DOE/CS/40008-T6

PRELIMINARY MARKET ANALYSIS

FOR

BRAYTON CYCLE HEAT RECOVERY SYSTEM
CHARACTERIZATION PROGRAM

SUBTASK 5.2 OF PHASE I PROGRAM PLAN

AUGUST 31, 1980

PREPARED FOR

DEPARTMENT OF ENERGY

CONTRACT NO. ~~DE-AC03-77CS40008~~
AC03-77CS40008

Doc 1980/14/00

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1.0 INTRODUCTION

The purpose of this task is to determine the market potential of the Brayton-cycle Subatmospheric System (SAS), especially as applied to the glass processing industry. The factors that determine the marketability of the system include the price of the system; the operational acceptance of the system in terms of size, maintenance needs, and energy output; and the numbers and kinds of furnaces potentially available for the Brayton system.

A great deal of supporting data was compiled for the glass industry inventory presented in Attachment A of this report. The characterization of the type of furnaces and location, as well as the volume, is presented therein From this data, an estimate of the Brayton-cycle sales buildup in the industry has been made.

One of the major aspects of this market activity is to evaluate the operating conditions of a Brayton-cycle system that would result in a two year (or better) payout. The turbine inlet temperature is one of the most important operating conditions relative to the requirement for a two year payout. The turbine inlet temperature of the subatmospheric cycle correlates to the amount of power produced from the system. The temperature attainable from the furnace to run the turbine may be constrained by the furnace construction or by its operational procedure and practices. It, therefore, is important to know how low in temperature the subatmospheric cycle can operate and still provide a two year payout. This will determine the minimum furnace exhaust temperature on which the system can operate economically.

Another important operating aspect of the Brayton-cycle system is its impact on NO_x formation. This waste heat recovery system has the unique ability to produce both electric power and air preheat. The use of waste heat to produce power reduces the amount of fuel used at the fossil fired power plant supplying electricity to the glass plant which reduces the NO_x emissions from the fossil power plant. NO_x displacement credit should be given to the Brayton system. Air preheat, when properly implemented, will also reduce NO_x in direct proportion to the amount of fuel saved. These factors, along with better fuel-to-air ratio control, increased cullet utilization and increased electrical boost may enable the glass industry to reduce NO_x to within acceptable levels per ton without expensive chemical processing equipment. The most stringent compliance standards for NO_x production are being instituted by the State of California. However, it is anticipated that the rest of the nation will follow California's lead in whatever stand it sets.

At today's energy costs, the waste heat recovery system can operate with a 1300°F inlet temperature and still meet a two year payout. The lowering of the required turbine inlet temperature for a two year payout is principally due to the rapid growth in both power and fuel prices. In the following sections, each of the areas which impact the sales of the Brayton-cycle systems will be examined.

2.0 MARKET SIZE

The glass industry is a major industry with over six billion dollars in product sales. Glass products are shipped from over 400 plants located across the country and the glass is produced in over 1,000 furnaces. The industry has grown in real terms each year which reflects the unique ability of glass to satisfy optical, decorative container and insulation requirements. The size of the industry in 1976 is shown by segment in Figure 1, and its forecast growth through 1985 by segment is shown in Figure 2. Several of these market segments are summarized in the following: Attachment A contains a complete list of all the plants that have been identified in the country and their size; Figure 3 shows the share of glass market as a percentage of total package market; Figure 4 shows the number of flat glass plants in the U.S. and their production capacity; Figure 5 shows the growth for pressed and blown glass in the years 1977-1982; and Figure 6 shows the growth in shipments of wool fiberglass. These figures indicate that the industry, by and large, is growing and will continue to grow, and represents an important part of our industrial base. A survey was conducted for the Environmental Protection Agency to identify what is representative of a model plant size for each industry segment. This survey was done for pollution control purposes but it is adaptable for our purposes. Figure 7 presents the model furnace sizes for the categories shown. For container furnaces, we believe that 200 tons-per-day of production would be fossil-fired

FIGURE 1

1976 PRODUCTION RATES AND VALUES OF SHIPMENTS

Segment	SIC Code	Production Rate in 1976	Dollar Value of Shipments in 1976 (in millions of dollars)
Flat Glass	3211	2.56 Tg (2.91 MM Tons)	645
Container Glass	3221	11.8 Tg (13.0 MM Tons)	3251
Pressed and Blown (N.E.C.)	3229	1.73 Tg (1.95 MM Tons)	1598
Wool Fiberglass	3296	0.896 Tg (0.986 MM Tons)	817

Tg is an abbreviation for 10^{12} grams.

MM tons represents one million tons.

FIGURE 2

PROJECTED 1985 PRODUCTION RATES

Segment	SIC Code	Annual Growth Rate (Percent)	1985 Production Rate Tg	(MM Tons)
Flat	3211	1.8	3.1	(3.4)
Container	3221	3.1	15.0	(17.0)
Pressed and Blown (N.E.C.)	3229	3.5	2.3	(2.5)
Wool Fiberglass	3296	7.1	1.5	(1.6)

FIGURE 3

SHARE OF TOTAL PACKAGING MARKET

	1961	1970	1976	1976
Paperboard	37.9 %	34.0 %	33.5 %	31.5 %
Metals	25.0	27.8	27.5	29.2
Plastics	5.3	9.1	12.0	13.1
Paper	15.6	13.7	11.9	11.5
→ Glass	8.6	9.8	9.8	9.8
Wood	4.5	3.8	3.6	3.5
Textile	2.5	1.5	1.2	1.0

Source: American Glass Review, May, 1977, p.12.

FIGURE 4

FLAT GLASS PLANTS

PRODUCER	PLANT LOCATION	CAPACITY (Tons/Day)
PPG Industries, Inc.	Fresno, California	400 TPD
	Mt. Zion, Illinois	450 TPD*
	Cumberland, Maryland	400 TPD
	Crystal City, Missouri	400 TPD
	Carlisle, Pennsylvania	900 TPD
	Meadville, Pennsylvania	800 TPD
	Wichita Falls, Texas	1,000 TPD
Libbey-Owens-Ford Co.	Ottawa, Illinois	400 TPD
	Lathrop, California	450 TPD
	Laurenburg, North Carolina	750 TPD
	Rossford, Ohio	1,000 TPD
	Toledo, Ohio	450 TPD
Ford Motor Company, Glass Division	Dearborn, Michigan	400 TPD
	Tulsa, Oklahoma	1,000 TPD
	Nashville, Tennessee	1,500 TPD
Guardian	Carleton, Michigan	900 TPD
ASG Industries, Inc.	Jeannette, Pennsylvania	270 TPD*
	Greenland, Tennessee	900 TPD*
	Kingsport, Tennessee	385 TPD
C.E. Glass Division of Combustion Engineering, Inc.	Floreffe, Pennsylvania	400 TPD
	Fullerton, California	70 TPD*
	St. Louis, Missouri	195 TPD*
	Cinnaminson, New Jersey	500 TPD
Fourco Glass Co.	Fort Smith, Arkansas	225 TPD*
	Clarksburg, West Virginia	200 TPD*
	Bridgeport, West Virginia	450 TPD

*These estimates represent reported sheet, plate, and/or rolled glass capacity; other estimates are measures of float capacity.

Source: Source Assessment: Flat Glass Manufacturing, U. S. Environmental Protection Agency.

FIGURE 5

ESTIMATED CURRENT AND NEW PLANTS FOR PRESSED AND BLOWN GLASS (1977-1982)

Industry	Number of Existing Plants	Production Capability of Average Plant (TPD)*	Capability of New Source (TPD)	Number of Sources Required
Machine Consumerware	13	100	300	1
Hand-Pressed and Blown Consumerware	90	5	50	2
TV Envelope Tubes	6	250	400	1
Incandescent Bulb Blanks	7	175	400	1
Optical Glass	8	50	50	2
Tubing	22	100	200	2

NOTE: Estimates are based on assumption that this segment of the industry will experience real growth of 4% from 1977 to 1982

* TPD - Tons Per Day

FIGURE 6

SHIPMENTS OF WOOL FIBER GLASS

	Structural Insulation			Other Insulation			Total Insulation		
	Shipments (Mil. lb.)	Value ($ mil.)	Apparent Value/lb.	Shipments (Mil. lb.)	Value ($ mil.)	Apparent Value/lb.	Shipments (Mil. lb.)	Value ($ mil.)	Apparent Value/lb.
1965	438	$ 92.5	$.211	608	$157.9	$.260	1046	$250.5	$.239
1966	462	104.8	.227	613	177.3	.289	1076	282.1	.262
1967	483	108.8	.225	554	170.5	.308	1038	279.3	.269
1968	567	133.0	.235	557	179.0	.321	1124	312.0	.278
1969	627	157.6	.251	576	197.6	.343	1203	355.2	.295
1970	645	165.6	.257	541	190.2	.352	1186	355.8	.300
1971	880	218.2	.245	627	207.1	.330	1517	425.3	.280
1972	1055	267.7	.254	683	219.4	.321	1738	487.1	.280
1973	1179	309.5	.263	725	249.3	.344	1904	558.8	.293
1974	1162	339.8	.292	781	310.2	.397	1943	650.0	.335
1975	1103	381.5	.346	572	294.1	.514	1675	675.6	.403
1976	1384	471.8	.341	608	345.6	.568	1992	817.4	.410
1977	2100	798.0	.380	750	465.0	.620	2850	1263.0	.443
Compound Growth Rates Least Squares:									
1965-77	12.0%	16.8%	4.5%	2.1%	8.4%	6.1%	7.9%	12.8%	4.7%
1970-77	12.8	19.7	6.6	2.6	13.1	9.9	8.6	16.2	7.1

Source: Commerce Department, Merrill Lynch estimates.

FIGURE 7

MODEL FURNACE SIZES

Industry Segment	Model Furnace Size Tons/Day
Container	250
Flat	700
Pressed and Blown	
Borosilicate	100
Opal	50
Lead	50
Soda-Lime	100
Wool Fiberglass	200

and the remainder (50 tons) electrically boosted. The cost per ton for container furnaces is shown in Figure 8.

The container industry represents a potential of over 121 megawatts of power from its waste heat. The flat glass industry represents over 27 megawatts of waste heat; the pressed and blown industry represents over 60 megawatts, and the wool fiberglass industry represents 65 megawatts. These markets alone would not justify a sufficient production base to ensure a low cost Brayton-cycle waste heat recovery system product. Figure 9 shows other markets to which this product could be adapted in sufficient quantities to ensure low cost production.

3.0 OPPORTUNITIES FOR WASTE HEAT SYSTEM INSTALLATION

3.1 FURNACE REBUILD

The life of an average glass furnace with a size of 200 tons per day has now been extended to between 7 and 8 years. The number of furnaces in the container industry of this size is 232. This means that an average of 33 furnaces per year are rebuilt, and is indicative of the rate potential for introducing the waste heat recovery technology into the glass industry. There are a great number of furnaces in the glass industry that do not match the model size. There are approximately 400 furnaces in the container industry alone, indicating that there are a large number of small capacity furnaces producing either cullet or special chemistry. This number greatly increases the opportunities for retrofit of these furnaces with waste heat recovery equipment. Furnaces in the flat glass area also experience life of approximately 7 years. There are currently some 26 furnaces in the flat glass area resulting in approximately 4 opportunities per year to install waste heat recovery equipment at rebuilt. The typical life of a mineral wool furnace is on the order of 4 years, requiring approximately 22 rebuilds per year. Life of the pressed and blown furnace is approximately 4 years, requiring 23 rebuilds per year. A typical furnace repair takes approximately 20 days from the time the furnace is shut down to the time it commences operation. The interface, mechanical and electrical, between the waste heat system and the furnace needs to be accomplished during this interval.

FIGURE 8

CONTAINER MID-RANGE ESTIMATES[1]
OF PRICE/COST RELATION
(500 TPD)

	1979
Price/Ton	$ 255
Profit before taxes and before Pollution Control (15%)	38.3
Direct Costs	216.7

[1] As supplied by the Glass Packaging Institute

FIGURE 9

WASTE HEAT APPLICATIONS
FOR BRAYTON-CYCLE TURBINE SYSTEM

1000 HP FRAME SIZE

MARKET POTENTIAL FOR ALPHA 700 KW SIZED UNIT

Waste Heat	MW	Potential Units
Furnace:		
Glass	300	600
Aluminum	50	100
Steel	25	50
Others	50	100
Fume Incineration:		
Chemical	100	200
Petroleum	100	200
Fired Turbine		
Enhanced Oil Recovery	5,000	10,000
Low Btu Gas	1,000	2,000
Cogeneration	1,000	2,000

In summary, there are a number of opportunities to install this equipment in the glass industry which can be readily implemented upon validation of the test program.

3.2 FURNACE REPAIR

In addition to major construction at the end of the campaign when the furnace is totally refurbished, repairs are usually made during the campaign life. These repairs occur approximately every 4 years in the container industry, every 4 years in the flat glass industry, every 2 years in the fiberglass industry and every 2 years in the pressed and blown industry. These rebuilds present additional opportunities for equipment installation. These furnace rebuilds usually require the furnace to be down for approximately 14 to 15 days. During this time, the equipment could be interfaced both mechanically and electrically with the furnace.

4.0 POLLUTION CONTROL ON GLASS FURNACES

The pollution control regulations currently pertain to removal of particulate from the furnace exhaust. These regulations are implemented on the furnaces as a result of local and state law, and the status (air quality) of the air pollution region in which the furnaces are operating. Pollution control equipment consists of either electrostatic, precipitate, bag houses, or wet scrubbers. All of these equipments are attached at the end of the furnace and would operate from the exhaust of the Brayton-cycle equipment. The description of these current emission control techniques are presented in Attachment B of this report.

New proposed standards will deal with NO_x and SO_x regulation. These standards may require the introduction of chemical processing of the waste gas stream. A number of very expensive equipments have been proposed for NO_x and SO_x pollution control. It is uncertain whether these techniques will be employed, or process modifications can achieve the same control.

5.0 EQUIPMENT COSTS

An estimate of the installed cost of the Brayton-cycle Waste Heat equipment is shown in Figure 10. This equipment cost has been adjusted for inflation using previous quotes that were made in March 1979. It is assumed that the Brayton units would be produced in quantities of 300 per year to achieve

FIGURE 10

COST ESTIMATES FOR SUBATMOSPHERIC SYSTEM

Item	Purchase or Fab Cost	Basis of Estimate	Markup	Sell Price	Comments
Turbocompressor and Gear Box	$ 60,000	Garrett Quote	1.6	$ 96,000	x 3 = 288,000
Generator and Generator Controls	6,000	$24/KW	1.6	9,600	28,800
Switch Gear	4,800	Onan Quote	1.6	7,680	23,040
Heat Exchanger 1 pass 1700 lbs.	8,160	$4.80/lb.	1.6	13,056	39,168
Inlet Plenum	624	260 lbs. @ 2.40/lb.	1.6	998	2,994
Outlet Plenum	624	260 lbs. @ 2.40/lb.	1.6	998	2,994
Heat Exchanger Support Structure	816	10% of heat exchanger	1.6	1,305	3,915
Modulating Valve	1,800		1.6	2,880	8.640
Cleaning System Valves	3,600		1.6	5,760	17,280
Air Storage Tank	N/A				
Control Unit	7,200		1.6	11,520	24,560
Blower	4,800		1.6	7,680	23,040
Installation	80,000			80,000	
Hardware Total					472,431

the cost figures shown in Figure 10. It therefore reflects mature system prices. The comparison of this cost per kw is presented in Figure 11. One can see from Figure 11 that the system is quite in line with other hardware prices as applied to similar applications. These cost estimates will be utilized in determining market penetration.

6.0 EQUIPMENT PERFORMANCE

The value of the product produced from our equipment is limited by a number of factors. The furnace construction and operating practices as well as the local energy costs of electricity and fuel are contributing factors.

To first assess the value of the product from our waste heat recovery system, we need to understand the amount of power and the amount of preheat the unit provides. Figure 13 shows the amount of kw produced per turbine as a function of turbine inlet temperature, and Figure 12 shows the amount of preheat produced as a function of turbine inlet temperature. These figures display the varying quantities of products that can be produced from the waste heat recovery system. The design point of the system uses a turbine inlet temperature of 1550^{O}F which produces 680 kw of electrical power for 3 turbines in a system and 750^{O}F of additional preheat. This design point was utilized in Figure 14 to examine sensitivities of market parameters, such as market price, sales price, and operation and maintenance expense. It can be seen by Figure 14 that under all conditions a return on investment (ROI) can be met without using leverage financing.

Figure 15 shows the relationship of simple payback and turbine inlet temperature of the equipment. It has been decided that a two year payback would be required for the system to be commercially viable. Figure 15 shows that a two year payback can be achieved with approximately 1310^{O}F turbine inlet temperature. In all cases evaluated, it is felt that at least 1300^{O}F flue gas temperatures can be achieved through air preheat. Even lower turbine inlet temperatures can be tolerated for the 29% industrial ROI, which is typical of most industries.

FIGURE 11

COMPETITIVE PRICING
(Engines with Generators Uninstalled)

Units	Size	Pressure Ratio	Compression Wheel Diameter	Turbine Wheel Diameter	Speed (RPM's)	Market Price	Cost/KW
Kongsberg Viking II	1400 KW	3.85:1	20"	22.5"	18,000	$ 380,000	$271/KW
Garrett 831-800	500 KW	11:1	2-Stage 9"	3-Stage N/A	41,730	200,000	400/KW
Garrett 990	3800 KW	12:1			7,200	1,300,000	180/KW
Garrett 85	250KW	3.2:1	2 compressors		40,700	100,000	400/KW
Solar Saturn	800 KW	6.2:1	8 stages	3 turbines	22,000	300,000	375/KW
Alpha Glass/ Garrett	750 KW	3.75:1	12.1"	13.5"	30,000	192,000	256/KW
Alpha Glass/ Garrett Recuperated	750 KW	3.75:1	12.1"	13.5"	30,000	350,000	466/KW
Alpha Glass/ Garrett Waste Heat	680 KW (3 SAS Units)	3.75:1	12.1"	13.5"	30,000	472,000	$670/KW

FIGURE 12

ESTIMATED WASTE GAS TEMPERATURE WITH PREHEATED COMBUSTION AIR

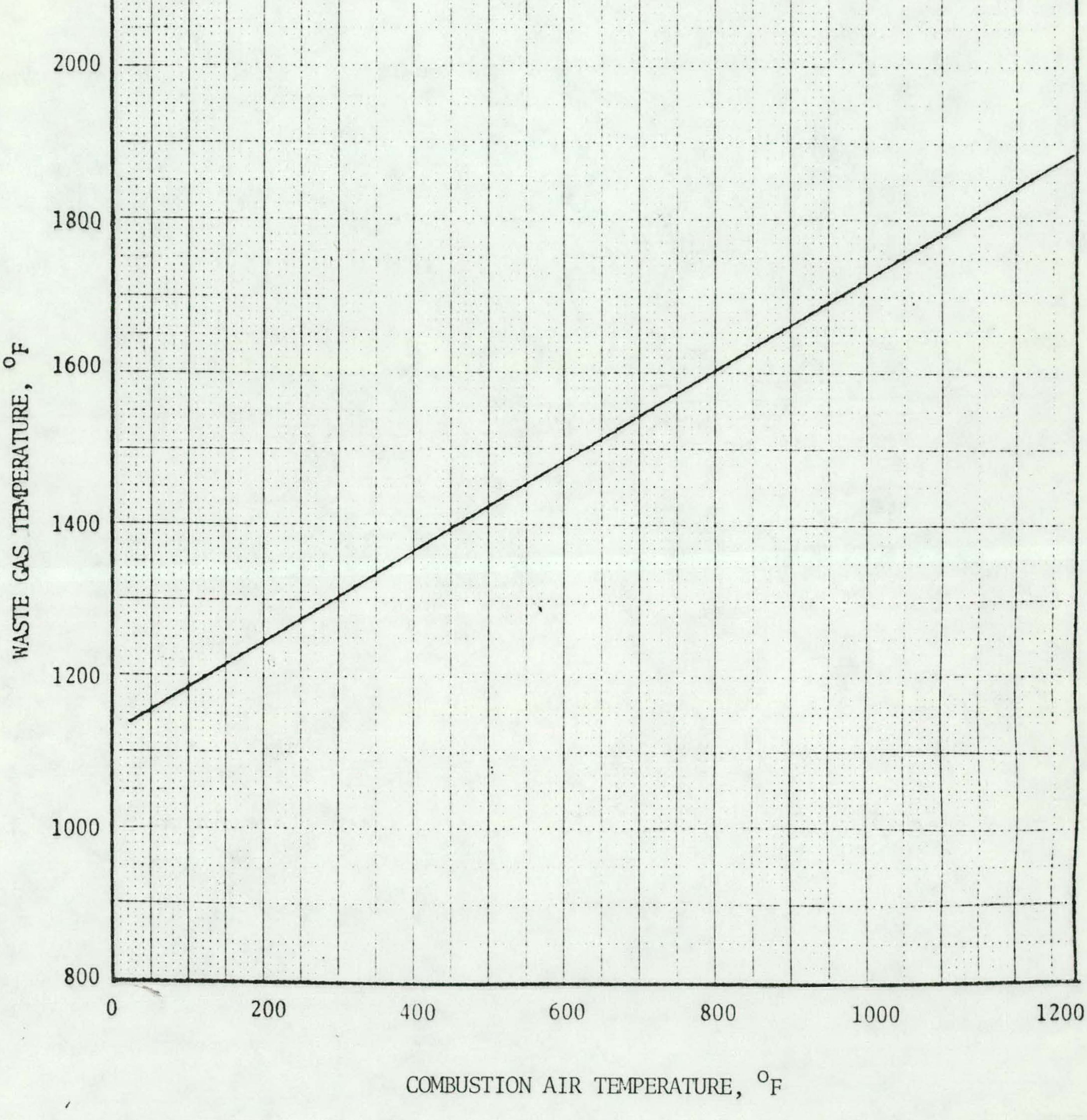

FIGURE 13

Effect of Turbine Inlet Temperature

Subatmospheric System

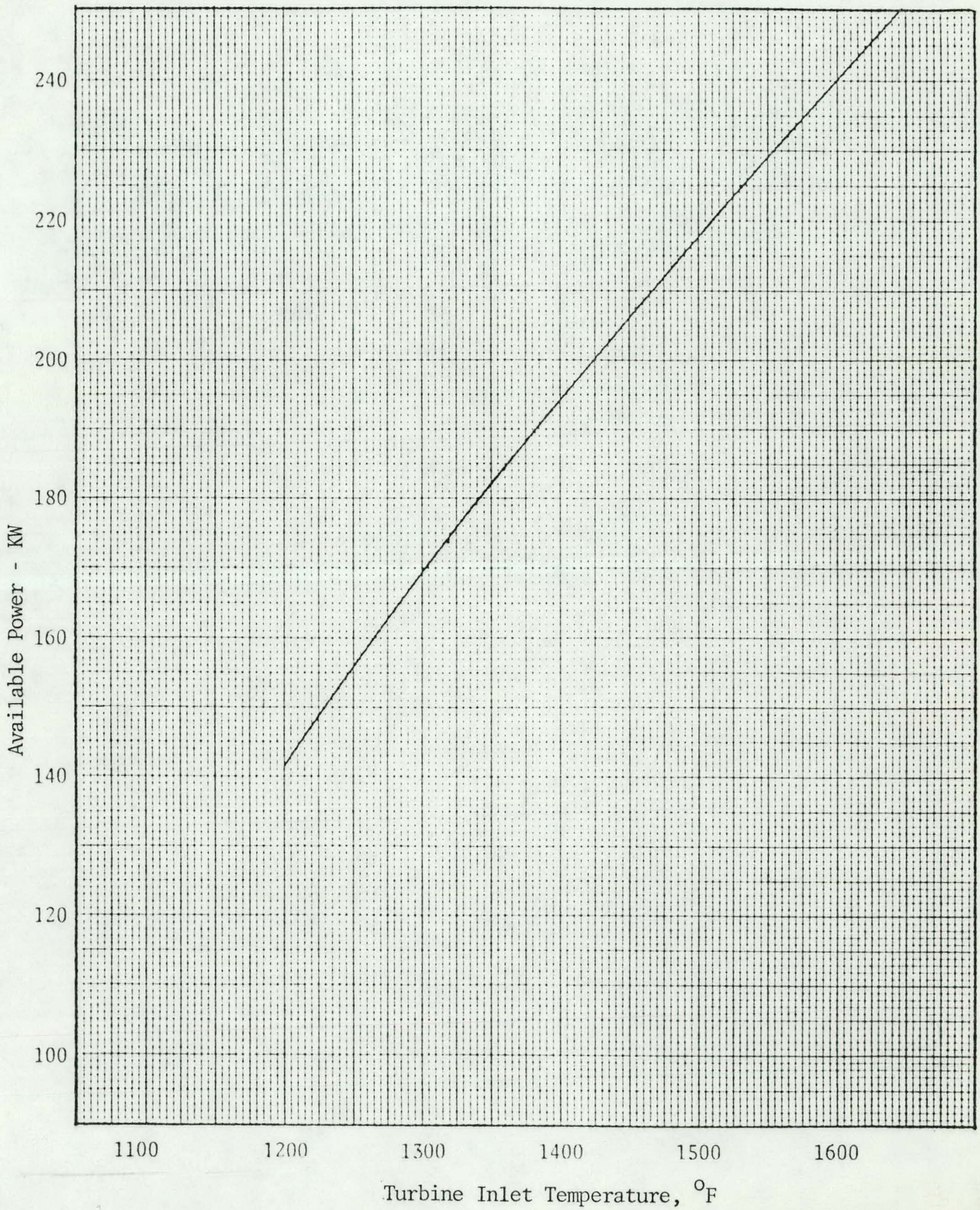

FIGURE 14

ROI SENSITIVITY ANALYSIS

KW	%	MBTU/TON	D/KW	D/Y	TPD	LIFE	%↑OM	%↑PE	%↑PF
680	.075	6	2.86	VAR.	200	7	.07	.1	.1

KWH	ΔFUEL MMBTU	$/KW	$/$10^6$ BTU	D/Y	CAPITAL INCREASES	O+M	COST	NOZZLE LIFE	TURBINE LIFE	ROI	CASE #
5,614,080	40,867	.04	3.80	344	Baseline	185,400	552,435	1/2 yr	1/2 yr	22.75	1
					+10%	203,940	607,679			18.95	2
					+20%	222,480	662,922			15.86	3
					+30%	241,020	718,166			13.05	4
5,663,040	41,224			347	Baseline	109,500	552,435	1/2 yr	1/2 yr	28.93	5
					+10%	120,450	607,679			26.01	6
					+20%	131,400	662,922			23.44	7
					+30%	142,350	718,166			21.15	8
5,712,000	41,580			350	Baseline	42,100	552,435	1 yr	3 yr	34.14	9
					+10%	46,310	607,679			31.75	10
					+20%	50,520	662.022			20.10	11
					+30%	54,730	718,166			27.04	12
5,744,640	41,818			352	Baseline	16,500	552,435	3 yr	7 yr	36.02	13
					+10%	18,150	607,679			33.62	14
					+20%	19,800	662,922			31,51	15
					+30%	21,450	718,166			29.17	16
5,614,080	40,857	.05	3.80	3.44	Baseline	185,400	552,435	1/2 yr	1/2 yr	27.76	17
					+10%	203,940	607,679			23.93	18
					+20%	222,480	662,922			21.23	19
					+30%	241,020	718,166			17.91	20

FIGURE 14 (CONT'D)

ROI SENSITIVITY ANALYSIS

KW	%	MBTU/TON	D/KW	D/Y	TPD	LIFE	%↑OM	%↑PE	%↑PF
680	.075	6	2.86	VAR.	200	7	.07	.1	.1

KWH	ΔFUEL MMBTU	$/KW	$/$10^6$ BTU	D/Y	CAPITAL INCREASES	O+M	COST	NOZZLE LIFE	TURBINE LIFE	ROI	CASE #
5,663,040	41,224			347	Baseline	109,500	552,435	1/2 yr	1 yr	33.58	21
					+10%	120,450	607,679			30.40	22
					+20%	131,400	662,922			27.55	23
					+30%	142,350	718,166			25.14	24
5,712,000	41,580			350	Baseline	42,100	552,435	1 yr	3 yr	37.95	25
					+10%	46,310	607,679			35.43	26
					+20%	50,520	662,922			33.07	27
					+30%	54,730	718,166			31.02	28
5,744,640	41,818			352	Baseline	16,500	552,435	3 yr	7 yr	39.41	29
					+10%	18,150	607,679			37.42	30
					+20%	19,800	667,922			34.73	31
					+30%	21,450	718,166			32.90	32
5,614,080	40,867	.06	3.80	344	Baseline	185,400	552,435	1/2 yr	1/2 yr	32.26	33
					+10%	203,940	607,679			28.38	34
					+20%	222,480	662,922			25.21	35
					+30%	241,020	718,166			22.28	36
5,663,040	41,224			347	Baseline	109,500	552,435	1/2 yr	1 yr	37.15	37
					+10%	120,450	607,679			34.36	38
					+20%	131,400	662,922			31.69	39
					+30%	142,350	718,166			28.82	40

FIGURE 14 (CONT'D)

ROI SENSITIVITY ANALYSIS

KW	%	MBTU/TON	D/KW	D/Y	TPD	LIFE	%↑OM	%↑PE	%↑PF
680	.075	6	2.86	VAR.	200	7	.07	.1	.1

KWH	ΔFUEL MMBTU	$/KW	$/$10^6$ BTU	D/Y	CAPITAL INCREASES	O+M	COST	NOZZLE LIFE	TURBINE LIFE	ROI	CASE #
5,712,000	41,5880			350	Baseline	42,100	552,435	1 yr	3 yr	41.61	41
					+10%	46,310	607,679			39.07	42
					+20%	50,520	662,922			36.39	43
					+30%	54,730	718,166			34.17	44
5,744,640	41,818			352	Baseline	16,500	552,435	3 yr	7 yr	43.45	45
					+10%	18,150	607,679			40.77	46
					+20%	19,800	662,922			38.18	47
					+30%	21,450	718,166			36.07	48
5,614,080	40,867	.06	4.50	344	Baseline	185,400	552,435	1/2 yr	1/2 yr	34.25	49
					+10%	203,940	607,679			30.50	50
					+20%	222,480	662,922			27.25	51
					+30%	241,020	718,166			24.37	52
5,663,040	41,224			347	Baseline	109,500	552,435	1/2 yr	1 yr	39.36	53
					+10%	120,450	607,679			36.17	54
					+20%	131,400	662,922			33.40	55
					+30%	142,350	718,166			30.99	56
5,712,000	41,580			350	Baseline	42,100	552,435	1 yr	3 yr	43.73	57
					+10%	46,310	607,679			40.76	58
					+20%	50,520	662,922			37.99	59
					+30%	54,730	718,166			35.64	60

FIGURE 14 (CONT'D)

ROI SENSITIVITY ANALYSIS

KW	%	MBTU/TON	D/KW	D/Y	TPD	LIFE	%↑OM	%↑PE	%↑PF
680	.075	6	2.86	VAR.	200	7	.07	.1	.1

KWH	ΔFUEL MMBTU	$/KW	$/$10^6$ BTU	D/Y	CAPITAL INCREASES	O+M	COST	NOZZLE LIFE	TURBINE LIFE	ROI	CASE #
5,744,640	41,818			352	Baseline	16,500	552,435	3 yr	7 yr	45.32	61
					+10%	18,150	607,679			42.17	62
					+20%	19,800	662,922			40.15	63
					+30%	21,450	718,166			37.48	64

FIGURE 15

PAYBACK VERSUS TURBINE INLET TEMPERATURE

7.0 MARKET GROWTH POTENTIAL

It is anticipated that the first subatmospheric Brayton-cycle system will be installed in calendar year 1982 under the DOE program. This system will serve as the required demonstration and validation to industry for the waste heat recovery using a Brayton-cycle. Our conversations with the glass industry have indicated the main marketing drawback to the Brayton-cycle has been a lack of understanding and acceptance of its performance characteristics. The industry requires that a system operate for a period of six months to a year prior to commercial procurement of a second system. This would mean that the second system will be installed probably after one year of operation of the first system and six months thereafter until a buildup is reached of one system per quarter. This buildup is shown in Figure 16. This buildup will be further evaluated when the costs of the initial unit versus a projected mature system are evaluated.

FIGURE 16

FORECAST MARKET GROWTH

SAS SYSTEM PENETRATION

YEAR	1980				1981				1982				1983				1984				1985			
QUARTERS	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4	1	2	3	4
SYSTEMS												1				1		1	1	1	1	1	1	1
UNITS												3				3		3	3	3	3	3	3	3

APPENDIX A

INVENTORY OF GLASS PLANTS IN U.S.

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APPENDIX A

SIC CODE 3211:	Flat Glass	$221/ton	(1976 price)
SIC CODE 3221:	Glass Containers	$250/ton	"
SIC CODE 3229:	Pressed and Blown Glass, not elsewhere classified	$819/ton	"
SIC CODE 3296:	Mineral Wool	$828/ton	"

EMPLOYMENT CATEGORY:

2 (20-49 employees)
3 (50-99 employees)
4 (100-249 employees)
5 (250-499 employees)
6 (500-999 employees)
7 (1000-2499 employees)
8 (2500-9999 employees)

APPENDIX A
(CONT'D)

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Alabama	3221	Brockway Glass	Montgomery		474.52	1.6	6
Arizone	3211	P.P.G. Industries	Phoenix		38.43	0.16	2
	3211	Aluminaire	Phoenix		39.67	0.16	2
Arkansas	3211	Fourco Glass	St. Smith	4	90.95	0.20	4
	3211	Feather-Lite	Malvern		127.68	0.53	4
	3211	Arkansas Glass Container	Jonesboro		90.95	0.20	4
	3229	Thomas Industries	Ft. Smith	18	29.77	0.31	4
	3229	Southwestern Glass	Van Buren		10.03	0.11	3
	3229	Arkseal Inc.	Harrison		3.67	0.04	2
California	3211	Libby-Owens-Ford	Lathrop		949.60	3.94	7
	3211	PPG	Fresno		53.30	0.22	3
	3211	Solartron Corp	San Francisco		29.75	0.12	2
	3211	Guardian Industries	Kingsburg		210.74	0.88	4
	3211	Sun Valley Tempered Glass	Oxnard		42.14	0.18	3
	3211	C-E Glass Co.	Carson		116.53	0.48	4
	3221	Ball Corp	El Monte		417.53	0.93	6
	3221	Brockway Glass	Oakland		169.86	0.38	5
	3221	Brockway Glass	Pomona		257.53	0.57	5
	3221	Gallo Glass	Modesto		561.09	1.25	6
	3221	Glass Containers	Antioch		943.56	2.10	7

APPENDIX A
(CONT'D)

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
California	3221	Glass Containers	Hayward		156.71	0.35	4
	3221	Glass Containers	Vernon		471.23	1.05	6
	3221	Madera Glass Div. of Indian Head	Madera		164.38	0.37	4
	3221	Kerr Glass	Santa Ana		86.57	0.19	4
	3221	Latchford Glass	Los Angeles		140.27	0.31	4
	3221	Latchford Glass	San Leandro		147.94	0.33	5
	3221	Latchford Glass	Huntington Park				
	3221	Owens-Illinois	Los Angeles				
	3221	Owens-Illinois	Oakland		1273.42	2.84	7
	3221	Owens-Illinois	Tracy		254.24	0.57	5
	3221	Thatcher Glass	Saugus		506.30	1.13	6
	3221	Glass Container	Fullerton		109.58	0.24	4
	3221	ACME Vial & Glass Corp	Los Angeles		20.82	0.05	2
	3229	Arrowhead Puritas Water	Gardena	1			
	3229	Brock Glass	Santa Ana	2			
	3229	The Glass Works	Huntington Beach	6			
	3229	Libby Glass Div of Owens-Illinois	City of Industry		46.16	0.48	5
	3229	Ray Lite-Glass	South Gate	6	3.67	0.04	2
	3229	C-E Glass	Fullerton		12.37	0.3	3
	3229	Reichold Chemical	Irwindale		7.02	0.07	2

APPENDIX A
(CONT'D)

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
California	3229	M B Glass Co.	El Monte		6.35	0.07	3
	3229	Astro Seal Co.	El Monte		3.67	0.04	2
	3229	Cambro Mfg Co	Huntington Beach		25.42	0.27	4
	3229	Dorothy C Thorpe	Sun Valley		3.67	0.04	2
	3229	T H Garner Co.	Claremont		9.03	0.09	3
	3229	Brock Glass Co	Irvine		3.67	0.04	2
	3229	Shore Frank Glass Co.	S. El Monte		4.68	0.05	2
	3229	Quartz General	El Monte		6.35	0.07	3
	3229	Koppe Precision Casting	Compton		5.01	0.05	2
	3229	M&M Lab Inc. Div of Bell Ind.	Sunnyvale		4.34	0.05	2
	3229	Glass Instruments	Pasadena		2.67	0.03	2
	3229	M&M Labs Inc.	Santa Clara		4.34	0.05	2
	3229	Reichold Chemicals	Huntington Beach		4.34	0.05	2
	3229	Glass Fiber	Azusa		26.75	0.28	4
	3296	Johns-Manville	Corona				
	3296	Johns-Manville	Willows				
	3296	Owens-Corning-Fiberglass	Santa Clara				
Colorado	3211	Cherry Creek Enterprises	Denver		29.75	0.12	2
	3211	Thermoglass Inc.	Denver		29.75	0.12	2

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Colorado	3221	Columbine Glass	Wheat Ridge				
	3221	Coors Container	Wheat Ridge		130.41	0.29	4
	3221	Geodesic Terrariums	Boulder		24.10	0.05	2
	3229	Pikes Peak Glass	Colorado Sprgs	2			
Connecticut	3211	Eclipse Glass	Thomaston		42.14	0.18	3
	3221	Glass Containers	Dayville		730.95	1.63	6
	3229	AGC Inc.	South Meridien		31.77	0.33	5
	3229	Macalaster Bicknell	New Haven		3.01	0.03	2
	3229	Conn Glass Processing Co.	Bristol		2.67	0.03	2
	3229	Glacierware Inc.	Clinton		3.67	0.04	2
	3229	Innotech	Trumbell				
	3229	Thermos Div. of Kings - Seeley Thermos	Norwich				
	3229	Thermos Div. of Kings - Seeley Thermos	Taftville				
Delaware	3211	Slocumb Ind.	Wilmington		32.23	0.13	2
Florida	3211	Guardian Ind.	Ft. Lauderdale				
	3221	Anchor Hocking	Jacksonville		355.06	0.79	6
	3221	Owens-Illinois	Lakeland		181.91	0.41	5
	3221	Industrial Glass	Bradenton		307.94	0.69	5

APPENDIX A
(CONT'D)

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Florida	3221	Thatcher Glass	Tampa		357.26	0.80	6
	3229	Pittsburgh Plate	Tampa		7.35	0.08	3
	3229	Dade Div. of American Hosp. Suppl.	Miami		7.02	0.07	2
	3211	Kennedy Sky-Lites	Orlando		21.07	0.09	2
Georgia	3221	Glass Containers	Forrest Park		296.98	0.66	5
	3221	Midland Glass	Warner Robins		204.93	0.46	4
	3221	Owens-Illinois	Atlanta		806.57	1.80	7
	3221	Newton Crouch	Griffin		40.54	0.09	3
	3229	Clark-Schwebel Fiber Glass	Washington		15.72	0.16	4
	3296	Certain-Teed Prod.	Athens				
	3296	Johns-Manville	Winder				
	3296	Owens-Corning Fiberglass	Fairburn				
Illinois	3211	Libbey-Owens-Ford	Ottawa		1402.09	5.82	7
	3211	PPG	Mt. Zion		490.91	2.04	5
	3211	Independent Insulating	Chicago		26.03	0.11	2
	3211	Elgin Precision	Carpenterville		26.03	0.11	2
	3211	Cadillac Glass	Chicago		148.75	0.62	4
	3211	Globe Amerada Glass Co.	Eld Grove Village		42.14	0.18	3

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Illinois	3211	Cardinal Glass	Rockford		42.14	0.18	3
	3211	Granite City Glass	Granite City		17.35	0.07	2
	3221	Anchor Hocking	Gurnee		295.89	0.66	6
	3221	Ball Corporation	Mundelein				
	3221	Hillsboro Glass	Hillsboro		175.34	0.39	5
	3221	Obear-Nestor Glass Div.of Indian Head	St. Louis		338.63	0.75	6
	3221	Obear-Nestor Glass Div.of Indian Head	Lincoln				
	3221	Kerr Glass	Plainfield		280.54	0.63	5
	3221	Metro Containers	Dolton		481.09	1.07	6
	3221	National Bottle	Joliet		140.27	0.31	4
	3221	Owens-Illinois	Alton		1718.35	0.83	8
	3221	Owens-Illinois	Streator		1400.54	3.12	7
	3221	Thatcher Glass	Streator		608.21	1.36	6
	3221	Capitol Mfg	Chicago		50.41	0.11	3
	3221	Braun Co.	Chicago		35.06	0.08	3
	3221	Continental	Chicago		41.64	0.09	3
	3221	Wheaton Plastic	Des Plaines		32.87	0.07	3
	3221	Pierce Glass	Lincoln		197.26	0.44	5
	3229	Eire Glass	Park Ridge				
	3229	Johnson Glass & Plastic Corp.	Chicago	6	9.03	0.09	3
	3229	Kimble Div. of Owens-Illinois	Chicago Heights		57.20	0.60	6

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Illinois	3229	Peltier Glass	Ottawa	8	11.37	0.12	3
	3229	Reha Glass	Chicago				
	3229	H S Martin Co.	Evanston		9.03	0.09	3
	3229	General Pool	Addison		9.03	0.09	3
	3229	Monogram of Evanston	Evanston		3.67	0.04	2
	3229	Hawley Products	St Charles		96.67	1.01	6
	3229	Plastic Rod	Chicago		3.67	0.04	2
	3229	A Glass Co.	Chicago		4.01	0.04	2
	3229	Kontes-Martin	Evanston		5.01	0.05	2
	3229	Reliance Glass	Bensenville		2.67	0.03	2
	3229	Union Wadding	Chicago		6.69	0.07	3
	3229	Hardy Corp.	Chicago		12.71	0.13	4
	3229	Beyer Manufacturing	Chicago		2.67	0.03	2
	3229	Classcrafters Illinois	Chicago		3.67	0.04	2
	3229	C & A Mfg Co.	Bensenville		2.67	0.03	2
	3229	Roper IBG	Aptakisic		40.81	0.43	5
	3229	Tyler & Hippach Glass Co.	Chicago		75.93	0.79	6
	3296	Johns-Manville	Waukegan				
Indiana	3221	Anchor Hocking	Winchester		635.15	1.46	7
	3221	Brockway Glass	Lapel		254.24	0.57	5
	3221	Foster-Forbes	Marion		583.01	1.30	6

APPENDIX A
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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Indiana	3221	Glass Containers	Gas City		156.71	0.35	4
	3221	Glass Containers	Indianapolis		392.32	0.87	6
	3221	Kerr Glass	Plainfield				
	3221	Midland Glass	Terre-Haute		357.26	0.80	5
	3221	Owens-Illinois	Gas City		572.05	1.28	6
	3221	Thatcher Glass	Lawrenceburg		405.47	0.90	6
	3221	Fulton Glass	Vincennes		20.32	0.05	2
	3221	Kerr Glass	Dunkirk		748.49	1.67	7
	3229	Canton Glass	Hartford City	11			
	3229	Corning Glass	Bluffton		85.30	0.89	6
	3229	Indiana Glass	Dunkirk	18	89.98	0.94	6
	3229	Kokomo Opalescent Glass	Kokomo				
	3229	Kimble Div. of Owens-Illinois	Warsaw		34.45	0.36	5
	3229	St. Clair Glass Works	Elwood	4			
	3229	Sinclair Glass	Hartford City	11			
	3229	Harris Mfg Co.	South Bend		3.67	0.04	2
	3229	Travomatic	Seymour		4.68	0.05	2
	3229	Prescotch Inc.	Evansville		7.35	0.08	3
	3229	Fiberfil	Evansville		21.40	0.22	4
	3229	Owens Corning Fiberglass	Valparaiso		8.69	0.09	3
	3296	Certain-Teed	Shelbyville				
	3296	Johns-Manville	Richmond				

APPENDIX A

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Iowa	3211	Libbey Owens Ford Glass	Mason City		143.80	0.60	4
Kansas	3296	Certain-Teed Products	Kansas City				
	3296	Certain-Teed Products	Wichita Falls				
	3296	Johns-Manville	McPherson				
	3296	Owens-Corning Fiberglass	Kansas City				
	3229	Westinghouse Electric Corp.	Saline				
Kentucky	3211	PPG Industries	Louisville		53.30	0.22	3
	3229	Corning Glass	Danville		85.30	0.89	6
	3229	Corning Glass	Harrodsburg		72.93	0.76	5
	3229	General Electric	Lexington				
	3229	General Electric	Somerset		24.08	0.25	4
	3229	GTE-Sylvania	Verseilles				
	3229	Venezian Art Glass	Calletsburg				
	3229	Louisville Optical Co.	Louisville		6.69	0.07	3
Louisiana	3221	Laurens Glass Div. of Indian Head	Ruston		225.75	0.50	5
	3221	Owens-Illinois	New Orleans		238.90	0.53	5

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Louisiana	3221	Underwood Glass	Harahan				
	3229	Libbey Glass Div. of Owens-Illinois	Shreveport		103.36	1.08	6
Maryland	3211	PPG Industries	Cumberland		338.63	1.59	5
	3221	Chattanooga Glass	Baltimore				
	3221	Columbia Glass	Baltimore		25.20	0.06	2
	3221	Carr-Lowrey Div. of Anchor Hocking	Baltimore		355.06	0.79	6
	3221	Flynn & Emrich	Baltimore		266.30	0.59	5
	3221	Glass Crafters	Sparrows Pt		88.76	0.20	4
	3221	Glass Vials	Baltimore		31.78	0.07	2
	3221	Wheaton Tubing	Easton		27.39	0.06	2
	3221	Maryland Glass	Baltimore		352.87	0.79	5
	3229	Anchor Hocking	Baltimore				
	3229	Kimble-Terumo Div. of Owens-Illinois	Elkton				
Massachusetts	3211	Guardian Industries	Webster				
	3211	Solar X Corp	Newton		64.46	0.27	3
	3211	North Shore Glass & Aluminum	Salem		17.36	0.07	2
	3221	Foster-Forbes	Milford		162.19	0.36	5
	3221	Owens-Illinois	Mansfield				
	3221	Shawmut Glass	Needham		13.15	0.03	2

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Massachu-setts	3221	Ropax Inc.	Norwood		24.11	0.05	2
	3229	American Optical	Southbridge		16.72	0.18	4
	3229	Emerson & Cuming	Canton				
	3229	GTE Sylvania	Danvers				
	3229	GTE Sylvania	Ipswich				
	3229	Valtec Corp.	West Boylston		65.23	0.68	5
Michigan	3211	Ford Motor	Dearborn				
	3211	Guardian Ind.	Carleton		210.75	0.88	4
	3211	Guardian Ind.	Detroit				
	3211	McGraw Glass Plant	Detroit		391.23	1.84	6
	3211	Guardian Ind.	Northville		303.73	1.26	4
	3211	Double Seal Insulated Glass	Flint		127.69	0.53	4
	3211	Van Guard Glass Fabrication	Holland		34.71	0.14	2
	3211	Thermoproof Glass	Detroit		65.70	0.27	3
	3221	Owens-Illinois	Charlotte		461.37	1.03	6
Minnesota	3221	Brockway Glass	Rosemount		304.66	0.68	5
	3221	Midland Glass	Shakopee		201.64	0.45	4
	3211	Minneapolis Glass	Minneapolis		29.75	0.12	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Mississipi	3221	Chattanooga Glass	Gulf Port		130.41	0.29	4
	3221	Chattanooga Glass	Mineral Wells		162.19	0.36	4
	3221	Glass Containers	Jackson		210.41	0.47	5
	3229	Ferro Corporation	Flowood				
	3229	General Electric	Jackson		17.06	0.18	3
	3229	Cataphote Div. of Ferro Corp.	Jackson		17.40	0.18	4
Missouri	3211	C - E Glass	Saint Louis		116.53	0.48	4
	3211	PPG Industries	Crystal City		762.41	3.17	6
	3229	Pittsburg Corning	Sedalia	3	17.40	0.18	4
	3229	Pittsburg Corning-JV PPG	Sedalia		20.41	0.21	4
	3229	Flex-O-Lite	St Louis		10.70	0.11	3
Nebraska	3229	Wheaton Tubing Products	Syracuse		8.03	0.08	3
New Hampshire	3229	GTE Sylvania	Greenland		13.72	0.14	3
New Jersey	3211	C - E Glass	Cinnaminson				
	3211	W. Skinner & Son	Hammonton		26.03	0.11	2
	3211	C - E Glass	Pennsauken		1470.28	6.11	7
	3221	Anchor Hocking	Salem		474.52	1.06	6

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
New Jersey	3221	Brockway Glass	Freehold		414.25	0.92	6
	3221	Kerr Glass	Millville		797.81	1.78	7
	3221	Leone Industries	Bridgeton		32.11	0.23	4
	3221	Metro Containers	Jersey City		42.74	0.95	6
	3221	Metro Containers	Carteret		288.22	0.64	5
	3221	Midland Glass	Cliffwood		625.17	1.40	6
	3221	Owens-Illinois	Bridgeton		955.62	2.13	7
	3221	Owens-Illinois	North Bergen		572.05	1.28	6
	3221	Thatcher Glass	Wharton				
	3221	Wheaton Glass	Millville		713.45	1.59	7
	3221	Newman Glass Works	Camden		16.44	0.04	2
	3221	Meteor Glass	Vineland		24.11	0.05	2
	3221	Metro Containers	Lyndhurst		427.40	0.95	6
	3221	Masden Industries	North Bergen		70.14	0.16	4
	3229	Friedrich & Dimmock	Millville				
	3229	Kimble Div. of Owens-Illinois	Vineland		230.15	2.41	7
	3229	Potters Industries	Carlstadt				
	3229	Thermal American Fused Quartz	Mintville				
	3229	Wheaton Glass	Millville				
	3229	Wheaton Products	Millville				
	3229	National Glass Plastic Inc.	Newfield		3.67	0.04	2

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
New Jersey	3229	Precision Electronic Glass	Vineland		3.67	0.04	2
	3229	Thermoseal Glass	Gloucester		3.67	0.04	2
	3229	Air Seal Insulating Glass	Gloucester		3.67	0.04	2
	3229	Adler Milton	Atlantic		3.35	0.04	2
	3229	Glass Products	Somers Point		8.36	0.09	3
	3229	Sediver Inc.	Carlstadt		4.35	0.05	2
	3229	O-1/Schott Process Systems	Vineland		21.74	0.23	4
	3229	Corning Pharmaceu-tical Pkg Systems	North Bergen		3.67	0.04	2
	3229	Franklin Glass Co.	Franklinville		3.35	0.04	2
	3229	Triton Associated	Buena		6.69	0.07	3
	3229	Doerr Glass	Vineland		2.34	0.02	2
	3296	Certain-Teed	Berlin				
	3296	Johns-Manville	Berlin				
	3296	Owens-Corning-Fiberglass	Barrington				
New York	3211	Bausch & Lomb	New York		169.34	0.71	5
	3211	Cosmetric Components Corp.	Glendale		29.75	0.12	2
	3211	New England Laminates Co.	Walden		57.03	0.24	4

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
New York	3211	Ventarama Skylight Corp.	Port Washington		32.23	0.13	2
	3221	Glenshaw Glass	Orangeburg		315.62	0.70	5
	3221	Leone Industries	Rochester		119.45	0.27	4
	3221	Owens-Illinois	Brockport		444.93	0.99	6
	3221	Thatcher Glass	Elmira		812.05	1.81	7
	3221	Arklys Inc.	Chester		24.11	0.05	2
	3221	Kleer Pak Plastic	Inwood		27.40	0.06	3
	3229	American Optical	Buffalo		812.05	1.81	7
	3229	Bausch & Lomb	Rochester				
	3229	Corning Glass	Corning		23.75	0.25	4
	3229	Corning Glass	Corning		1792.03	18.76	9
	3229	Eastman Kodak	Rochester				
	3229	Gillinder Brothers	Port Jervis	5	12.71	0.13	4
	3229	Warren L. Kessler	Bethpage	21			
	3229	Super Glass	Brooklyn	15	34.79	0.36	5
	3229	Corning Glass Works	Canton		34.12	0.36	4
	3229	Corning Glass Works	Horseheads		8.70	0.09	3
	3229	Pfeiffer Glass	Rochester		15.05	0.16	4
	3229	Matson Mfg	Long Island City		19.07	0.20	4
	3229	Peerless Art	Brooklyn		3.67	0.04	2
	3229	Chesler Glass	Brooklyn		9.03	0.09	3
	3229	Bent Glass Works	Kew Gardens		7.69	0.08	3
	3229	Cavalier Glass	Long Island City		4.01	0.04	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
New York	3229	Lunette de Paris	Glen Head		6.36	0.07	3
	3229	Elmont Glass	Garden City		3.01	0.03	2
	3296	Owens-Corning Fiberglass	Delmar				
North Carolina	3211	Libbey-Owens-Ford	Laurinburg		618.61	2.57	6
	3211	Thermopane Glass	Clinton		143.80	0.60	4
	3221	Ball Corporation	Asheville		209.32	0.47	5
	3221	Laurens Glass Div. of Indian Head	Henderson		373.70	0.83	6
	3221	Owens-Illinois	Winston-Salem		238.90	0.53	5
	3221	Kerr Glass Mfg	Wilson		211.51	0.47	5
	3229	PPG Industries	Lexington		256.91	2.69	7
	3229	PPG Industries	Shelby		234.83	2.46	7
	3229	United Merchants	Statesville				
Ohio	3211	Guardina Industries	Millbury				
	3211	Guardina Industries	Upper Sandusky				
	3211	Libbey-Owens-Ford	East Toledo		1816.15	7.54	7
	3211	Libbey-Owens-Ford	Rossford		2062.85	8.57	8
	3211	Paul Manufacturing	Lewisburg		23.01	0.11	2
	3211	Ohio Plate Glass	Toledo		42.15	0.18	3
	3211	Advance Glass	Newark		17.36	0.07	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Ohio	3211	C - E Glass	Lancaster		203.31	0.84	4
	3221	Chattanooga	Mount Vernon		368.22	0.82	5
	3221	Kaufman Container Co.	Independence		17.53	0.04	2
	3229	Brockway Glass	Zanesville		122.43	1.28	7
	3229	Anchor Hocking	Lancaster		42.82	4.48	8
	3229	E. O. Brody	Cleveland				
	3229	Corning Glass	Greenville	3	102.36	1.07	6
	3229	Crystal Art Glass	Cambridge	1			
	3229	Federal Glass	Columbus				
	3229	General Electric	Willoughby				
	3229	General Electric	Logan		38.14	0.40	4
	3229	General Electric	Bucyrus				
	3229	General Electric	Niles		47.34	0.50	5
	3229	General Electric	Cleveland		258.92	2.71	7
	3229	Guernsey Glass	Cambridge	3			
	3229	Labind Glass	Grand Rapids				
	3229	Lancaster Glass	Lancaster		102.03	1.07	6
	3229	Imperial Glass Corp. a subsidiary of Lennox Crystal, Inc.	Bellaire	9			
	3229	Libbey Glass Div. of Owens-Illinois	Toledo		252.90	2.65	7
	3229	TV Products Div. of Owens-Illinois	Columbus		109.36	1.15	6

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Chio	3229	TV Products Div. of Owens-Illinois	Perrysberg				
	3229	RCA Corporation	Circleville		80.95	0.85	6
	3229	Rcdefer-Gleason Glass	Bellaire	5	20.41	0.21	4
	3229	Techniglas, Inc.	Newark	1			
	3229	Variety	Cambridge	2	3.67	0.04	2
	3229	Holophane Div. of Johns-Manville	Newark		59.21	0.62	5
	3229	Johns-Manville	Waterville		26.76	0.28	4
	3229	Quality Glass	Cambridge		6.36	0.07	3
	3229	Johns-Manville Fiberglass	Defiance		75.27	0.79	5
	3229	Tiffin Glass	Tiffin		102.36	1.07	4
	3229	Cambridge Glass	Cambridge		15.72	0.16	4
	3229	Reichhold Glass Fiber	Bremen		44.49	0.47	5
	3229	White Consolidated Industries	Cleveland		12.71	0.13	4
	3229	Cadillac Glass	McComb		3.01	0.03	2
	3229	Accurate Glass & Mirrow Co.	Columbus		3.67	0.04	2
	3229	Commercial Aluminum Cookware	Perrysburg		7.69	0.08	3
	3229	Curt Products Inc.	Willoughby		5.02	0.05	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Chio	3229	Midwest Architechtural Metals	Eastlake		3.01	0.03	2
	3229	Lancaster Colony	Columbus		3.35	0.04	2
	3296	Johns-Manville	Waterville				
	3296	Johns-Manville	Defiance				
	3296	Owens-Corning Fiberglass	Newark				
Oklahoma	3211	AGS Industries	Okmulgee				
	3211	Ford Motor Co.	Tulsa		756.21	3.14	6
	3211	Pittsburgh Plate Glass Co.	Oklahoma City		53.31	0.22	3
	3211	Tulsa Glass Plant	Tulsa		419.02	1.74	5
	3221	Ball	Okmulgee		278.36	0.62	5
	3221	Brockway Glass	Muskogee		428.49	0.96	6
	3221	Brockway Glass	Ada		257.53	0.57	5
	3221	Kerr	Sands Springs		155.62	0.35	5
	3221	Liberty Glass	Sapulpa		561.10	1.25	6
	3221	Midland Glass	Henryetta		268.49	0.60	5
	3229	Bartlett-Collins	Sapulpa	2	50.85	0.53	5
	3229	Corning Glass	Muskogee	2	104.04	1.09	6
	3229	Scott Glass	Cedars				
	3229	Scott Glass Products	Pocola		39.67	0.16	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Oregon	3221	Owens-Illinois	Portland		317.81	0.71	6
Pennsyl-vania	3211	ASG Industries	Jeannette				
	3211	PPG Industries	Carlisle		368.19	1.53	5
	3211	PPG Industries	Meadville		709.11	2.94	6
	3211	Pittsburgh Plate Glass Co.	Ford City		1306.64	5.43	7
	3211	J. Melvin Freed	Perkasie		94.22	0.39	4
	3211	Franklin Glass	Butler		26.03	0.11	2
	3211	Perilstein Glass	Philadelphia		79.34	0.33	4
	3211	PPG Industries	Altoona		33.47	0.14	2
	3211	Pierce Glass	Port Allegheny		360.75	1.50	6
	3211	Houze Glass	Point Marion		182.24	0.76	4
	3221	Brockway Glass	Washington				
	3221	Diamond Glass	Roversford		293.70	0.65	5
	3221	Foster Forbes	Oil City				
	3221	Glass Containers Corporation	Knox		313.42	0.70	5
	3221	Glass Containers Corporation	Marienville		256.96	0.56	5
	3221	Glass Containers Corporation	Parker		230.14	0.51	5
	3221	Glenshaw Glass	Glenshaw		702.47	1.57	7
	3221	Menlo Containers	Washington				
	3221	Owens-Illinois	Clarion				

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Pennsyl-vania	3221	Anchor Hocking	Connellsville		677.26	1.51	7
	3221	Brockway Glass	Brockway		352.88	0.79	6
	3221	Metropak Containers	Washington		249.86	0.56	5
	3221	Owens Illinois Glass	Clarion		529.32	1.18	6
	3221	National Bottling	Horsham		298.08	0.66	5
	3221	Oil City Glass	Oil City		13.15	0.03	2
	3221	Erno Products	Philadelphia		24.11	0.05	2
	3229	Corning Glass	Charleroi		160.57	1.68	6
	3229	Corning Glass	State College		102.36	1.07	6
	3229	Corning Glass	Wellsboro	2	87.98	0.92	6
	3229	Corning Glass	Bradford	1			
	3229	General Electric	Bridgewill		26.76	0.28	4
	3229	K. R. Haley Glass	Greensburg				
	3229	Jeannette Corp.	Jeannette	4	134.48	1.41	6
	3229	Jeannette Shade and Novelty	Jeannette	5	11.37	0.12	3
	3229	J. H. Millstein	Jeannette				
	3229	Kopp Glass	Swissvale		20.74	0.22	4
	3229	Lennox Crystal	Mount Pleasant	2	34.46	0.36	5
	3229	Mayflower Glass Works	Latrobe				
	3229	Kimble Div. of Owens-Illinois	Philadelphia				
	3229	Kimble Div. of Owens-Illinois	Pittston				

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Pennsylvania	3229	TV Prod. Div. of Owens-Illinois	Pittston				
	3229	Pennsylvania Glass Products	Pittsburg		34.12	0.36	5
	3229	Phoenix Glass	Monaca	8	53.52	0.56	6
	3229	Pittsburg Corning	Port Allegheny	3	25.42	0.27	4
	3229	Schott Optical Glass	Duryea		63.56	0.67	6
	3229	L. E. Smith Glass	Mount Pleasant		34.12	0.36	5
	3229	Victory Glass	Jeannette		20.07	0.21	4
	3229	Westmoreland Glass	Grapeville	5	29.77	0.31	4
	3229	Owens-Corning Fiberglass	Huntington		175.29	1.84	6
	3229	Owens Illinois	Pittsburgh		57.20	0.60	6
	3229	National Plastics	Jeannette		14.38	0.15	4
	3229	Behrenberg Glass	Delmont		6.36	0.07	3
	3229	Glass Beads	Latrobe		4.35	0.05	2
	3229	Corning Glass Works Inc.	Greencastle		83.96	0.88	5
	3229	Sentinel Glass	Hatboro		3.35	0.04	2
	3229	Fredericks Co.	Huntingdon Vly		7.69	0.08	3
	3229	Hydra Matic Packing Co.	Huntingdon Vly		6.69	0.07	3
	3229	George J. Kreier	Philadelphia		3.67	0.04	2
	3229	B P Fiberglass	Horsham		2.68	0.03	2

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Pennsyl-vania	3229	Houston Electronics	Kane		22.75	0.24	4
	3296	Certain-Teed	Mountaintop				
Rhode Island	3211	Geo J. Geisser	E. Providence		21.07	0.09	2
	3211	Conklin Limestone	Lincoln		17.36	0.07	2
	3211	Quick-Crete Taggert Sand	Lincoln		210.75	0.09	2
	3211	Cardi Corp	Middletown		210.75	0.09	2
	3221	National Bottle Corporation	Coventry		245.48	0.55	5
	3229	Corning Glass Works	Central Falls		102.36	1.07	6
	3229	Coby Glass Products	Woonsocket		12.71	0.13	4
	3229	Tillotson-Pearson	Warren		9.37	0.10	3
	3229	Owen-Corning-Fiberglass	Ashton		87.64	0.92	6
South Carolina	3221	Laurens Glass Div. of Indian Head	Laurens		338.63	0.75	6
	3229	Owens-Corning Fiberglass	Aiken		263.60	2.76	7
	3229	Owens-Corning Fiberglass	Anderson		270.63	2.83	7
	3229	Beden-Baugh Products	Lauren		7.02	0.07	3
	3229	International Reinforced Plastics	Denmark		10.70	0.11	3

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Tennesse	3211	ASG Industries	Greenland				
	3211	ASG Industries	Kingsport		163.64	0.68	4
	3211	Ford Motor Co.	Nashville		2314.51	9.61	8
	3211	Gemtron Corp.	Sweetwater		66.94	0.28	3
	3211	Laukhuff Stained Glass Inc.	Memphis		21.07	0.09	2
	3211	Architectural Metals Co.	Knoxville		210.75	0.09	2
	3211	Avondale Farms Creamery	Knoxville		115.29	0.48	4
	3211	Dorco Mfg Co.	Gallatin		39.67	0.16	2
	3211	Hillsdale Industries Inc.	Knoxville		42.15	0.18	3
	3221	Chattanooga Glass	Chattanooga		598.36	1.33	6
	3229	Reichold Chemical	Nashville		79.62	0.83	5
	3229	Owens-Corning Fiberglass	Jackson		158.23	1.66	6
	3229	PPG Industries	Knoxville		4.35	0.05	2
Texas	3211	PPG Industries	Wichita Falls		1089.69	4.53	7
	3211	Layne Glass	Fort Worth		29.75	0.12	2
	3211	Northrup Inc.	Hutchins		64.46	0.27	3
	3221	Anchor Hocking	Houston		133.70	0.30	4
	3221	Chattanooga Glass	Corisicana		230.14	0.51	5
	3221	Glass Containers Corp.	Palestine		392.33	0.87	6

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Texas	3221	Kerr Glass	Waxahachie		108.49	0.24	4
	3221	Owens-Illinois	Waco		955.62	2.13	7
	3229	EMC Glass	Decatur	7			
	3229	Multicolor Glass	San Antonio	2			
	3229	Ewald Red Tractor	E. Karnes City		3.67	0.04	2
	3229	Natex Fiberglass	Carrollton		3.67	0.04	2
	3229	Owens-Corning Fiberglass	Amarillo		24.75	0.26	4
	3229	Scientific Glass & Instrument	Houston		9.37	0.10	3
	3229	Glenco Scientific	Houston		6.69	0.07	3
	3229	Owens-Corning Fiberglass	Conroe		30.78	0.32	4
	3296	Johns-Manville	Cleburne				
	3296	Owens-Corning Fiberglass	Waxahachie				
Virginia	3211	Pittsburgh Plate	Richmond		53.31	0.22	3
	3229	Corning Glass Works	Danville		119.42	1.25	6
Washington	3211	Northwestern Ind.	Seattle		59.51	0.25	3
	3211	Nuclear Pacific	Seattle		29.72	0.12	2
	3221	Northwestern Div. of Indian Head	Seattle		395.62	0.88	6
	3229	Ershings Inc.	Bellingham		15.72	0.16	4

STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
Washington	3229	Pyrotek Inc.	Spokane		6.36	0.07	3
	3229	Penberty Glass Div. of Nuclear Pacific	Seattle				
West Virginia	3211	Fourco Glass	Clarksburg				
	3211	Libbey-Owens-Ford	Charleston		391.74	1.63	5
	3211	Fourco Glass	Bridgeport		709.11	2.94	6
	3211	Rolland Glass	Clarksburg		189.67	0.79	4
	3211	L. G. Wright Glass	New Martinsville		30.99	0.13	2
	3221	Kerr Glass	Huntington		180.82	0.40	5
	3221	National Bottle Corporation	Parkersburg		175.34	0.39	5
	3221	Owens-Illinois	Fairmont		668.49	1.49	7
	3221	Owens-Illinois	Huntington		1059.73	2.36	7
	3221	Helmick Corp	Fairmont		60.27	0.13	3
	3221	Chattanooga Glass	Keyser		211.51	0.47	4
	3229	Blenko Glass	Milton		19.07	0.20	4
	3229	Brockway Glass	Clarksburg	6	53.52	0.56	6
	3229	Demuth Glass Div. of Brockway	Parkersburg	1			
	3229	Colonial Glass	Weston	1			
	3229	Corning Glass	Martinsburg	1			
	3229	Corning Glass	Parkersburg	2	89.94	0.94	6
	3229	Crescent Glass	Wellsboro				
	3229	Beaumont	Morgantown		20.41	0.21	4

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
West Virginia	3229	Davis Lynch Glass	Roversford				
	3229	Elite Company	Cameron				
	3229	Erskine Glass	Wellsburg		6.36	0.07	3
	3229	Fenton Art Glass	Williamstown	11	50.85	0.53	5
	3229	Fostoria Glass	Moundsville	3	43.49	0.46	6
	3229	Gentile Glass	Star City	2			
	3229	Gladding-Vitro-Agate	Parkersburg	12			
	3229	Hamon Hancrafted Glass	Dunbar	3			
	3229	Harvey Industries	Clarksburg	7			
	3229	Kanawha Glass	Dunbar	8	7.02	0.07	3
	3229	Lewis County Glass	Jane Lew	1	14.05	0.15	4
	3229	Louie Glass	Weston	3	25.42	0.27	4
	3229	Mid-Atlantic Glass	Ellenboro	1	14.72	0.15	4
	3229	Minners Glass	Salem	2			
	3229	Pennsboro Glass	Pennsboro	1	8.36	0.09	3
	3229	Pilgrim Glass	Ceredo	8	14.38	0.15	4
	3229	Rainbow Art Glass	Huntington	7			
	3229	Scandia Glass Works	Kenova	6	5.69	0.06	2
	3229	Seneca Glass	Morgantown		15.72	0.16	4
	3229	Earl Shelby Glass	Huntington				
	3229	Sloan Glass	Culloden				
	3229	Viking Glass	New Martinsville	4	25.42	0.27	4

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STATE	SIC CODE	MANUFACTURER	PLANT LOCATION	NUMBER OF FURNACES	TON/DAY	INDUSTRY %	EMPLOYMENT CATEGORY
West Virginia	3229	Viking Glass	Huntington	6			
	3229	West Virginia Glass Specialty	Weston	3	56.87	0.60	5
	3229	Westinghouse Electric Corp.	Fairmount				
	3229	Paul Wissmach Glass	Paden City				
	3229	Corning Glass Works	Paden City		67.24	0.70	5
	3229	Bailey Glass	Morgantown		19.40	0.20	4
	3229	Sloan Glass Inc.	Culloden		5.69	0.06	2
	3229	Crescent Glass	Wellsburg		12.38	0.13	3
	3229	Alco Glassware	Salem		17.06	0.18	4
	3229	Harvey Industries	Nutr. Ft. Stnwd		12.71	0.13	4
	3229	Quality Glass	Morgantown		3.35	0.04	2
	3229	Davis Lynch Glass	Star City		26.76	0.28	4
	3229	Brockway Glass Demuth Div.	Vienna		40.48	0.42	5
	3296	Johns-Manville	Vienna				
Wisconsin	3221	Foster-Forbes Glass	Burlington		323.29	0.72	6

ATTACHMENT B

EMISSION CONTROL TECHNIQUES
IN
GLASS INDUSTRY

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1.0 EMISSION CONTROL TECHNIQUES

1.1 INTRODUCTION

As identified in Chapter 3.0 of this document, emissions of nitric oxides, particulates, and sulfur oxides comprise the largest weight of pollutants released to the atmosphere by the uncontrolled manufacture of glass products. Examination of the emissions of these key pollutants for the three major operations of glass manufacturing, namely, raw material handling, glass melting, and forming and finishing, shows that essentially 100 percent of the oxides of nitrogen, 98 percent of the particulate, and essentially all of the oxides of sulfur are generated in the melting of glass. Because emissions are centered in the glass melting operations, the emission control techniques described in this chapter deal with reduction of airborne emissions in the furnace exhaust. In addition to the previously mentioned major pollutants, which are emitted from all fossil-fuel fired glass melting furnaces, other pollutants emitted only from the production of special glass formulations pose potential health problems. These pollutants are: florine, lead, and arsenic.

As broadly applied in the glass industry, manufacturing methods termed "process modifications" lower glass melting furnace emissions either by altering raw material recipes or by modifying furnace equipment. In contrast to this definition, add-on control equipment refers to devices which treat only the glass melting furnace gaseous exhaust. In the next section of this chapter process modifications are discussed; all-electric melters are described in Section 4.3; in the following three sections add-on control techniques are described; in the last sections the control techniques are summarized and reduction of arsenic, lead, fluorine, and sulfur oxide emissions are discussed. For each glass furnace test, the values of pertinent manufacturing rates and control system parameters are listed in this chapter. No additional discussions of the tests are made elsewhere in this document.

In general, two stack sampling methods have been used to measure particulate levels in the stack gases from glass melting furnaces. Both methods ensure that the sample withdrawn from the stack accurately represents the stack exhaust. Both methods use the same sampling equipment -- a stack probe, a filter, and a set of impingers maintained at a temperature of 0°C (32°F). The basic difference between the two methods is the configuration of the sampling equipment. In one method, called the EPA Method 5,[1] the filter is maintained at about 120°C(250°F) and is placed upstream of the impingers. In the other method, developed by the Los Angeles Air Pollution Control District,[2] the impingers are placed upstream of the filter. The calculation of particulate emissions in the EPA Method 5 involves determining the dry weight of particulates captured in the probe and in the filter. In the Los Angeles method, the increase in weight of the impingers is measured by evaporating the impinger solutions, and this dry weight is included with the dry weights of particles captured in the probe and filter to determine particulate emissions.

The EPA Method 5 has become the standard method for analyzing particulate emissions and is used as the basis of emissions in this document. Although no study has compared results of these methods on the same furnace exhaust, knowing the chemical composition of glass particulate emissions comparisons can be projected. It is expected that the Los Angeles sampling configuration should not affect the particulate catch to any extreme. Additionally, the Los Angeles testing method should calculate slightly higher particulate emission levels than the EPA Method 5.[3]

1.2 PROCESS MODIFICATIONS

1.2.1 BATCH FORMULATION ALTERATIONS

Process modifications employed in the manufacturing of glass to lower emissions include reducing amounts of materials in the feed which vaporize at furnace temperatures, increasing the fraction of recycled glass in the furnace feed, installing sensing and controlling equipment on the furnace, modifying burner design and firing pattern, and utilizing electric boosting. The applicability of electric boosting for lowering glass melting furnace emissions is discussed in the following subsection. Some process modifications offer the double benefits of lowering pollutant emission rates and of lowering fossil fuel consumption rates.

Because emission tests are not available to document the lowering of particulate emissions by using process modifications, the evidence substantiating the efficacy of these methods is not ~~as quantitative~~ as ~~is that for the other control strategies~~ discussed later in this chapter. Nevertheless, these control methods and the approach to particulate emission control warrant consideration.

One of the principles used by glass manufacturers to lower emissions is straightforward; they alter raw material recipes to lower or eliminate volatile constituents in the feed to the furnaces. Significant among compounds which have been removed from the feed in container glass manufacture is arsenic.[4] Feed rates of soda, fluorides, and selenium have been minimized. Since glass formulations fall in the area of proprietary information, no emission tests were obtained that show the decrease of emissions concomitant with decreases of volatile compounds. The amounts of volatile raw batch materials may be decreased until one of two general types of lower constraints are reached. One lower limit is prescribed by the glassmaking process itself. An example of this type is soda whose batch levels may be reduced until the glass product quality falls below production criteria. The other limitation on some batch constituents may be glass product specifications. Two examples of this sort are the govermental regulations requiring minimum levels of lead and arsenic in television tubes[5] and the military specifications for textile fiberglass.[6]

Another alteration of raw material recipes which affect pollutant emissions involves increasing the levels of recycled glass in the raw batch mix. Since this recycled glass does not require heat to react, the furnace may be maintained at a lower temperature than that needed for a smaller cullet fraction. The lower temperature reduces the amounts of pollutants generated in the combustion of fossil fuel and compounds vaporized from the glass bed. Once again, no emission test data are available to substantiate these results quantitatively. Normal cullet fractions in container glass range around 15 to 20 percent.[7] For some specialty glasses, the mass fraction of cullet in the feed may increase to around 70 percent. Glass manufacturers claim that cullet may be used only up to the level at which impurities in the cullet deleteriously affect glass product quality.

1.2.2 ELECTRIC BOOSTING

Electric boosting is the term applied to the technique of dissipating electrical current through molten glass. Electrical energy is converted to heat because of the high electrical resistance of the molten glass. For a fixed furnace throughput, utilizing electric boosting decreases the required bridgewall temperature decreasing the fuel consumption rate and thereby decreasing both particulate and gaseous pollutant levels. Boosting normally has been used to increase production rate since it does not require substantial modifications of the glass furnace. Boosting is commonly employed in glass container plants and is less commonly found in other types of glass plants.

In general, documentation of the lowering of emissions by electric boosting has not been available in the format of EPA Method 5 emission testing. For one natural gas-fired glass container furnace using electric boosting the particulate emissions per kilogram of glass produced dropped about 55 percent from the uncontrolled level when the boosting electrodes supplied about 18 percent of the total energy consumed in the furnace, despite a 12-percent increase in glass production rate. Emissions of SO_2 did not decrease when boosting was used.[8] At another glass container furnace electric boosting lowered the particulate emissions approximately 60 percent.[9] Although information on the percentage of the total energy supplied by electric boosting was not available, on a rough basis electric boosting provided less energy for this furnace than for the first furnace.

1.2.3 SUMMARY OF PARTICULATE EMISSIONS WITH PROCESS MODIFICATIONS

To assess the levels of particulate emissions from glass melting furnaces using process modifications including electric boosting, the particulate emissions prorated on glass production were determined for the two furnaces discussed in Section 1.2.2 and for furnaces identified by the Glass Packaging Institute as practicing most types of furnace and process control techniques.[10] For all these electrically boosted furnaces the particulate emission values range from 0.34 to 0.88 g/kg (0.68 to 1.76 lb/ton).[11,12] Although some of these emission tests do not match rigorous EPA Method 5 procedures, they are adequate enough to indicate rough levels of emissions.

Because of the narrow extent of these data and because of the lack of ample supporting emission tests, these values only exemplify the range to which particulate emission levels can be reduced by process modifications including electric boosting. As such, they overlap with the emission levels indicated in Tables 3-5 and 3-6 and show that, in general, levels of particulate emissions from glass melting furnaces using process modifications are indistinguishable from the uncontrolled cases discussed in Chapter 3.0.

1.3 ALL-ELECTRIC MELTERS

In contrast to conventional fuel-fired furnaces, in a cold top electric furnace the surface of the melter is maintained at ambient temperature, and fresh raw batch materials are fed continuously over the entire surface. As molten glass is withdrawn from the melter, raw batch drops in the melter gradually heating and finally reacting in the liquid phase. This processing minimizes losses from vaporization. The gases discharged through the batch crust consist of carbon dioxide and water vapor.

Design objectives for all-electric melters have not been based primarily on emission control, rather on efficient melting and product control. Construction is less expensive than fossil fuel furnaces since there are no regenerator chambers, port necks, checkers, flues, reversing valves, and in most cases, stacks can be eliminated. Additionally, there is no need for ductwork, combustion blowers, fans, extra piping, burners, or special refractory shapes.

Accomplishment of design objectives resulted in the low surface temperature and finer control on the glass melt formulation and therefore small levels of emissions. The exact level of emission control capability is not soundly documented since some electric melting units employ no exhaust stacks and are vented openly inside the plant building. However, from the nature of the melting process, potential emissions can be deduced and possible relative amounts of emissions can be estimated. Since there is no combustion taking place, fuel-derived pollutants are eliminated. The only air emissions are from the decomposition of carbonates, sulfates, nitrates, with the majority of the exhausts being CO_2. Finer control of the glass melting process has meant lower emissions since electric melters retain borates, phosphates, and fluorides more than fossil fuel burning furnaces.[13] In addition, there is no solid disposal problem as with fabric filters or with electrostatic precipitators and no water disposal problem as with scrubber systems.

The development of all-electric melters has occurred relatively recently. All-electric melting technology has several key limitations which, at present, hinder the application of this technique throughout the entire glass industry. Not all glasses possess the electrical properties required for successful all-electric melter operation; other glass formulations attack the electrodes presently used in all-electric melters.[14] Additionally, the all-electric technology may not be advanced enough to satisfactorily produce glass in large capacities.

Actual emission test results from all-electric furnaces are presented in Table 1.1. Little operational information was available on the melters except that they were maintained at normal operating conditions during the emission tests. The borosilicate glass melters were tested in accordance with the EPA Method 5 procedure; while the soda-lime melter, although not using EPA Method 5, used an EPA approved sampling procedure with results including both condensed and filtered particulate. The particulate emissions from both glass formulations were about equal in magnitude

Table 1.1. ALL ELECTRIC GLASS MELTING FURNACE PARTICULATE EMISSIONS TESTS

Emission Test Reference Number[a]	Glass Industry Category	Glass Type	All-Electric Furnace Particulate Emissions			
			Mass Emission		Particulate Concentration Corrected to 12 Percent Excess Oxygen[d]	
			g/kg	(lb/ton)	$Kg/nm^3 \times 10^{-4}$ [b]	(Gr/DSCF)[c]
16	Wool Fiberglass	Soda-Lime Borosilicate	0.05	(0.10)		
17	Wool Fiberglass	Soda-Lime Borosilicate	.07	(.14)		
18	Wool Fiberglass	Soda-Lime Borosilicate	.09	(.18)		
19	Glass Container	Soda-Lime	.12	(.24)	9.6	(0.39)

[a] References are listed at the end of the chapter.

[b] Kilograms per normal cubic meter at 0°C and 760 mm. Hg.

[c] Gr/DSCF at 70°F and 1 atmosphere

[d] Gr/DSCF at 12 percent excess oxygen is calculated by the following formula:

$$\text{Gr/DSCF at 12 percent oxygen} = (\text{Gr/DSCF at test conditions})\left(\frac{9}{21 - \text{measured } O_2 \text{ percent}}\right)$$

and ranged from 0.05 to 0.12 g/kg (0.1 to 0.24 lb/ton) based on glass produced. These tests only partly indicate the emission control achievable since only some all-electric melters have installed the exhaust stacks required for emission sampling. In visits made to glass manufacturing facilities, all-electric melters were observed which discharged into the plant building. At these installations no visible emissions were detected and neither were fluoride or sulfur odors detected.[15] Based on these observations, the emissions from the emission tests represent relatively high levels of particulate emitted from all-electric melters.

In summary, all-electric melting has demonstrated that particulate emission levels equivalent to or less than 0.1 g/kg (0.2 lb/ton) can be maintained in the production of soda-lime and borosilicate glasses. Comparison of all-electric melters with other control techniques is made in Section 4.8.

1.4 CONVENTIONAL FABRIC FILTER SYSTEMS

Several glass manufacturing facilities utilize fabric filter systems to collect particulates in the glass melting furnace exhaust. In these systems, the furnace exhaust is first cooled and then passed through a fabric filter which retains particulate, allowing gases to vent to the atmosphere. The physical characteristics of the filtering fabrics and the agglomerating tendency of submicron particles have made fabric filter systems viable control techniques for glass melting furnace particulates.

Figure 1-1 illustrates a typical baghouse system. In operation, a fan pulls the furnace gases through devices which cool the gases to a temperature compatible with the filter material. Cooling is accomplished by duct cooling, dilution air addition, or water injection. The gases are then forced through the filter

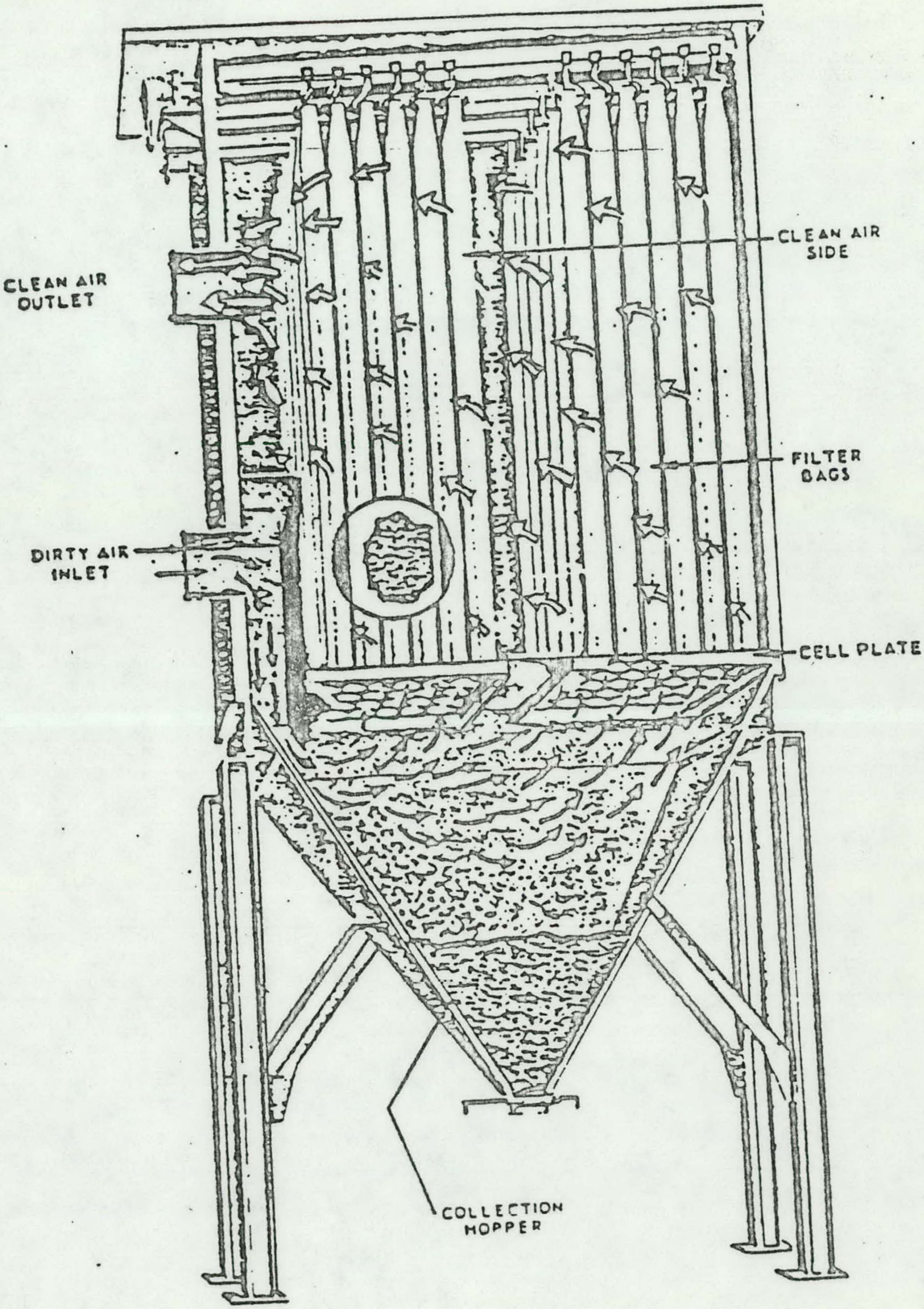


Figure 1-1. A Simple Two Cell Inside Out Baghouse Equipped for Shake Cleaning[23]

bags. Periodic cleaning of the bags is necessary to maintain high collection efficiencies. Filter bags are cleaned through shaking or reverse air pulsations. Conveyors transfer the collected dusts to hoppers for disposal.

Fabric filter systems are claimed to have advantages of high collection efficiency (99 percent),[20] low pressure drop across the system, and low energy requirements.[21] Collection efficiencies are not affected by the electrical resistivity of the particles. In addition, bag life is about 2 years depending on bag construction material.[22] There are certain disadvantages to the application of fabric filters to glass melting furnace gases. The temperature of gases entering the fabric filter must be below a maximum value to inhibit attack on the filtering media as well as above a minimum value to prevent condensation of sulfur trioxides. Additionally, too high a moisture content of the gases can form an irremovable plug within a filter bag.

Table 1-2 lists emission test results for furnaces using baghouse systems. The following summarizes testing parameters and irregularities encountered for each test.

Test 24 results are from a natural gas-fired soda-lime glass melting regenerative furnace. Emission tests used the Los Angeles approved particulate sampling configuration. The fabric filter system consists of 6 modules entailing a total bag surface area of 1,204 m^2 ((12,960 ft^2). The design a/c ratio is 1:1 but during testing the a/c ratio was about 0.65:1. The pressure drop across the system is normally 1,250 to 1,500 Pascals (Pa), which is equivalent to 5 to 6 inches of water.

Central to the interpretation of this test data is the design basis of this fabric filter system. The unit was designed only to meet local opacity regulations. Since the unit met the regu-

Table I-2. PARTICULATE EMISSION TEST RESULTS FOR GLASS MELTING FURNACES EQUIPPED WITH FABRIC FILTERS

Emission Test Reference Number[a]	Glass Industry Category	Glass Type	Air/ Cloth Ratio	Particulate Removal Efficiency Percent	Fabric Filter Outlet Particulate Emissions			
					Mass Emissions		Particulate Concentration Corrected to 12% Excess Oxygen	
					g/kg	(lb/ton)	$kg/Nm^3 \times 10^{-4}$	(gr/DSCF)
24	Pressed and Blown: Soda-lime	Soda-lime	0.65 : 1	72	0.12	(0.24)	0.26	(0.011)
25	Pressed and Blown: Other than soda-lime	Soda-lead-borosilicate	0.6 : 1	94.8	.17	(.34)	.22	(.009)
26	Wool Fiberglass	Borosilicate	0.85 : 1		.2	(.4)	.36	(.015)
27	Wool fiberglass	Soda-lime-borosilicate	0.5 : 1		.55	(1.1)	-	(.059)[b]
28	Wool fiberglass	Soda-lime-borosilicate	-		.26	(.52)	-	(.02)[b]

[a] References are listed at the end of the chapter.

[b] Not corrected to 12 percent oxygen

[c] Fuel Oil

lations after startup, no improvement of particulate collection was attempted.

In operation the system incurred mechanical failures in the first year of operation but slightly modifying the fabric filter internals eliminated the difficulties. Also, the original on-stream cleaning method used reverse air blown between the bags to collapse the inner bag, and cleaning the bag without taking a section offstream. This original method was modified to the present arrangement of a reverse air cleaning cycle where a bag-house section is taken offstream, but the double bag construction was retained.

The results for emission test 25 were measured on a glass melting regenerative furnace burning low sulfur number 5 fuel oil and producing soda-lead borosilicate glass, a specialty glass classified in the Pressed and Blown category of manufacturing. Emission tests using EPA Method 5 were made on the furnace exhaust before and past the fabric filter allowing the calculation of the particulate removal efficiency. The design value of the air-to-cloth ratio (a/c) is 0.6:1 with all 4 modules exposed to furnace exhaust and is 0.8:1 with 3 modules exposed to the furnace gases and 1 module being cleaned. In addition, no operational difficulties with this fabric filter system were reported.

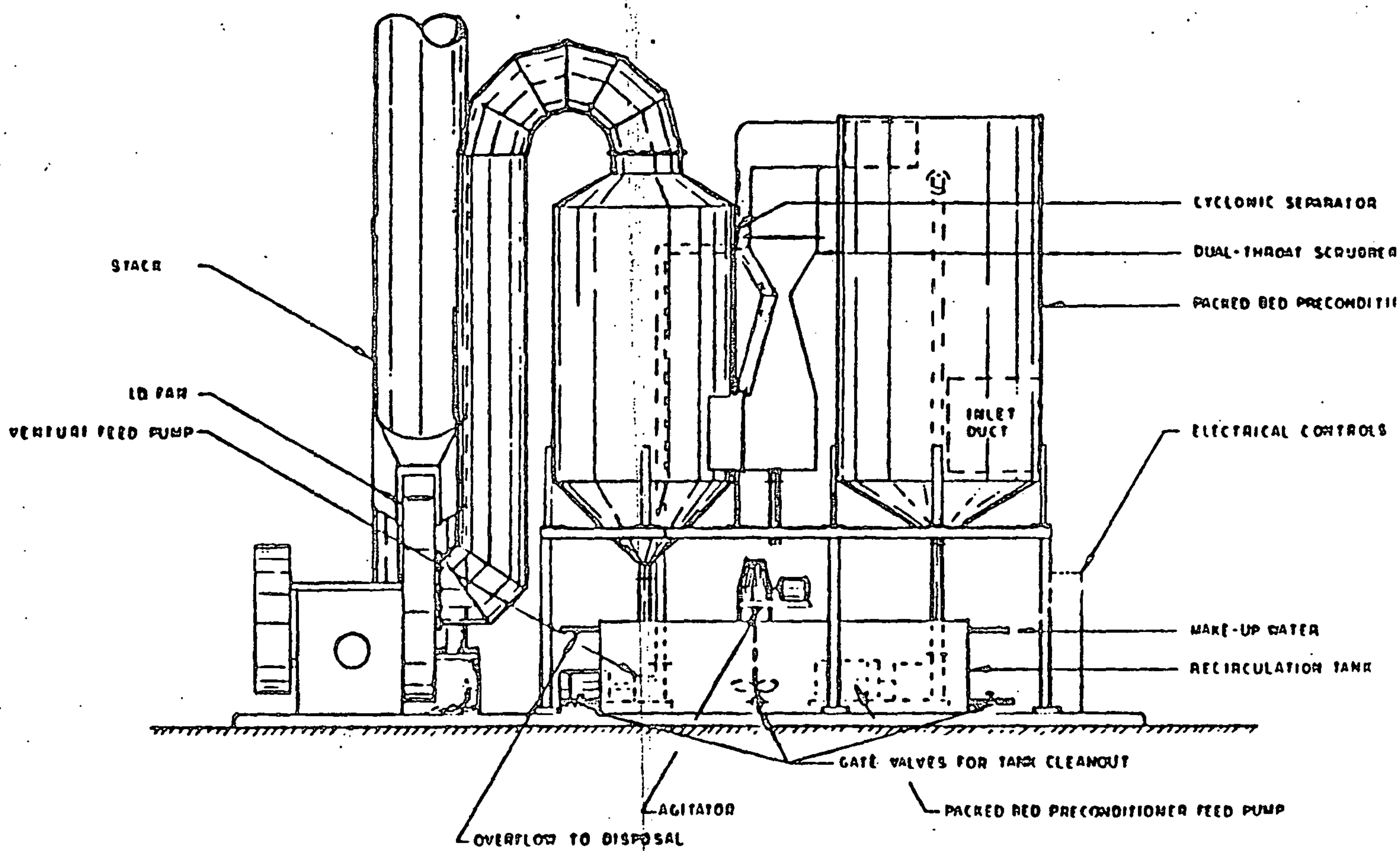
Data listed for emission test 26 are the preliminary results for an EPA Method 5 test recently performed on a natural gas-fired glass melting furnace producing wool fiberglass. This fabric filter is considered undersized by the glass manufacturer.

Emission tests 27 and 28 report particulate emissions as calculated by the front half and back half catches for the EPA Method 5 sampling configuration, and therefore these results are higher than the Method 5 particulate determinations. The glass formulation melted in these furnaces is soda-lime borosilicate producing an endproduct classified in the wool fiberglass industry category. The furnace of test 27 is a regenerative type. The fabric filter in test 28 controls emissions from a small recooperative-type furnace, a raw material batch house, and an electric melt-gas boosted furnace. Particulate concentrations in the fabric filter discharge are not corrected to 12-percent oxygen as the oxygen concentrations during the tests were not available.

Particulate emissions for the tests listed in Table 1-2 range from 0.12 g/kg (.24 lb/ton) to 0.55 g/kg (1.1 lb/ton). The high collection efficiency claimed for fabric filters is substantiated in the soda-lead borosilicate glass test. As mentioned before, particulate collection efficiency of the fabric filter treating soda-lime furnace exhaust may be lower than the efficiency which is technically feasible because particulate collection was never maximized in this system. In conclusion, fabric filters have demonstrated reductions of particulate emissions to levels equivalent or less than 0.2 g/kg (0.4 lb/ton) for glass formulations in two glass industry categories, wool fiberglass and Pressed and Blown:other than soda-lime. Additionally based on the assessment of test 24, appropriately sized and optimized fabric filter systems can be expected to reduce particulate emissions from soda-lime melting furnaces to levels of 0.1 g/kg (0.2 lb/ton).

1-5 VENTURI SCRUBBER SYSTEMS

Although scrubber systems have been built to control particulate emissions in the glass industry, presently only a few devices are in use controlling glass container emissions. The most common system in operation is the venturi scrubber. A typical venturi scrubber system is depicted in figure 1-2. In a venturi scrubber, particle-laden gases are accelerated through



COURTESY OF FMC CORPORATION

Figure 1-2. Typical Scrubber System

a restriction in the ducting where water is injected into the gas stream. The velocity of the gas stream provides the dual function of atomizing the scrubbing fluid while providing a differential velocity between particles and the resulting liquid droplets. By utilizing high power fans to accelerate the gas stream, it is possible to generate high gas velocities at the throat of the venturi. Since the particulates are mostly water soluble, the scrubber provides a means of removing these emissions. Additionally, some gases are absorbed as condensibles.

The scrubber liquor is acidic due to the absorbed acid gases, and, before being recycled to the venturi, it is pH controlled by caustic solution injection. A bleed stream and makeup water addition insure that the scrubber liquor is not saturated. Typically, a bleed rate of 1.3×10^{-4} m^3/s (2GPM) is discharged for 2.1 kg/s (200 TPD) glass container plant. Even for a larger furnace, the bleed rate would be expected to be less than 3.2×10^{-4} m^3/s (5 GPM).[29]

The pressure drop to obtain high velocities in the throat of a scrubber is directly proportional to the gas velocity squared and liquid to gas ratio; therefore, high velocities are possible only at substantial pressure drops which result in high fan energy expenditures. Typical pressure drops are about 7,500 Pa (30 inches of water).[30]

Table 1-3 lists emission test results for furnaces using scrubber systems. Due to the limited number of such systems used in the glass industry, limited data were available. The following summarizes testing parameters and irregularities for the data available.

Test 31 results are for a dual throat venturi scrubber installed on a glass container furnace burning 0.5 percent sulfur fuel oil. The liquid water-to-gas ratio is $3.9 \times 10^{-3}(m^3/s)/(m^3/s)$

Table 1-3. PARTICULATE EMISSION TEST RESULTS FOR GLASS MELTING FURNACES EQUIPPED WITH VENTURI-SCRUBBERS

Emission Test Reference Number[a]	Glass Industry Category	Glass Type	Particulate Removal Efficiency Percent	Venturi-scrubber Outlet Particulate Emissions			
				Mass Emissions		Particulate Emissions Corrected to 12% Excess Oxygen	
				g/kg	(lb/ton)	$kg/Nm^3 \times 10^{-4}$	(gr/DSCF)
31[b]	Container	Soda-lime	82.5	0.37	(0.74)	-	(0.042)[c]
32	Container	Soda-lime		.12	(.24)	.38	(.016)
33[b]	Container	Soda-lime	79.6	.14	(.28)	.40	(.016)
34	Container	Soda-lime		.20	(.40)	.56	(.023)

[a] References are listed at the end of the chapter.

[b] Oil fired

[c] Not corrected to 12 percent excess oxygen

(0.0029 gpm/SCFM) for this system with an 8,212 Pa (33-inch water) pressure drop. There is an estimated 0.0053 kg/s (42 lb/hr) of Na_2SO_4 dissolved in the water discharge which is diluted by plant cooling water and discharged without further treatment. Although the system was not designed for SO_2 control, about 90 percent of the SO_2 was removed from the furnace exhaust. This system has experienced startup problems and after startup, two major maintenance problems have occurred: replacement of fan due to lining failure and rebuilding of hydraulic reservoir tank due to collapse. The testing method is that of EPA Method 5.

Tests 32 and 34 results are from a packed-bed preconditioned chamber, variable throat scrubber installed on a natural gas-fired glass melting furnace. Test 32 is an emission test using the Los Angeles testing method and Test 34 uses EPA Method 5. The design liquid to gas ratio is 2.3×10^{-3} $[m^3/s]/[m^3/s]$ (0.0017 GPM/SCFM) with 7,500 Pa (30-inch water) pressure drop. The liquid effluent is released directed to the sewer. Also a weak alkaline solution, which is recirculated through the packed tower and venturi scrubber, is used to scrub SO_2 and particulates from the gases. The design calls for 0.0011 m^3/s (16.8 GPM) of makeup water, 9.64×10^{-7} m^3/s (22 GPD) of 50 percent caustic and produces a waste liquid stream of 8.2×10^{-4} m^3/s (1.3 GPM) containing 1 to 2 percent dissolved solids and 1 to 2 kg/m^3 (1,000 to 2,000 ppm) suspended solids. There has been no major equipment failure to date, no plugging has been experienced, and no problems with corrosion have arisen. A number of minor operating difficulties have been encountered; almost all are related to the instrumentation system. In addition to the particulate reduction, there was a 75 percent reduction in sulfur oxides with a 7 ppm SO_2 system discharge.

Test 33 results are from a packed-bed preconditioning chamber, dual throat scrubber using the EPA method 5 testing procedure for an oil-fired glass container furnace. The liquid-to-gas ratio is 9.4×10^{-3} $[m^3/s]/[m^3/s]$ (0.07 GPM/SCFM) estimated from design conditions with an 8,500 Pa (34 inch water) pressure drop. There is a 6.3×10^{-4} m^3/s to 9.5×10^{-4} m^3/s (10 to 15 GPM) bleed rate which is discharged directly to the sanitary sewer. This system has experienced a problem with the scrubber exhaust fan which caused the system to be shut down. During the 3 months of operation, it was necessary to clean the impeller blades and fan housing twice to eliminate in imbalance. Also, there were problems with the pH control system, the soda ash solution mixing apparatus, and other minor items. The system has been operating continuously for 3 months. Operational and maintenance problems are still being analyzed. In addition to particulate reduction, sulfur oxides were reduced 86.3 percent with a 100 ppm discharge concentration.

Table 1-3 lists particulate emission tests for venturi scrubbers installed on glass container melting furnaces. Test number 33 reports results for an oil-fired furnace. Although the pull rate for this test was only 57 percent of the maximum furnace capacity, this test data was included as it substantiates the particulate control efficiencies achievable from venturi scrubbers. As discussed previously, tests 32 and 34 are from the same furnace but represent different sampling methods. The emissions per kilogram of glass produced for these tests range from 0.12 to 0.20 g/kg (0.24 to 0.4 lb/ton). These tests demonstrate that venturi scrubbers can lower the particulate emissions from uncontrolled glass container melting furnaces to a level equivalent to or less than 0.20 g/kg (0.4 lb/ton). Comparison of scrubber systems with other control techniques is discussed in Section 1.8.

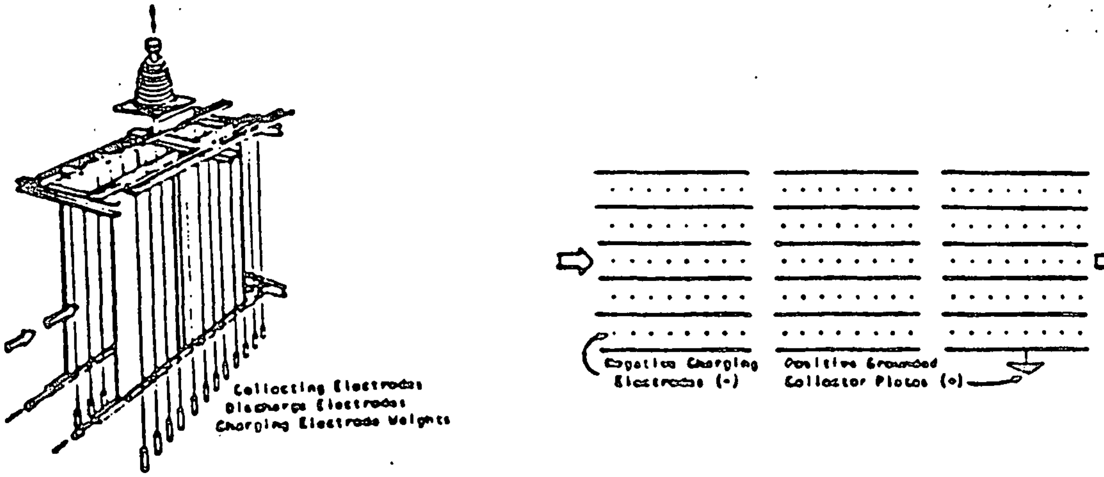
1.6 ELECTROSTATIC PRECIPITATORS

Presently, more than 19 electrostatic precipitators are installed on glass furnace exhaust systems throughout the country, more than any other control technique.

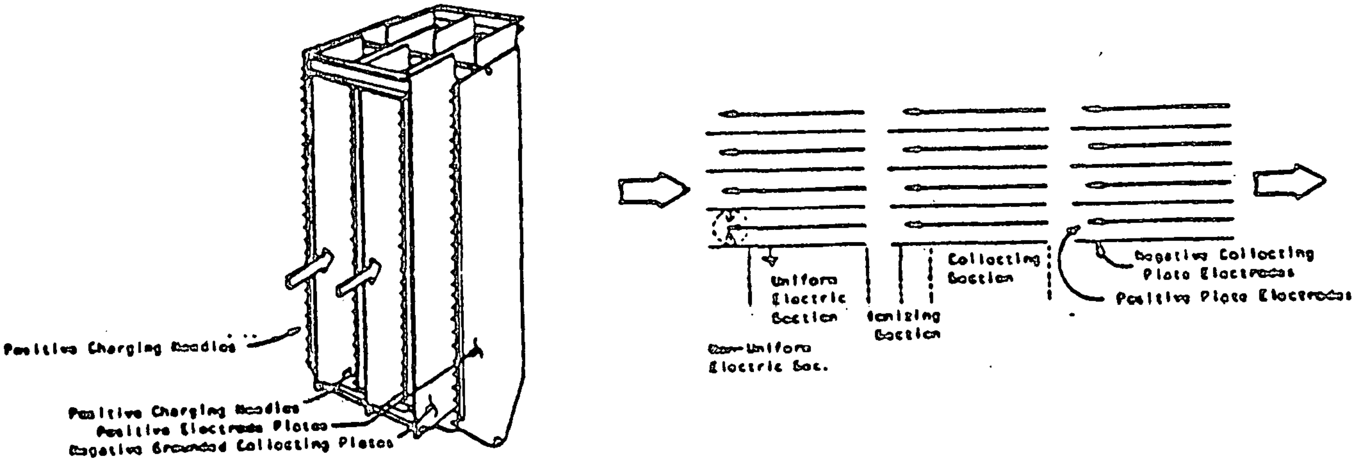
The fundamental steps of electrostatic precipitation are particle charging, collection, and removal and disposal of the collected material. Particulate charging is accomplished by generating charge carriers which are driven to the particulates by an electric field. Collection occurs as the charged particulates migrate to electrodes to which the charged particles adhere. Applying a mechanical force to collection electrodes dislodges the collected material which then falls into hoppers. Effective transfer of dust to the hopper depends on the formation of chunks or agglomerations of dust which fall with a minimum of re-entrainment.

There are two types of electrostatic precipitators used in the glass industry. Both types are shown in Figure 1-3. One type consists of a large rectangular chamber divided by a number of parallel rows of collection plates that form gas flow ducts. Between these plates are hung a number of small diameter wires which are connected to a high voltage direct current potential forming a corona discharge around the wire. This corona generates electrons which migrate into the incoming gas stream to form gas ions which attach these charged particles. The charged particles in turn are collected by the grounded collection plates.

The other type of ESP has a multitude of stainless steel needles fastened to the leading and trailing edge of the discharge plates. This design configuration requires a low voltage which allows close spacing between the two collecting surfaces in



Conventional Electronic Precipitator



CAFCO Electronic Precipitator

Figure 1-3. Both Types of Electrostatic Precipitators Used on Glass Melting Furnace Exhaust[35] each field - the positively charged discharge plates, which have the attached needles, and the grounded collector plates. This close plate spacing permits short collecting sections and relatively high flow - through velocities.[35] Additionally, the regions between the needles exhibit a uniform electric field which aids particle agglomeration. Dust is retained on both the collector plates and discharge plates.

Electrostatic precipitators can be designed and guaranteed to collect 99 percent of the particulate in the glass melting furnace exhaust.[36] Resistivity of the particulate is a determining design parameter; if the particulate cannot conduct the ionic current from the corona discharge, it will be entrained and will be released to the atmosphere. Resistivities are highly dependent on temperature with a decrease in resistivity with increasing temperatures. Some typical resistance figures for variance types of glass are:[35]

Borosilicate glass	-- 10^{12} ohm - cm
Lead glass	-- 10^{11} ohm - cm
Soda lime glass	-- 10^{7} to 10^{10} ohm - cm (Depending on temperature and moisture content)[37]

Table 1-4 lists emission test results for electrostatic precipitator-controlled glass melting furnace exhaust. In some plant configurations one or more electrostatic precipitators collect particulates from several furnaces. In these cases the table entrics list the total pull rates from all furnaces whose exhausts are controlled during testing and the sum of the particulate emissions of all electrostatic precipitators in the plant. The

[illegible] PARTICULATE EMISSION TEST RESULTS FOR GLASS MELTING FURNACES EQUIPPED WITH ELECTROSTATIC PRECIPITATORS

Emission Test Reference Number[a]	Glass Industry Category	Glass Type	Specific Collection Area		Percent of Design SCFM During Test	Particulate Removal Efficiency %	Precipitator Outlet Particulate Emissions			
							Mass Emissions		Particulate Concentration Corrected to 12% Excess Oxygen	
			$m^2/(m^3/s)$	(ft^2/SCFM)			g/kg	(lb/ton)	$kg/m^3 \times 10^{-4}$	(Gr/DSCF)
38	Container	Soda-lime	b	b		91	0.05	(0.12)	0.14	(0.006)
39	Container	Soda-lime	138	(0.65)	83		.07	(.14)	.36	(.015)
40	Container	Soda-lime	237	(1.12)	116		.05	(.12)	.25	(.010)
41	Pressed and Blown: Other than Soda-lime	Borosilicate	225	(1.05)	100					
42	Pressed and Blown: Other than Soda-lime	Borosilicate	138	(0.65)	89		.57	(1.14)	1.37	(.056)
43	Pressed and Blown: Other than Soda-lime	Borosilicate	290	(1.37)	83		.48	(.95)	.18	(.007)
44	Pressed and Blown: Other than Soda-lime	Borosilicate	179	(.85)			.10	(.20		(.002)[c]
45	Pressed and Blown: Other than Soda-lime	Fluoride/ Opal	379	(1.79)	84		.17	(.34)	.32	(.012)
46	Pressed and Blown: Other than Soda-lime	Lead	233	(1.09)	75	93	.05	(.12)	.10	(.004)
47	Pressed and Blown: Other than Soda-lime	Lead	337	(1.59)	117		.08	(.16)	.12	(.005)[c]
48	Pressed and Blown: Other than Soda-lime	Lead					.08	(.16)	.15	(.006)
49	Pressed and Blown: Other than Soda-lime	Lead	103	(.86)	91		.07	(.14)	.05	(.002)
50	Pressed and Blown: Other than Soda-lime	Lead	195	(.92)	80		.18	(.36)		(.004)[c]
51	Pressed and Blown: Other than Soda-lime	Lead				97	.27	(.54)	.42	(.017)
52	Pressed and Blown: Other than Soda-lime	Potash-Soda-lead	237	(1.12)	122		.03	(.06)	.30	(.012)
53	Wool Fiberglass	Borosilicate	220	(1.04)			.36	(.72)	.64	(.026)
54	Wool Fiberglass	Borosilicate	222	(1.05)			.09	(.19)	.18	(.007)
55	Wool Fiberglass	Borosilicate	216	(1.02)			.09	(.17)	.12	(.005)

a. References are listed at the end of the chapter

b. Claimed proprietary

c. Not corrected to 12% excess oxygen

following are summaries of the testing parameters and irregularities.

Test 38 results are from a test employing the Los Angeles testing procedure on a furnace producing soda-lime glass. No data were available for ESP operational parameters. The unit has been running successfully since startup.

Test 39 results are from a test employing the Los Angeles testing procedure on a soda-lime melting furnace. The design specific collection area of the unit is 138 $m^2/[Nm^3/s]$ (0.65 ft^2/SCFM), and during testing the unit was operating at about 83 percent of design SCFM. Natural gas was fired during testing. There have been generally satisfactory results with the operation of this unit.

Test 40 results, also on a soda-lime furnace, are from a test employing the EPA Method 5 procedure. The design specific collection area of the unit is 237 m^2 $[Nm^3/s]$ (1.12 ft^2/SCFM), and during testing the unit was operating at about 116-percent of design conditions.

Tests 41 through 44 report particulate emissions from borosilicate glass formulations melted in furnaces classified in the Pressed and Blown:other than soda-lime category.

Test 41 results are from a test employing the EPA Method 5 procedure. The design specific collection area of the unit is 225$m^2/[Nm^3/s]$ (1.06 ft^2/SCFM), and during testing the unit was operating at about design conditions. Natural gas was fired during the testing period. There have been no major problems encountered with this unit.

Test 42 results are from a test employing the EPA Method 5 procedure. The design specific collection area of the unit is

$138 m^2/[Nm^3/s]$ (0.65 ft^2/SCFM), and during testing the system was operating at about 89-percent of design SCFM. Natural gas was fired during testing. There are no available comments regarding operating problems.

Test 43 results are calculated using EPA Method 5. This electrostatic precipitator is sized for two glass melting furnaces, but only one furnace was operating during the test. The glass pull rate is calculated as 85% of the process weight rate. The manufacturer has encountered dust build-up on the blades of the fan used with this electrostatic precipitator.

Particulate emissions from test 44 are evaluated from the EPA Method 5 technique. Number 5 fuel oil was fired for this test. There are no other available comments regarding the operation of this precipitator or regarding difficulties encountered in its use.

Results listed for test 45 report particulate emissions for an electrostatic precipitator installed on a glass melting furnace producing fluoride-opal glass. Pull rate is assumed to be 85% of process weight rate. Natural gas was combusted during this test.

Tests 46 through 51 consist of particulate emissions from electrostatic precipitators installed on Pressed and Blown:other than soda-lime furnaces melting lead glass formulations.

EPA Method 5 was used to determine the particulate emissions for test 46. The design value of specific collection area is 233 $m^2/[Nm^3/s]$ (1.09 ft^2/SCFM); and during the test, the flow rate through the unit was 75-percent of the design value. The glass pull rate is calculated as 85% of the process weight rate. Problems arising in the application of this control device were: dust build-up on the blades of the exhaust fan, broken insulators, and arcing.

Test 47 results are from a test employing the EPA Method 5 procedure. The design specific collection area of the unit is 337 $m^2/[Nm^3/s]$ (1.59 ft^2/SCFM), and during testing the unit was operating at about 117-percent of design flow rate. Natural gas was fired during testing. There have been no major operational problems encountered.

In test 48, the particulate emissions are reported from an EPA Method 5 test. Natural gas was used during this test. Again, pull rate is assumed to equal 85% of process weight rate.

Test 49 lists particulate emissions for a natural gas-fired furnace using EPA Method 5. Pull rate is calculated as being 85% of the process weight rate. No additional comments are available about the unit.

Test 50 results are from a test employing the EPA Method 5 procedure. The design specific collection area of the unit is 195.07 $m^2/[Nm^3/s]$ (0.92 ft^2/SCFM), and during testing the unit was operating at about 80-percent design SCFM. Natural gas was used in the furnace during testing and there was no available information as to operating problems encountered with the device.

No other information is available on test 51 other than the testing procedure followed EPA Method 5, the furnace fired natural gas, and the data listed in Table 1-4.

Test 52 results are from a natural gas-fired furnace producing potash-soda-lead glass with emissions determined by a sampling train similar to the EPA Method 5 train with two exceptions: A Whatman filter was used and the filter temperature was not maintained at 250°C. The design specific collection area is 237 $m^2/[Nm^3/s]$ (1.12 ft^2/SCFM), and during testing the unit was operating at about 120 percent design flow rate. No data were available as to collection efficiency; the capture dust was analyzed as follows:

79.4 percent PbO, 1.66 percent As_2O_3, 5.33 percent As_2O_5. There have been no major operational problems with this unit.

Tests 53 through 55 report particulate emissions from wool fiberglass plants equipped with electrostatic precipitators. No other information or comments from the glass manufacturer are available other than those listed in the Table.

The particulate emissions for soda-lime formulations produced in the container industry category and for the lead, fluoride-opal, and potash-soda-lead formulations produced in the Pressed and Blown:other than soda-lime industry category which are listed in Table 1-4 range from .03 g/kg to .27 g/kg (.06 lb/ton to .54 lb/ton). These results include tests on both precipitator configurations illustrated in Figure 4-3. For borosilicate glass formulations manufactured in the Pressed and Blown:other than soda-lime category and in the wool fiberglass category, the particulate emission test results range from .09 g/kg to .57 g/kg (.17 to 1.14 lb/ton). Two factors could explain the higher emissions for borosilicate emissions despite the larger special collection area, the higher electrical resistivity of borosilicate dusts and the tendency for the collected dusts to bridge in the precipitator.[56] Since the resistivity of the lead dusts is nearly equal to the resistivity of borosilicate dusts and since the lead particulate is collectible, the second factor may control the collection of borosilicate glass melting furnace emissions.

In conclusion, electrostatic precipitators have demonstrated particulate emission control levels of 0.06 g/kg (.12 lb/ton) for soda-limc, lead and potash-soda-lead glass formulations, and levels of about .2 g/kg (.4 lb/ton) for borosilicate glass formulations. Comparison of electrostatic precipitators with other control techniques is discussed in Section 4.8.

1.7 ADDITIONAL AND DEVELOPING CONTROL TECHNIQUES

1.7.1 FABRIC FILTER WITH ADDITIVE INJECTION

This control technique utilizes continuous injection of chromatographic solids to agglomerate submicron particulate and to absorb gaseous pollutants. These chromatographic solids are separted from the gas stream by a conventional fabric filter. The solids can be recycled or can be disposed in landfill. This dry system consists of the following equipment: a gas quench-humidification system, a metering additive injector, and a fabric filter. Typical pressure drop across the system is about 2,000 Pa (9 inches of water). The additive injection and fabric filter system has been tested on emissions from a furnace producing float glass, the most common type of flat glass, on the fiberglass furnace emissions, and on container glass melting furnace emissions.

Although emission testing methods are not indicated for the float glass or fiberglass tests, particulate removal efficiencies are reported to be over 95 percent.[57] In emission tests of a container glass melting furnace using this system the particulate removal efficiency average 85 percent with a zero opacity visible outlet emission.[58] For all types of glass, the grain loadings are less than 0.12×10^{-4} kg/NM^3 (0.005 Gr/DSCF).

1.7.2 MIST ELIMINATORS

Mist eliminators, developed primarily for removing liquid mist emissions in the sulfuric acid industry, have been pilot tested on a slipstream of a natural gas-fired flass container melting furnace. The mist eliminators utilize impaction, interception, and Brownian movement to collect on irrigated fibers. Gases containing mist and spray particles pass through a fiber bed. The particles are collected on the fibers in the bed and coalesce into liquid films. These films fall from the fiber bed by gravity and the liquid drains out through drain legs. The mist eliminator element consists of a cylindrical fiber bed with gas flow through the annular bed and out the center of the element. Gases emerge from the bed and rise to the system exit.

The results of particulate sampling with an Andersen particle fractionating sampler show a 96.4-percent collection efficiency of particulate smaller than 3 microns across the high efficiency element, but due to condensation of nonsulfate compounds and reentrainment from the prefilter the total system collection efficiency was 93.6-percent.[59] The measured concentration of SO_2 and SO_3 vapor did not decrease through the system. Total pressure drop through the system was about 2,600 Pa (10.5 inches of water).

Because of the sampling method used and because of the preliminary state of this pilot application of the mist eliminator to glass melting furnace exhaust, no firm conclusion about the particulate removal efficiency can be made in this document.

1.8 SUMMARY OF PARTICULATE CONTROL TECHNIQUES

Table 1-5 assesses the levels of particulate emissions emitted from the control systems discussed in this chapter for each industrial glass category except flat glass manufacturing. The emission levels listed in Table 1-5 represent particulate control technically achievable as substantiated by test reports, and therefore

Table 1-5. REPRESENTATIVE PARTICULATE EMISSIONS FROM GLASS MELTING FURNACES

Glass Industry Category	Glass Type	All-Electric Melting		Fabric Filter		Venturi Scrubber		Electrostatic Precipitator	
		g/kg	(lb/ton)	g/kg	(lb/ton)	g/kg	(lb/ton)	g/kg	(lb/ton)
Container	Soda-lime	.12	(.24)			.20	(.40)	.06	(.12)
Pressed and Blown: Soda-lime	Soda-lime			.12	(.24)				
Pressed and Blown: Other than Soda-lime	Lead							.08	(.16)
Pressed and Blown: Other than Soda-lime	Fluoride/ Opal							.17	(.34)
Pressed and Blown: Other than Soda-lime	Borosilicate			.17	(.34)			.50	(1.0)
Wool Fiberglass	Borosilicate	.07	(.14)	.25	(.50)			.10	(.20)

reflect the lower values from previous tables.

All-electric melting of glass has been shown to be effective in greatly reducing the particulate emissions from glass melting furnaces without the addition of add-on control equipment. This technique is not applicable to the entire glass industry as, at present, only formulations of appropriate resistivity and furnaces of relatively moderate production rates can utilize all-electric melting.

Fabric filters have been installed on existing furnaces classified in both the Pressed and Blown categories and in the Wool Fiberglass category. As mentioned previously, in the fabric filter system installed on the soda-lime formulation, particulate collection was never maximized, implying that the emissions could be lowered for this chiefly melted glass type.

Venturi-scrubbers have been installed on existing container glass furnaces. Scrubbers have not been used to control borosilicate emissions because the chemicals discharged in the liquid effluent present more of a disposal problem than those from soda-lime glasses.[60]

Electrostatic precipitators have been installed widely in the glass manufacturing industry. Significant amounts of emission testing substantiate the values listed in the table.

Switching fuels from natural gas to fuel oil adds particulate formed in combustion to the particulate formed in producing glass. The add-on control devices discussed in this chapter would be expected to be equally efficient in controlling particulate emissions with either fuel. As demonstrated in Tables 1-3 and 1-4, venturi scrubbers and electrostatic precipitators have previously been used on fuel oil-fired glass melting furnaces.

Although as of June 1978, no add-on control system continuously controls particulate emissions from flat glass manufacturing, there is no technical evidence to preclude their use. The flat glass furnaces produce more soda-lime glass than container furnaces, but the physical and chemical natures of the resulting particulate are identical. Because of the greater glass production in flat glass furnaces and therefore the larger exhaust volume than in container furnaces, an electrostatic precipitator would probably best control the particulate emissions. For this reason and because one flat glass manufacturer is presently installing an electrostatic precipitator, these devices are listed as the regulatory options for the flat glass industrial category in chapters 6 and 7.

1.9 CONTROL OF SULFUR OXIDES, FLUORIDE, ARSENIC, AND LEAD EMISSIONS FROM GLASS MANUFACTURING

Because sulfur oxides are present in gaseous form in glass melting furnace exhaust, the control of sulfur oxides requires a different approach than the control of particulate. One control technique, the wet scrubber, had demonstrated on commercial scale glass plants good control of both sulfur oxides and particulates simultaneously. As documented in this chapter, 75 and 85 percent reductions of sulfur oxides were measured for two variable throat, venturi scrubber systems. The concentrations of sulfur oxide emissions, calculated as SO_2, from these facilities were 7 ppm and 100 ppm respectively.

Although one test on an electrostatic precipitator showed some sulfur oxide removal, in general, the other add-on control techniques discussed in this chapter do not reduce the levels of sulfur oxides unless other equipment is installed. The one test showed a 40 percent reduction in SO_3 and a 15 percent reduction of SO_2 across an electrostatic precipitator.[61] This result has not been documented in other tests. Treating the exhaust stream with an alkaline spray has been claimed to convert the gaseous sulfur oxides to solids which can then be collected by a fabric filter or an electrostatic precipitator.

In addition, if sulfur oxides are not treated in the glass melting furnace exhaust when certain fuel oils are burned, they may lower collection efficiencies of electrostatic precipitators. If the fuel oil contains vanadium, the reaction of sulfur trioxide to sulfuric acid will be catalyzed. This sulfur acid not only is corrosive to the metal internals of the precipitator but also makes the agglomerated particulate stick to the collector plates lowering collection efficiencies.[62]

Fluorine used in several glass formulations classified in pressed and blown glass manufacturing may be emitted in both particulate and gaseous forms in the melting furnace exhaust. Tests on the uncontrolled glass melting furnace emissions show, on the average, that one half of the fluorine is present in the particulate catch and the other half is present in the impinger and therefore exists as a gas in the exhaust.[63]

Not much analysis has been reported, but that which was available shows electric boosting reduces fluoride emissions about 75 percent in particulate but increased the fluoride in gaseous from 43 percent.[64] When the exhaust from an opal glass manufacturing furnace was treated with a lime slurry, 85 percent of the fluoride emissions were captured in an electrostatic precipitator.[65]

Little test data on arsenic emissions are available. One test shows that about 80 percent of the arsenic captured in an emission test was in particulate form.[66] Electrostatic precipitators have been shown to be 99.4-percent effective and 42-percent effective in capturing this particulate form of arsenic.[67]

Electrostatic precipitators have been shown, in two tests, to collect 70 percent and over 90 percent of lead particulate entering the unit in glass melting furnace exhaust.[68]

1.9 REFERENCES FOR CHAPTER 1.0

1. 40 CFR Part 60 - Appendix A

2. Los Angeles County Air Pollution Control District, Air Pollution Source Testing Manual, Chapter 4, 1972

3. Memo from D. Bivins, E.M.B. to W.O. Herring, I.S.B., 10/28/77

4. Schorr, J.R., et al, Source Assessment: Glass Container Manufacturing Plants, EPA Contract 68-02-1323 Task 37. October 1976, Page 71.

5. Personal communication with J. Cherill, Environmental Engineer, Corning Glass, September 28, 1977

6 Personal communication with L. Froberg, Director of Support Science and Technology Laboratory, Owens/Corning Fiberglas, September 29, 1977.

7. Reference 1, Page 23.

8. Burre, D.C., Position Paper - Proposed Regulation Change for Pressed, Blown, or Spun Soda-Lime Glass Melting Furnaces, Carr-Lowrey Glass Company, October 22, 1975.

9. Response to 114 Questionnaire by Brockway Glass Company, Brockway Pennsylvania, October 12, 1977

10. Glass Packaging Institute, Issue Paper on Air Control Technology in the Glass Container Industry, September 1, 1977, Page 3.

11. Response to 114 Questionnaire by Glass Container Corporation, Fullerton, California, October 14, 1977.

12. Stack Test conducted by Ball Corporation, December 14, 1976.

13. Losel, R.E, "Practical Data for Electric Melting," The Glass Industry, February 1976, Page 26.

14. Arrandale, R.S. "Pollution Control in Fuel Fired Tanks," Part 5, The Glass Industry, December 1974, Page 17.

15. W.O. Herring, Trip Report to Corning Glass Works, Draft dated October 7, 1977.

16. Response to 114 Questionnaire by Owens/Corning Fiberglass, Toledo, Ohio, November 28, 1977.

17. Reference 16.

18. Reference 16.

19. Report Number C02230 SCAQMD, Los Angeles, California, December 12, 1974, January 30, 1975, February 11, 1975.

20. Schorr, J. R., et al., Source Assessment: Pressed and Blown Glass Manufacturing Plants, EPA Contract 68-02-1326, Task 37, Page 103.

21. Teller, A. J., "Control of Furnace Emissions," The Glass Industry, February 1976, Page 22.

22. Response to 114 Questionnaire by Corning Glass, Corning New York, October 12, 1977.

23. Draft of SSEIS: Proposed Standards of Performance for Electric Utility Steam Generating Units, Vol. I, Particulate Matter, fig. 4-3.

24. Report Number C-2027-B, SCAQMD, Los Angeles, California, November 29, 1973.

25. Response from 114 Questionnaire from Owens, Illinois, Toledo, Ohio, October 24, 1977.

26. Preliminary Data on Emission Test done by the EPA at Owens/Corning Fiberglass.

27. Reference 16.

28. Reference 16.

29. FMC Booklet on Glass Furnace Emission Systems, FMC Corporation, Environmental Equipment Division, Itasca, Illinois

30. Reference #11

31. Reference #11

32. Report Number C-2186, SCAQMD, Los Angeles, California, January 24, 1975, January 29, 1975, January 31, 1975.

33. Reference 9.

34. Preliminary Data on Emission Test done by the EPA at Glass Containers Corporation.

35. Custer, W., Electrostatic Cleaning of Emissions from Lead, Borosilicate, and Soda Lime Furnaces, in Collected Papers of the 35th Annual Conference on Glass Problems, University of Ohio, 1974.

36. Reference 4, Page 79.

37. Reference 25.

38. Report Number C-2205, SCAQMD, Los Angeles, California, May 2, 1975.

39. Report Number C-2232, SCAQMD, Los Angeles, California, January 7, 1975, January 28, 1975, February 27, 1975.

40. Reference 25.

41. Response to 114 Questionnaire from General Electric, Richmond Heights, Ohio, October 17, 1977.

42. Reference 25.

43. Reference 22.

44. Reference 41.

45. Reference 22.

46. Reference 22.

47. Reference 41.

48. Reference 22.

49. Reference 22.

50. Reference 25.

51. Data provided by GTE Sylvania

52. Reference 25.

53. Data provided by J. N. Siegfried and J. J. McCarthy, Johns-Manville Co., March 7, 1978.

54. Reference 53.

55. Reference 53.

56. Reference 35.

57. Reference 21.

58. Report Number C-2227 SCAQMD, Los Angeles, California, December 18, 1974, January 3, 1975, January 9, 1975.

59. Monsanto Enviro-Chem, Brink Mist Eliminator Booklet, St. Louis, Missouri.

60. Personal Communication at Meeting with Owens/Corning Fiberglass, September 29, 1977.

61. Reference 25.

62. Personal Communication with B. Gallagher, Precipitaire, September 23, 1977.

63. Reference 22.

64. Reference 22.

65. Reference 22.

66. Reference 22.

67. Reference 22.

68. Reference 22.