while the removal of a chemisorbed component is much more difficult.

Activated Carbon Adsorption--

The most commonly used industrial adsorption systems are based on activated carbon as the adsorbent. Activated carbon is effective in capturing certain organic vapors by the physical adsorption mechanism. In addition, adsorbate may be vaporized for recovery by regeneration of the adsorption bed with steam. Oxygenated adsorbents such as silica gels, diatomaceous earth, alumina, or synthetic zeolites exhibit a greater selectivity than activated carbon for capturing some compounds.

The design of a carbon adsorption system depends on the chemical characteristics of the VOC being recovered, the physical properties of the off gas stream (temperature, pressure, and volumetric flow rate), and the physical properties of the adsorbent. The mass flow rate of VOC from the gas phase to the surface of the adsorbent (the rate of capture) is directly proportional to the difference in VOC concentration between the gas phase and the solid surface. In addition, capture rate is dependent on the adsorbent bed volume, the surface area of adsorbent available to capture VOC, and the rate of diffusion of VOC through the gas film at the gas and solid phase interface. Physical adsorption is an exothermic operation that is most efficient within a narrow range of temperature and pressure. A schematic diagram of a typical fixed bed, regenerative carbon adsorption system is shown in Figure 10.

The inlet gases to an adsorption unit are typically filtered to prevent bed contamination. Vapors entering the adsorber stage of the system are passed through the porous activated carbon bed. Adsorption of inlet vapors occurs in the bed until the activated carbon is saturated with VOC. When the

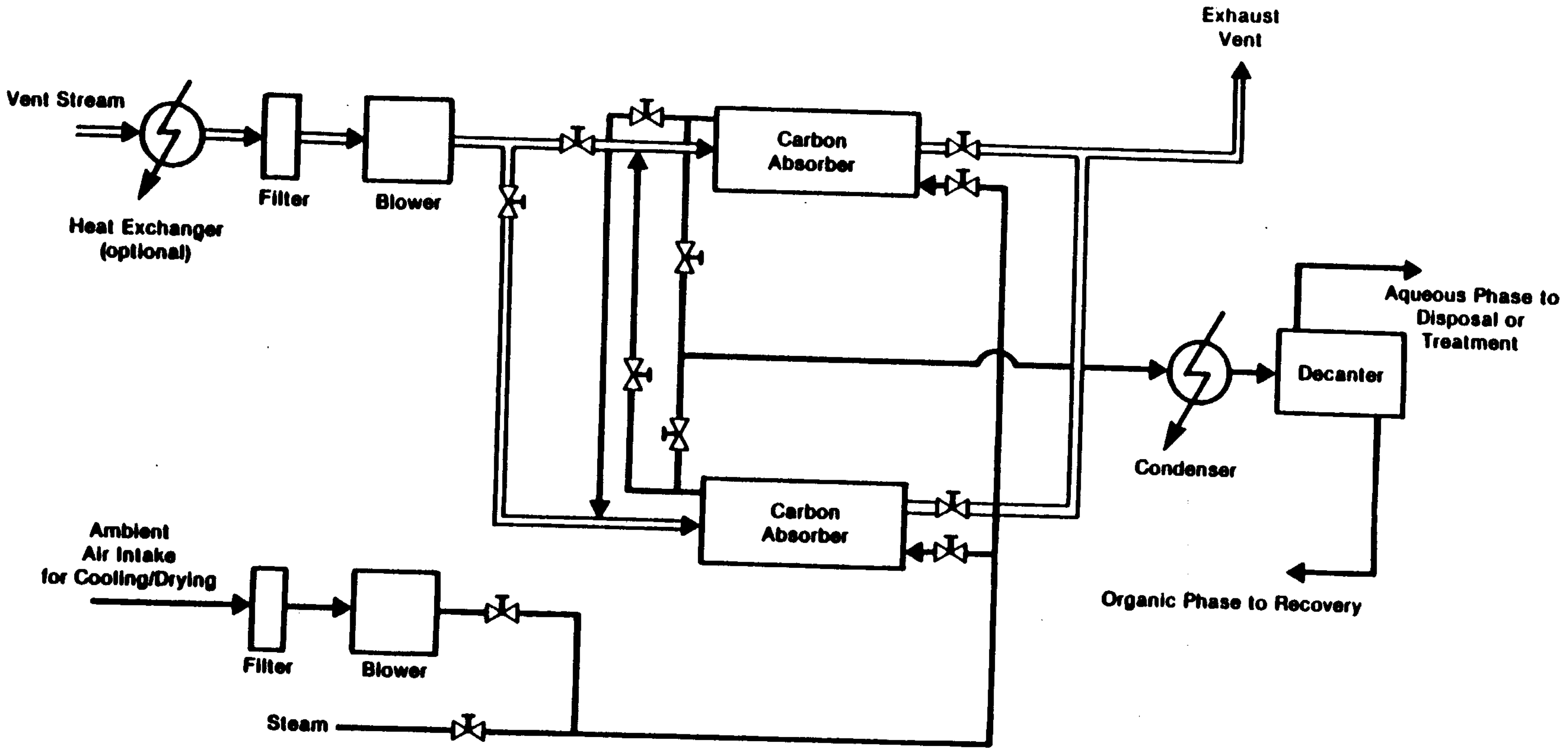


Figure 10. Carbon Adsorber System Process Flow Diagram

bed is completely saturated resulting in breakthrough, the incoming VOC-laden gases are typically routed to an alternate bed while the saturated bed is regenerated, usually with steam.

There are no known applications of carbon adsorption to fiberglass boat manufacturing. One concern is the emission reduction associated with low VOC concentrations. The emission reduction achievable with carbon adsorbers decreases rapidly when the inlet VOC concentration drops below 100 ppmv.[102] As stated previously, average VOC concentrations can range from 1 to 80 ppmv for the fiberglass boat manufacture industry. An additional concern is polymerization as styrene on the carbon. Polymerization of styrene on the carbon, if it occurred, would quickly deactivate the bed.

A second concern is the potential for bed fires when adsorbing ketones, such as acetone. The reason for this bed fire potential is that ketones have a high heat of adsorption. However, in other industrial applications, it has been shown that if proper operation procedures are followed, bed fires can be avoided.[103] Proper procedures for controlling heat build up in the bed include: (1) using low ash (low metals) carbon, since metals are believed to catalyze exothermic reactions with ketones; (2) ensuring constant and even air flow through the bed to remove heat; (3) preventing high concentration and low air flow conditions; (4) installing instrumentation to monitor temperature conditions; (5) installing an emergency water cooling system; and (6) desorbing the solvent or blanketing the bed with nitrogen prior to system shutdown.

Another major concern is the vast difference in the capacity for carbon to adsorb acetone versus styrene. At .0002 psia, the adsorptive capacity for styrene is 30 percent, while the adsorptive capacity for acetone is only 1 to 2 percent, thus making the removal of acetone the limiting design criteria.[104]

Conventional carbon adsorption systems have traditionally been applied to streams with VOC contents in the range of 1,000 to 10,000 ppmv to recover solvent for reuse. With high flow/low concentrations, streams such as those found in boat manufacturing, costs of carbon adsorption is expected to be high.

For a 14,400 scfm flow rate the installed capital cost for a conventional carbon adsorption system would be approximately $500,000. Annual operating costs would be approximately 5 percent of the initial capital investment or $25,000/yr. The total annualized cost would be approximately $109,000.

There are several variants of the system previously described which use the same adsorption mechanisms. The first system uses a fibrous activated carbon adsorbent formed into a honeycomb. The honeycomb continuously rotates. Zones of the structure alternately pass through the VOC laden stream and a stream of hot air used for desorption. The hot air stream, which has a much higher concentration of VOC, must then be treated using a conventional carbon adsorber or incinerator.[105]

As stated previously there are no known applications of carbon adsorption to fiberglass boat manufacturing. There is, however, a fiberglass horse trailer manufacturing site that is currently using a carbon adsorber to control styrene emissions. No data was available to determine the efficiency of the system, however, an appreciable reduction in odor was noted by neighboring facilities. This site has not experienced problems with polymerization of styrene on the carbon. The adsorber is a tower of 48 trays approximately 2 feet square and 1 inch deep each. The trays are sent off-site for high temperature regeneration at a cost of $7 to $9 per tray. The trays are changed out every two to four months.[106]

The trailer facility is relatively small compared to a boat manufacturing facility, therefore, cycle times for tray regeneration may be less frequent than would be expected for a boat manufacturing facility. No appreciable amount of acetone is in the exhaust to the adsorber.

Although this facility has not experienced any operational problems, the potential for operational problems still exists in the application of integrated carbon adsorption systems at boat plants. First, the styrene emissions from boat plants would typically be much higher. At higher styrene emission rates, polymerization of the styrene is more likely to occur. Secondly, the carbon is sent off-site for high temperature regeneration. Even if styrene polymerized on the carbon, it would not present a problem. The polymer would be burned off by the high temperature regeneration. However, for the VOC emission rates at most boat plants, integrated carbon adsorption systems (with on-site regeneration capabilities) would likely be more practical and more economic. The VOC reduction efficiency of these systems would be more sensitive to polymerization. Regeneration with hot steam or nitrogen would not remove polymer deposits as effectively as the high temperature regeneration, and a significant portion of the adsorption sites may be deactivated permanently.

Polyad™ Adsorption System--

The Polyad™ system uses a fluidized bed containing a macroporous polymer, Bonapore™. The polymer continuously circulates between the adsorption and desorption sections. Two facilities using this technology are currently in operation in Sweden. One uses the process to control exhaust air emissions from a furniture painting spray booth, and the other to control exhaust air emissions from a spray booth used for making various polyester products.[107] No test data was available to determine the efficiency of the Polyad™ system for these two facilities.

This system has not been demonstrated at boat manufacturing operations, however, the vendor, Nobel Chemetur, is continuing efforts to determine the applicability of the Polyad™ system for controlling styrene and acetone emissions.

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GLOSSARY

OSHA	Occupational Safety and Health Administration
PEL	Permissible Exposure Limits

TECHNICAL REPORT DATA

(Please read Instructions on the reverse before completing)

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16. ABSTRACT The report presents an assessment of volatile organic compound (VOC) emissions from fiberglass boat manufacturing. A description of the industry structure is presented, including estimates of the number of facilities, their size, and geographic distribution. The fiberglass boat manufacturing process is described, along with sources and types of VOC emissions. Model plants representative of typical facilities are also described. Estimates of VOC emissions are presented on per plant and national bases. VOC emissions from this industry consist mainly of styrene emission from gel coating and lamination, and acetone or other solvent emissions from clean-up activities. Finally, potential VOC control technologies are evaluated for this industry, including a discussion of technical feasibility. Limited cost data are also presented.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS		b. IDENTIFIERS/OPEN ENDED TERMS	c. COSATI Field/Group	
Pollution	Acetone	Pollution Control	13B	
Organic Compounds	Polyester Resins	Stationary Sources	07C	11I
Volatility		Volatile Organic Compounds (VOCs)	20M	
Glass Fibers			11E, 11E	
Boats		Fiberglass	13J	
Styrene				

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ASSESSMENT OF VOC EMISSIONS FROM FIBERGLASS BOAT MANUFACTURING

CONTROL TECHNOLOGY CENTER

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PREFACE

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

The technical guidance projects, such as this one, focus on topics of national or regional interest that are identified through contact with state and local agencies. In this case, the CTC became interested in assessing the magnitude of VOC emissions from fiberglass boat manufacturing and possible emission control techniques available to reduce these emissions.

This document describes the fiberglass boat manufacturing industry and the sources of VOC emissions during the manufacturing process. Emissions control methods such as material substitution, process changes, and add-on control equipment are discussed. Both demonstrated control technologies and evolving control technologies are presented.