the additive materials, such as enzymes also cause serious health problems. Equipment involving enzymes requires very efficient ventilation in addition to proper dust collection. Dust emissions in most cases represent a significant product loss, and their collection and return to process (usually as an ingredient of the slurry to be spray dried) is necessary for economic plant operation as well as for air pollution control.

Air Pollution Control Equipment

Dust generated by granule processing, conveying, and storage equipment does not create unique air pollution control problems. Usually, baghouses provide the best control. Collection efficiencies for baghouses are high; in many cases, efficiencies exceed 99 percent. No extreme conditions of temperature or humidity have to be met, but filter fabrics selected must show good resistance to alkaline materials. Baghouses utilizing intermittent shaking mechanisms should not have filtering velocities exceeding 3 fpm. Baghouses with continuous cleaning mechanisms may have filtering velocities as high as 6 fpm.

GLASS MANUFACTURE

Glass has been made for over 3,500 years, but only in the last 75 years have engineering and science been able to exploit its basic properties of hardness, smoothness, and transparency so that it can now be made into thousands of diverse products.

The economics and techniques connected with mass production of glass articles have led to the construction of glass-manufacturing plants near or within highly populated areas. Unfortunately, airborne contaminants generated by these glass plants can contribute substantially to the air pollution problem of the surrounding community. Control of dust and fumes has, therefore, been, and must continue to be, inherent to the progress of this expanding industry.

Air pollution control is necessary, not only to eliminate nuisances, but also to bring substantial savings by extending the service life of the equipment and by reducing operating expenses and down time for repair. Reduction in plant source emissions can be accomplished by several methods, including control of raw materials, batch formulation, efficient combustion of fuel, proper design of glass-melting furnaces, and the installation of control equipment.

TYPES OF GLASS

Nearly all glass produced commercially is one of five basic and broad types: Soda-lime, lead, fused silica, borosilicate, and 96 percent silica. Of these, modern soda-lime glass is well suited for melting and shaping into window glass, plate glass, containers, inexpensive tableware, electric light bulbs, and many other inexpensive, mass-produced articles. It presently constitutes 90 percent of the total production of commercial glass (Kirk and Othmer, 1947).

Typical compositions of soda-lime glass and the four other major types of commercial glass are shown on Table 204. Major ingredients of soda-lime glass are sand, limestone, soda ash, and cullet. Minor ingredients include salt cake, aluminum oxide, barium oxide, and boron oxide. Minor ingredients may be included as impurities in one or more of the major raw ingredients. Soda-lime glasses are colored by adding a small percentage of oxides of nickel, iron, manganese, copper, and cobalt, and elemental carbon as solutions or colloidal particles (Tooley, 1953).

Although glass production results in tens of thousands of different articles, it can be divided into the following general types (Kirk and Othmer, 1947):

	%
Flat glass	25
Containers	50
Tableware	8
Miscellaneous instruments, scientific equipment, and others	17

GLASS-MANUFACTURING PROCESS

Soda-lime glass is produced on a massive scale in large, direct-fired, continuous melting furnaces. Other types of glass are melted in small batch furnaces having capacities ranging from only a few pounds to several tons per day. Air pollution from the batch furnaces is minor, but the production of soda-lime glass creates major problems of air pollution control.

A complete process flow diagram for the continuous production of soda-lime glass is shown in Figure 587. Silica sand, dry powders, granular oxides, carbonates, cullet (broken glass), and other raw materials are transferred from railroad hopper cars and trucks to storage bins. These materials are withdrawn from the storage bins, batch weighed, and blended in a mixer. The mixed batch is then conveyed to the feed~~ers~~ attached to the side of the furnace. Although dust emissions are created during

Table 204. COMPOSITIONS OF COMMERCIAL GLASSES (Kirk and Othmer, 1947)

Component	Composition, %[a]				
	Soda-lime	Lead	Borosilicate	96% silica	Silica glass
SiO_2	70 to 75 (72)	53 to 68 (68)	73 to 82 (80)	96	99.8
Na_2O	12 to 18 (15)	5 to 10 (10)	3 to 10 (4)	-	-
K_2O	0 to 1	1 to 10 (6)	0.4 to 1	-	-
C_aO	5 to 14 (9)	0 to 6 (1)	0 to 1	-	-
PbO	-	15 to 40 (15)	0 to 10	-	-
B_2O_3	-	-	5 to 20 (14)	3	-
Al_2O_3	0.5 to 2.5 (1)	0 to 2	2 to 3 (2)	-	-
M_gO	0 to 4 (3)	-	-	-	-

[a] The figures in parentheses give the approximate composition of a typical member.

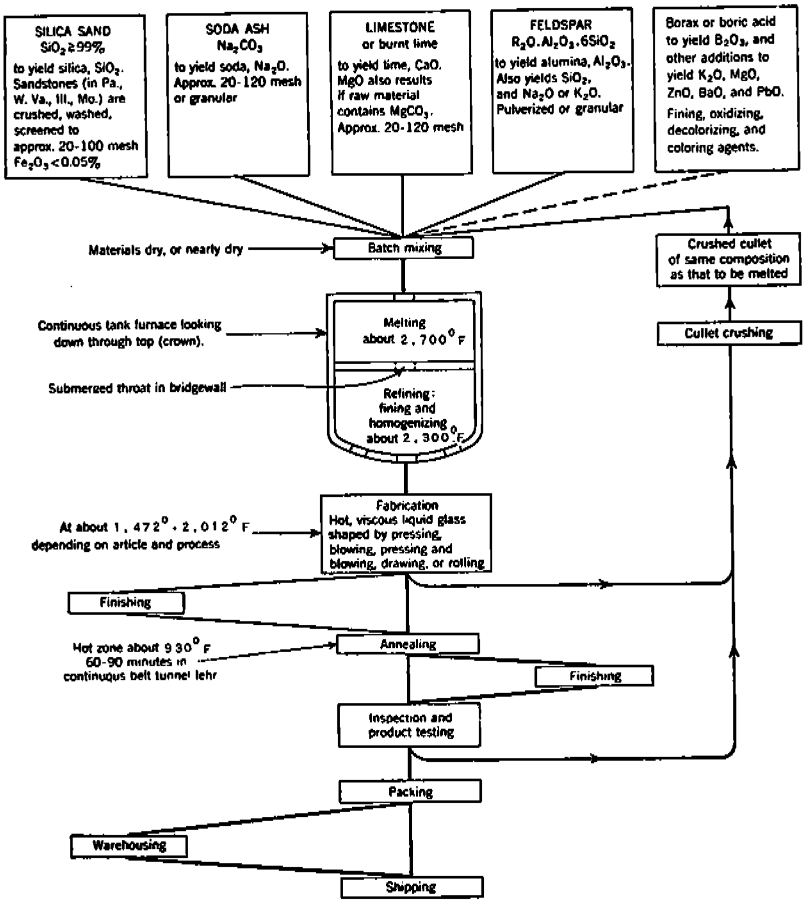


Figure 587. Flow diagram for soda-lime glass manufacture (Kirk and Othmer, 1947).

these operations, control can be accomplished by totally enclosing the equipment and installing filter vents, exhaust systems, and baghouses.

Screw- or reciprocating-type feeders continuously supply batch-blended materials to the direct-fired, regenerative furnace. These dry materials float upon the molten glass within the furnace until they melt. Carbonates decompose releasing carbon dioxide in the form of bubbles. Volatilized particulates, composed mostly of alkali oxides and sulfates, are captured by the flame and hot gases passing across the molten surface. The particulates are either deposited in the checkers and refractory-lined passages or expelled to the atmosphere.

The mixture of materials is held around 2,700°F in a molten state until it acquires the homogeneous character of glass. Then it is gradually cooled to about 2,200°F to make it viscous enough to form. In a matter of seconds, while at a yellow-orange hot temperature, the glass is drawn from the furnace and worked on forming machines by a variety of methods including pressing, blowing in molds, drawing, rolling, and casting.

One source of air pollution is hydrocarbon greases and oils used to lubricate the hot delivery systems and molds of glass-forming machines. The smoke from these greases and oils creates a significant amount of air pollution separate from furnace emissions.

Immediately after being shaped in the machines, the glass articles are conveyed to continuous annealing ovens, where they are heat treated to remove strains that have developed during the molding or shaping operations and then subjected to slow, controlled cooling. Gas-fired or electrically heated annealing ovens are not emitters of air contaminants in any significant quantity. After leaving the annealing ovens, the glass articles are inspected and packed or subjected to further finishing operations.

Glass-forming machines for mass production of other articles such as rod, tube, and sheet usually do not emit contaminants in significant amounts.

HANDLING, MIXING, AND STORAGE SYSTEMS FOR RAW MATERIALS

Material-handling systems for batch mixing and conveying materials for making soda-lime glass normally use commercial equipment of standard design. This equipment is usually housed in a structure separate from the glass-melting furnace and is commonly referred to as a "batch plant." A flow diagram of a typical batch plant is shown in Figure 588. In most batch plants, the storage bins are located on top, and the weigh hoppers and mixers are below them to make use of the gravity flow.

Major raw materials and cullet (broken scrap glass) are conveyed from railroad hopper cars or hopper trucks by a combination of screw conveyors, belt conveyors, and bucket elevators, or by pneumatic conveyors (not shown in Figure 588) to the elevated storage bins. Minor ingredients are usually delivered to the plant in paper bags or cardboard drums and transferred by hand to small bins.

Ingredients comprising a batch of glass are dropped by gravity from the storage bins into weigh hoppers and then released to fall into the mixer. Cullet is ground and then mixed with the dry ingredients in the mixer. Ground cullet may also bypass the mixer and be mixed instead with the other blended materials in the bottom of a bucket elevator. A typical batch charge for making soda-lime flint glass in a mixer with a capacity of 55 cubic feet consists of:

	lb
Silica sand	2,300
Cullet	650
Soda ash	690
Limestone	570
Niter	7
Salt cake	12
Arsenic	2
Decolorizer	1
	4,232

Raw materials are blended in the mixer for periods of 3 to 5 minutes and then conveyed to a charge bin located alongside the melting furnace. At the bottom of the charge bin, rotary valves feed the blended materials into reciprocating- or screw-type furnace feeders.

In a slightly different arrangement of equipment to permit closer control of batch composition, blended materials are discharged from the mixer into batch cans that have a capacity of one mixer load each. Loaded cans are then conveyed by monorail to the furnace feeders. Trends in batch plant design are toward single reinforced-concrete structures in which outer walls and partitions constitute the storage bins. Complete automation is provided so that the batch plant is under direct and instant control of the furnace foreman.

The Air Pollution Problem

The major raw materials for making soda-lime glass--sand, soda-ash, and limestone--usually contain particles averaging about 300 microns in size. Particles less than 50 microns constitute only a small portion of the materials, but are present in sufficient quantities to cause dust emissions during conveying, mixing, and storage operations. Moreover, minor raw materials such as salt cake and sulfur can create dust emissions during handling. Dust is the only air contaminant from batch plants, and the control of dust emissions poses problems similar to those in industrial plants handling similar dusty powder or granular materials.

Hooding and Ventilation Requirements

Dust control equipment can be installed on conveying systems that use open conveyor belts. A considerable reduction in the size of the dust

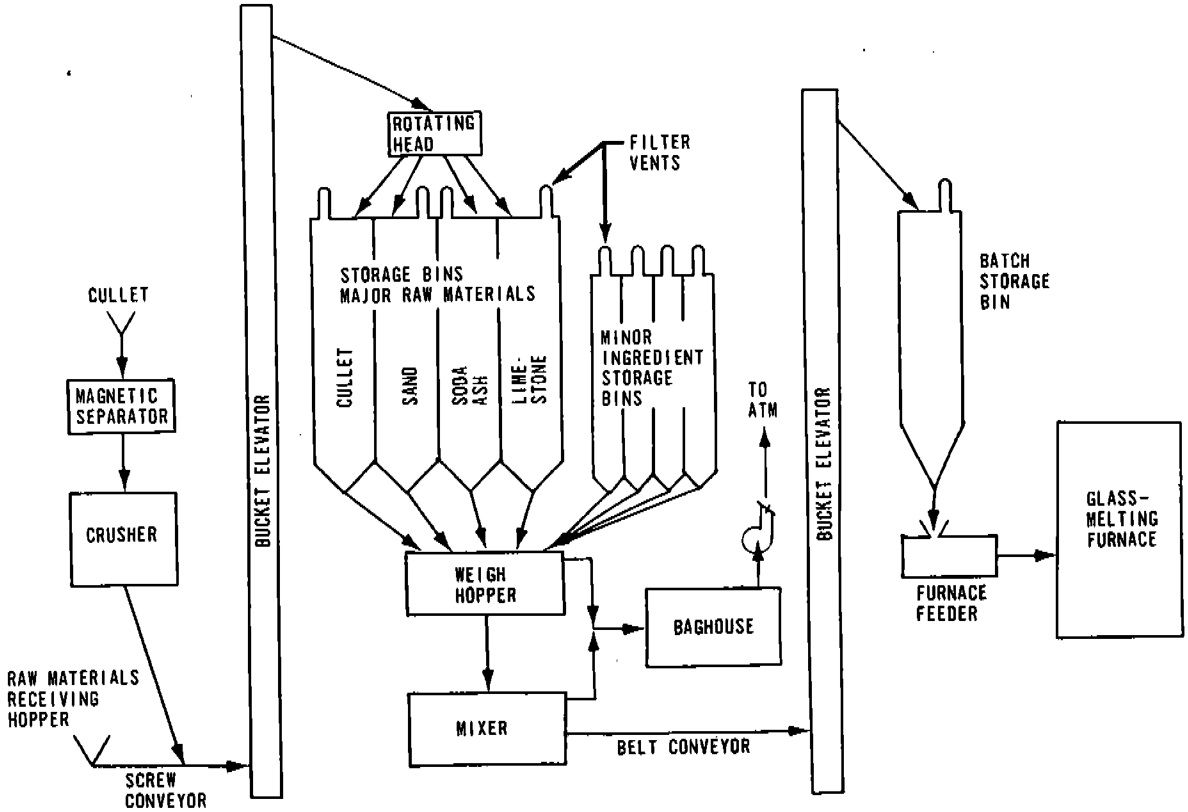


Figure 588. Process flow diagram of a batch plant.

control equipment can be realized by totally enclosing all conveying equipment and sealing all covers and access openings with gaskets of polyurethane foam. In fact, by totally enclosing all conveying equipment, exhaust systems become unnecessary, and relatively small filter vents or dust cabinets can be attached directly to the conveying equipment and storage bins.

On the other hand, exhaust systems are required for ventilating the weigh hoppers and mixers. For example, a 60-cubic-foot-capacity mixer and a 4,500-pound-capacity mixer each require about 600 cfm ventilation air. Seals of polyvinylchloride should be installed between the rotating body of the mixer and its frame to reduce ventilation to a minimum.

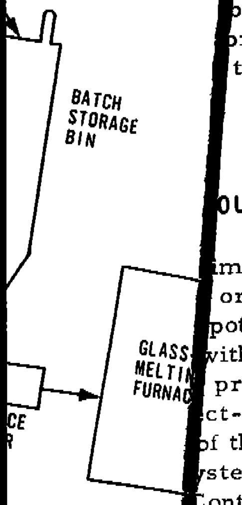
Railroad hopper cars and hopper bottom trucks must be connected to sealed receiving hoppers by fabric sleeves so that dust generated in the hoppers during the loading operation is either filtered through the sleeves or exhausted through a baghouse.

Local exhaust systems for dust pickup are designed by using the recommended practice of the Committee on Industrial Ventilation (1960). For example, the ventilation rate at the transfer point between two open belt conveyors is 350 cfm per foot of belt width, with 200 fpm minimum velocity through the hood openings.

Air Pollution Control Equipment

Because dust emissions contain particles only a few microns in diameter, cyclones and centrifugal scrubbers are not as effective as baghouses or filters are in collecting these small particles; consequently, simple cloth filters and baghouses are used almost exclusively in controlling dust emissions from batch plants.

Filter socks or simple baghouses with intermittent shaking mechanisms are usually designed for a filter velocity of 3 fpm, but baghouses with continuous cleaning devices such as pulse jets or reverse air systems can be designed for filter velocities as high as 10 fpm. Filtration cloths are usually cotton, though nylon, orlon, and dacron are sometimes used. Dusts collected are generally noncorrosive. Filters or baghouses for storage bins are designed to accommodate not only displaced air from the filling operation but also air induced by falling materials. Filtration of air exhaust from pneumatic conveyors used in filling the bins must also be provided. Filters with at leas a 1-square-foot area should be mounted on the hand-filled minor-ingredient bins.



hutes of special design are used for g the minor ingredient bins. They are hed securely with gaskets to the top of The bags are dropped into a chute knives across the bottom. The knives bag, and as the materials fall into the roken bag seals off the escape of dust top of the chute.

OUS SODA-LIME GLASS-MELTING FURNACES

mited quantities of special glasses such or borosilicate are melted in electrically pots or in small-batch, regenerative fur- ith capacities up to 10 tons per day, the production, soda-lime glass, is melted ct-fired, continuous, regenerative furnaces. f these furnaces have added electric induc- stems called "boosters" to increase capac- ontinuous, regenerative furnaces usually in capacity from 50 to 300 tons of glass y; 100 tons is the most common capac- und in the United States.

nuous, regenerative, tank furnaces differ sign according to the type of glass products factured. All have two compartments. In rst compartment, called the melter, the dry edients are mixed in correct proportions and ontinuously fed onto a molten mass of glass ng a temperature near 2,700°F. The dry mate- melt after floating a third to one-half of the across the compartment and disappearing into surface of a clear, viscous-liquid glass. Glass s from the melter into the second compartment, mmonly referred to as the refiner, where it is ed for homogeneity and heat conditioned to inate bubbles and stones. The temperature gradually lowered to about 2,200°F. The ount of glass circulating within the melter refiner is about 10 times the amount with- awn for production (Sharp, 1954).

egenerative furnaces for container and tableware anufacture have a submerged opening or throat eparating the refiner from the melter. The throat revents undissolved materials and scum on the urface from entering the refiner. Glass flows rom the semicircular refining compartment into ong, refractory-lined chambers called forehearths. il or gas burners and ventilating dampers ac- curately control the temperature and viscosity of he glass that is fed from the end of the forehearth o glass-forming machines.

Continuous furnaces for manufacturing rod, tube, and sheet glass differ from furnaces for container and tableware manufacture in that they have no throat between the melter and refiner. The compartments are separated from each other by floating refractory beams riding in a drop arch across the entire width of the furnace. Glass flows from the rectangular-shaped refiner directly into the forming machines.

Regenerative firing systems for continuous glass furnaces were first devised by Siemens in 1852, and since then, nearly all continuous glass furnaces in the United States have used them. In Europe, continuous glass furnaces employ both recuperative and regenerative systems.

Regenerative firing systems consist of dual chambers filled with brick checkerwork. While the products of combustion from the melter pass through and heat one chamber, combustion air is preheated in the opposite chamber. The functions of each chamber are interchanged during the reverse flow of air and combustion products. Reversals occur every 15 to 20 minutes as required for maximum conservation of heat.

Two basic configurations are used in designing continuous, regenerative furnaces - end port, Figure 589, and side port, Figure 590. In the side port furnace, combustion products and flames pass in one direction across the melter during one-half of the cycle. The flow is reversed during the other half cycle. The side port design is commonly used in large furnaces with melter areas in excess of 300 square feet (Tooley, 1953).

In the end port configuration, combustion products and flames travel in a horizontal U-shaped path across the surface of the glass within the melter. Fuel and air mix and ignite at one port and discharge through a second port adjacent to the first on the same end wall of the furnace. While the end port design has been used extensively in smaller furnaces with melter areas from 50 to 300 square feet, it has also been used in furnaces with melter areas up to 800 square feet.

Continuous furnaces are usually operated slightly above atmospheric pressure within the melter to prevent air induction at the feeders and an overall loss in combustion efficiency. Furnace draft can be produced by several methods: Induced-draft fans, natural-draft stacks, and ejectors.

The Air Pollution Problem

Particulates expelled from the melter are the result of complex physical and chemical reactions that occur during the melting process.

Glass has properties akin to those of crystalline solids, including rigidity, cold flow, and hardness. At the same time, it behaves like a super-

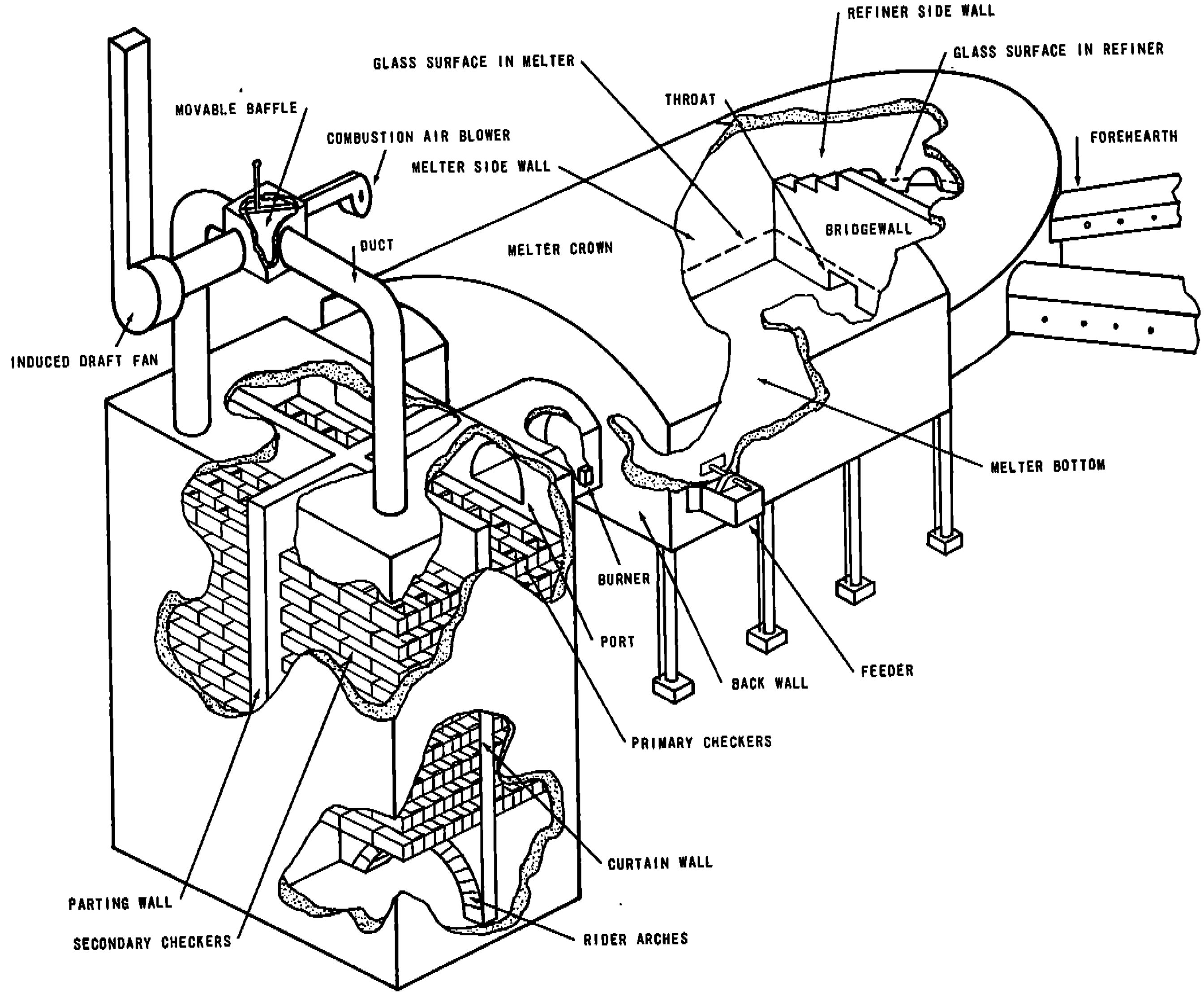


Figure 589. Regenerative end port glass-melting furnace.

cooled liquid. It has nondirectional properties, fracture characteristics of an amorphous solid, and no freezing or melting point. To account for the wide range of properties, glass is considered to be a configuration of atoms rather than an aggregate of molecules. Zachariasen (1932) proposed the theory that glass consists of an extended, continuous, three-dimensional network of ions with a certain amount of short-distance-ordered arrangement similar to that of a polyhedral crystal.

These dissimilar properties explain in part why predictions of particulate losses from the melter based solely upon known temperatures and vapor pressures of pure compounds have been inaccurate. Other phenomena affect the generation of particulates. During the melting process, carbon dioxide bubbles and propels particulates from the melting batch. Particulates are entrained by the fast-moving stream of flames and combustion gases. As consumption of fuel and refractory temperatures of the furnace increase with glass tonnage, particulates also increase in quantity. Particulates, swept from the melter, are either collected in the checkerwork and gas passages or exhausted to the atmosphere.

Source test data

In a recent study, many source tests of glass furnaces in Los Angeles County were used for determining the major variables influencing stack emissions. As summarized in Table 205, data include: Particulate emissions, opacities, process variables, and furnace design factors. Particle size distributions of two typical stack samples are shown in Table 206. These particulate samples were obtained from the catch of a pilot baghouse venting part of the effluent from a large soda-lime container furnace.

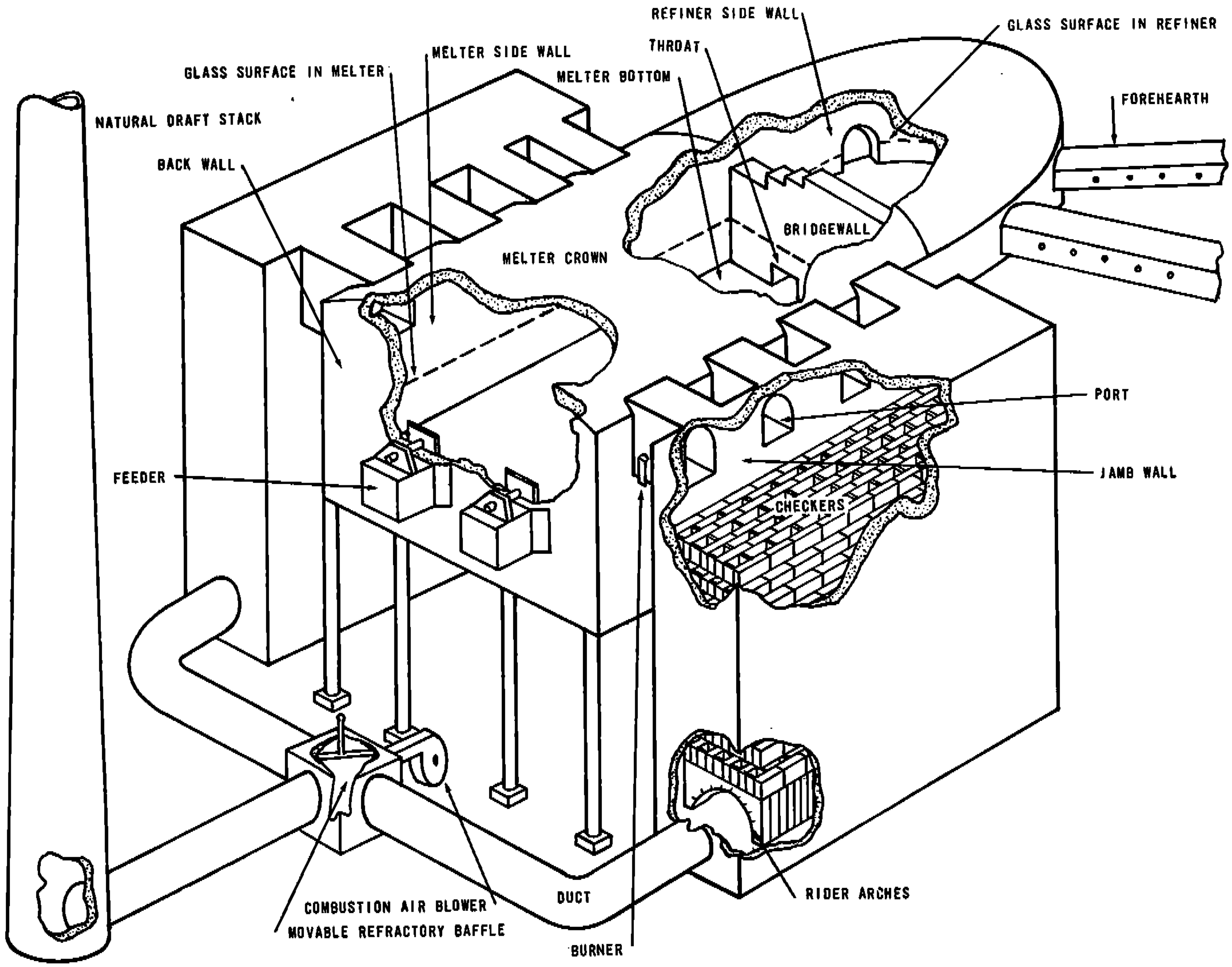


Figure 590. Regenerative side port glass-melting furnace.

Chemical composition of the particulates was determined by microquantitative methods or by spectrographic analysis. Five separate samples, four from a pilot baghouse, and one from the stack of a soda-lime regenerative furnace, are given in Table 207. They were found to be composed mostly of alkali sulfates although alkalies are reported as oxides. The chemical composition of sample 5 was also checked by X-ray crystallography. In this analysis, the only crystalline material present in identifiable amounts was two polymorphic forms of sodium sulfate.

Opacity of stack emissions

From the source test data available, particulate emissions did not correlate with the opacity of the stack emissions. Some generalizations on opacity can, however, be made. Opacities usually increase as particulate emissions increase. More often than not, furnaces burning U. S. Grade 5 fuel oil have plumes exceeding 40 percent white opacity while operating at a maximum pull rate, which is the glass industry's common term for production rate. Plumes from these same furnaces were only 15 to 30 percent white opacity while burning natural gas or U. S. Grade 3 (P.S. 200) fuel oil. Somewhat lower opacities may be expected from furnaces with ejector draft systems as compared with furnaces with natural-draft stacks or induced-draft fans.

Hooding and Ventilation Requirements

In order to determine the correct size of air pollution control equipment, the volume of dirty exhaust gas from a furnace must be known. Some of the more important factors affecting exhaust volumes include: Furnace size, pull rate, com-

Table 205. SOURCE TEST DATA FOR GLASS-MELTING FURNACES

Test No.	Type of furnace[a]	Type of fuel[b]	X_1 (particulate emissions), lb/hr	X_2 (process wt ratio), lb/hr-ft^2 of melter area	X_3, wt fraction of cullet in charge[c]	X_4 (checker volume), ft^3/ft^2 of melter	Maximum opacity of stack emissions, %
C-339b	EP	0-300	7.00	16.7	0.300	5.40	50
C-339	EP	G	3.00	13.8	0.300	5.40	10
C-382-1	EP	G	4.60	16.5	0.300	5.40	10
C-382-2	EP	G	6.40	18.2	0.300	5.40	10
C-536	EP	0-200	4.70	17.5	0.199	5.40	10
C-383	EP	G	8.40	17.9	0.300	6.50	20
Pri Lab	EP	G	3.86	10.9	0.094	8.00	25
Pri Lab	EP	G	4.76	14.6	0.094	8.00	25
Pri Lab	EP	G	4.26	17.1	0.157	8.00	25
Pri Lab	EP	G	6.84	17.4	0.094	8.00	25
Pri Lab	EP	G	4.62	18.5	0.365	9.00	--
Pri Lab	EP	0-300	3.96	14.6	0.269	9.00	45
Pri Lab	EP	G	7.16	20.2	0.175	9.00	20
C-101	EP	G	9.54	15.2	0.300	5.00	20
C-120	EP	G	9.90	14.2	0.320	5.00	20
C-577	SP	0-300	12.70	24.2	0.134	6.90	35
C-278-1	SP	G	3.97	18.3	0.361	6.93	20
C-278-2	SP	0-300	8.44	18.5	0.360	6.93	20
C-653	SP	G	8.90	22.0	0.131	8.74	40
C-244-1	SP	G	6.30	7.5	0.182	7.60	25
C-244-2	SP	G	3.00	5.4	0.100	7.60	25
C-420-1	SP	G	6.30	10.7	0.100	7.60	10
C-420-2	SP	G	6.60	13.2	0.100	7.60	5
C-743	SP	G	10.20	26.2	0.047	8.25	25
C-471	SP	G	6.70	11.6	0.276	5.60	30

[a] EP = end port, regenerative furnace; SP = side port, regenerative furnace.
[b] G = natural gas; 0-200 = U.S. Grade 3 fuel oil; 0-300 = U.S. Grade 5 fuel oil.
[c] Constants: Sulfate content of charge 0.18 to 0.34 wt %.
Fines (-325 mesh) content of charge 0.2 to 0.3 wt %.

bustion efficiency, checker volume, and furnace condition.

Exhaust volumes can be determined from fuel requirements for container furnaces given by the formula of Cressey and Lyle (1956).

$$F = [50 + 0.6A] + 4.8T \qquad (151)$$

where

F = total heat, 10^6 Btu/day

A = melter area, ft^2

T = pull rate, tons/day.

This straight-line formula includes minimum heat to sustain an idle condition plus additional heat for a specified pull rate. Fuel requirements for bridgewall-type, regenerative furnaces are also given by Sharp (1955) and are shown in Figure 591. The melter rating parameter of 4 square feet of melter surface area per daily ton of glass should be used to estimate the fuel requirements of container furnaces at maximum pull rates, but 8 square feet per ton can be used for estimating fuel requirements for non-bridgewall furnaces supplying glass for tableware and for sheet, rod, and tube manufacture. Fuel requirements given are averages for furnaces constructed before 1955; consequently, these furnaces generally require more fuel per ton of glass than do furnaces constructed since 1955. After the fuel requirements are determined, exhaust volumes are computed on the basis of combustion with 40 percent excess combustion air. Forty percent excess combustion air is chosen as representing average combustion conditions near the end of the campaign/ (a total period of operation without shutting down for repairs to the furnace).

Exhaust volumes determined from fuel requirements are for furnaces with induced-draft sys-

Table 206. SIZE DISTRIBUTION OF PARTICULATE EMISSIONS (MICROMEROGRAPH ANALYSES)

Furnace 1	Flint glass	Furnace 2	Amber glass
Diameter (D), μ	% (by wt) less than D	Diameter (D), μ	% (by wt) less than D
36.60	100	17.40	100
22.00	99.5	15.70	99.8
18.30	98.6	14.00	99.4
16.50	97.7	12.20	96.8
14.60	94.0	11.60	92.5
12.80	84.6	11.00	89.5
12.20	80.7	10.50	87.2
11.60	76.6	9.90	83.4
11.00	72.7	9.30	78.7
10.40	67.7	8.80	75.0
9.80	62.4	8.10	73.4
9.20	58.3	7.00	60.3
8.50	51.8	5.80	47.6
7.30	43.1	4.65	35.6
6.10	34.4	3.49	25.4
4.88	28.0	2.91	20.5
3.66	21.3	2.33	16.4
3.05	18.6	1.74	10.9
2.44	14.9	1.45	8.9
1.83	11.0	1.16	5.3
1.52	8.3		
1.22	4.1		

tems or natural-draft stacks. Exhaust volumes for ejector systems can be estimated by increasing the exhaust volume by 30 to 40 percent to account for ejector air mixed with the furnace effluent.

Exhaust gases from furnaces with natural-draft stacks or induced-draft fan systems usually range in temperature from 600° to 850°F, but exhaust gas temperatures from furnaces containing ejectors are lower and vary from 400° to 600°F. In Table 208 are found chemical analyses of gaseous components of exhaust gases from large, regenerating, gas-fired furnaces melting three kinds of soda-lime glass.

Air Pollution Control Methods

As the furnace campaign progresses, dust carryover speeds destruction of the checkers. Upper courses of the firebrick checker glaze when subjected to high temperatures. Dust and condensate collect on the brick surface and form slag that drips downward into the lower courses where it solidifies at the lower temperature and plugs the checkers. Slag may also act somewhat like flypaper, tenaciously clinging to the upper courses and eventually sealing off upper gas passages.

Hot spots develop around clogged checkers and intensify the destructive forces, which are reflected by a drop in regenerator efficiency and a rise in fuel consumption and horsepower required to overcome additional gas flow resistance through the checkers. Checker damage can finally reach a point where operation is no longer economical or is physically impossible because of collapse. Thus, successful operation of modern regenerative furnaces requires keeping dust carryover from the melter to an absolute minimum, which also coincides with air pollution control objectives by preventing air contaminants from entering the atmosphere. Aside from reducing air contaminants, benefits de-

Table 207. CHEMICAL COMPOSITION OF PARTICULATE EMISSIONS (QUANTITATIVE ANALYSES), METALLIC IONS REPORTED AS OXIDES

Sample source	Baghouse catch	Baghouse catch	Baghouse catch	Baghouse catch	Millipore filter
Test type of glass components	No. 1 amber, wt %	No. 2 flint, wt %	No. 3 amber, wt %	No. 4 flint, wt %	No. 5 flint, wt %
Silica (SiO_2)	0.03	0.3	0.1	4.1	3.3
Calcium oxide (C_aO)	1.70	2.3	0.8	19.2	
Sulfuric anhydride (SO_3)	46.92	25.1	46.7	30.5	39.4
Boric anhydride (B_2O_3)	3.67	1.3			
Arsenic oxide (As_2O_3)	7.71				
Chloride (Cl)	0.01				
Lead oxide (PbO)	0.39				
$K_2O + Na_2O$	29.47	28.1	26.1	36.5	39.2
AL_2O_3		3.5		0.2	
Fluoride		8.6			
Fe_2O_3			0.1	0.6	
MgO				1.4	
ZnO			0.5		
Unknown metallic oxide (R_2O_3)					6.5
Loss on ignition	10.10	30.8	25.7	7.5	11.6

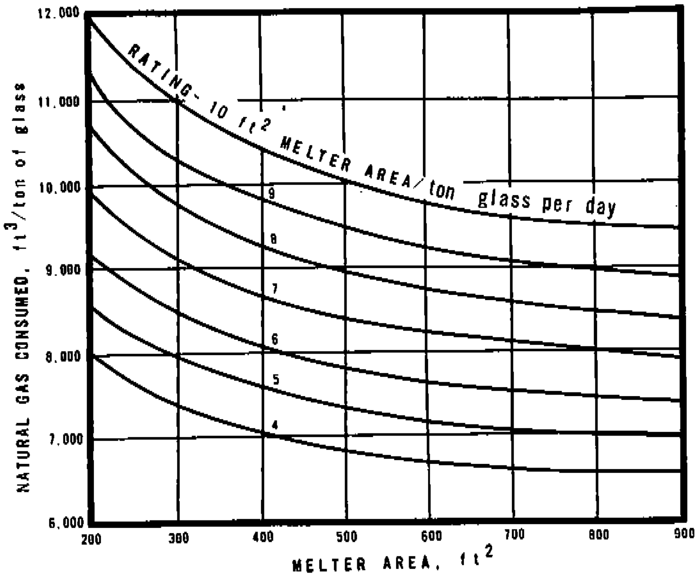


Figure 591. Natural gas for bridgewall-type regenerative furnaces (Sharp, 1955).

rived from reducing dust carryover are many and include longer furnace campaigns, lower maintenance costs, and savings on fuel.

In order to determine which design and operating variables have the greatest effect upon dust carryover and particulate emissions, statistical analysis was performed on the source test data given in Table 205.

By the method of Brandon (1959), particulate emissions, the dependent variable were found to correlate with the following independent variables and nonquantitative factors:

1. Process weight, lb/hr-ft^2;
2. cullet, wt % of charge;
3. checker volume, ft^3/ft^2 melter;
4. type of furnace, side port or end port;
5. type of fuel, U.S. Grade 5 (PS300) oil or natural gas;
6. melter area, ft^2.

Several simplifying assumptions are made so that furnaces of different sizes can be compared. Process weight per square foot of melter describes a unit process occurring in each furnace regardless of size. Cubic feet of checkers per square foot of melter not only defines the unit's dust-collecting capability but is also a measure of fuel economy. Source tests C-382 and C-536 in Table 205 (and other source tests) show no appreciable difference in particulate emissions from burning natural gas or U.S. Grade 3 fuel oil.

Correlation of particulate emissions with weight percent sulfate (SO_3) and minus 325-mesh fines in the charge was not possible because of insufficient test data. Limited data available indicate that particulate emissions may double when total sulfate (SO_3) content of the batch charge is increased from 0.3 to 1.0 weight percent. Total sulfates (SO_3) include equivalent amounts of elemental sulfur and all compounds containing sulfur. Sulfates usually comprise over 50 percent of the particulate emissions. They act as fluxing agents preventing the melting dry-batch charge from forming a crust that interferes with heat transfer and melting (Tooley, 1953). Compounds of arsenic, boron, fluorine, and metallic selenium are also expected to be found along with sodium sulfate in the particulate emissions because of their high vapor pressures.

Data roughly indicate that particulate emissions increase severalfold when the quantity of minus 325-mesh fines increases from 0.3 weight percent to 1 or 2 weight percent.

Statistical analysis using the method of curvilinear multiple correlation by Ezekiel (1941) results in the following equation, which describes particulate emissions, the dependent variable, as a function

Table 208. CHEMICAL COMPOSITION OF GASEOUS EMISSIONS FROM GAS-FIRED, REGENERATIVE FURNACES

Gaseous components	Flint glass	Amber glass	Georgia green
Nitrogen, vol %	71.9	81.8	72.5
Oxygen, vol %	9.3	10.2	8.0
Water vapor, vol %	12.4	7.7	12.1
Carbon dioxide, vol %	6.4	8.0	7.4
Carbon monoxide, vol %	0	0.007	0
Sulfur dioxide (SO_2), ppm	0	61	14
Sulfur trioxide (SO_3), ppm	0	12	15
Nitrogen oxides (NO, NO_2), ppm	724	137	NA
Organic acids, ppm	NA[a]	50	NA
Aldehydes, ppm	NA	7	NA

[a] NA = not available.

of four independent variables and two nonquantitative independent factors. This equation is valid only when two other independent variables--sulfate content and content of minus 325-mesh fines of the batch--lie between 0.1 to 0.3 weight percent and, also, when fluorine, boron, and lead compounds are either absent from the batch charge or present only in trace amounts.

$$X_1 = a + 0.0226(X_2)^2 - 0.329\,X_2 - 4.412\,X_3 - 0.9379\,X_4 - 0.635\,(X_5)^2 + 6.170\,X_5 \qquad (152)$$

where

X_1 = particulate emissions, lb/hr

X_2 = process wt, lb/hr-ft^2 melter

X_3 = wt fraction of cullet in charge

X_4 = checker volume, ft^3/ft^2 melter

X_5 = melter area, ft^2/100

a = constant involving two nonquantitative independent factors relating the type of furnace (side port or end port) and the type of fuel (U.S. Grade 5 fuel or natural gas).

a = -0.493 end port - U.S. Grade 5 fuel oil

a = -0.623 side port - U.S. Grade 5 fuel oil

a = -1.286 end port - natural gas

a = -1.416 side port - natural gas.

Particulate emissions computed by this equation for 25 source tests show a standard deviation from measured particulate emissions of ± 1.4 pounds per hour. Further statistical refinement failed to yield a lower standard deviation.

Emissions to the atmosphere can be predicted by using equation 152 or Figures 592 to 595, which are based upon this equation. The curves should be used only within the limits indicated for the variables. The curves should not be extrapolated in either direction with the expectation of any degree of accuracy, even though they appear as straight lines. Particulate emissions are first determined from Figure 592, then positive or negative corrections obtained from Figures 593 to 595 are added to the emissions obtained from Figure 592.

Design and operation of soda-lime, continuous, regenerative furnaces to alleviate dust carryover and minimize particulate emissions are discussed in succeeding paragraphs. Advantages of all-electric, continuous furnaces for melting glass are also cited.

Control of raw materials

Although glassmakers have traditionally sought fine-particle materials for easier melting, these materials have intensified dust carryover in regenerative furnaces. A compromise must be reached. Major raw materials should be in the form of small particles, many of them passing U.S. 30-mesh screen, but not more than 0.3 weight percent passing U.S. 325-mesh screen. Because crystals of soda ash, limestone, and other materials may be friable and crush in the mixer, producing excessive amounts of fines, screen analyses of individual raw materials should not be combined for estimating the screen analyses of the batch charge. Crystalline shape and density of raw materials should be thoroughly investigated before raw material suppliers are selected.

Since particulate emissions from soda-lime regenerative furnaces increase with an increase in equivalent sulfate (SO_3) present in the batch charge, sulfate content should be reduced to an absolute minimum consistent with good glassmaking. Preferably, it should be below 0.3 weight percent. Equivalent sulfate (SO_3) content of the batch includes all sulfur compounds and elemental sulfur. Compounds of fluorine, boron, lead, and arsenic are also known to promote dust carryover (Tooley, 1953), but the magnitude of their effect upon emissions is still unknown. In soda-lime glass manufacture, these materials should be eliminated or should be present in only trace amounts.

From the standpoint of suppressing stack emissions, cullet content of the batch charge should be kept as high as possible. Plant economics may, nevertheless, dictate reduction in cullet where fuel or cullet is high in cost or where cullet is in short supply. Some manufacturing plants are able to supply all their cullet requirements from scrap and reject glassware.

Batch preparation

There are a number of ways to condition a batch charge and reduce dust carryover. Some soda-lime glass manufacturers add moisture to the dry batch, but the relative merits of this process are debatable. Moisture is sprayed into the dry-batch charge at the mixer as a solution containing 1 gallon of surface-active wetting agent to 750 gallons of water. Surface tension of the water is reduced by the wetting agent so that the water wets the finest particles and is evenly distributed

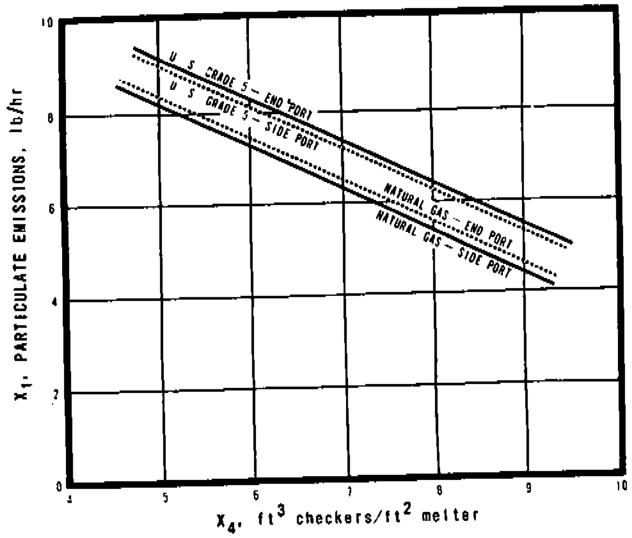


Figure 592. Particulate emissions versus checker volume per ft^2 of melter.

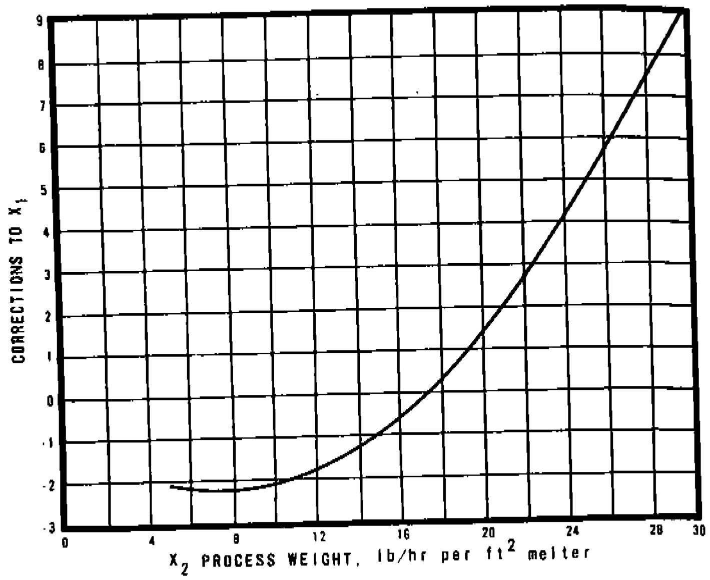


Figure 593. Correction to particulate emissions for process weight per ft^2 melter.

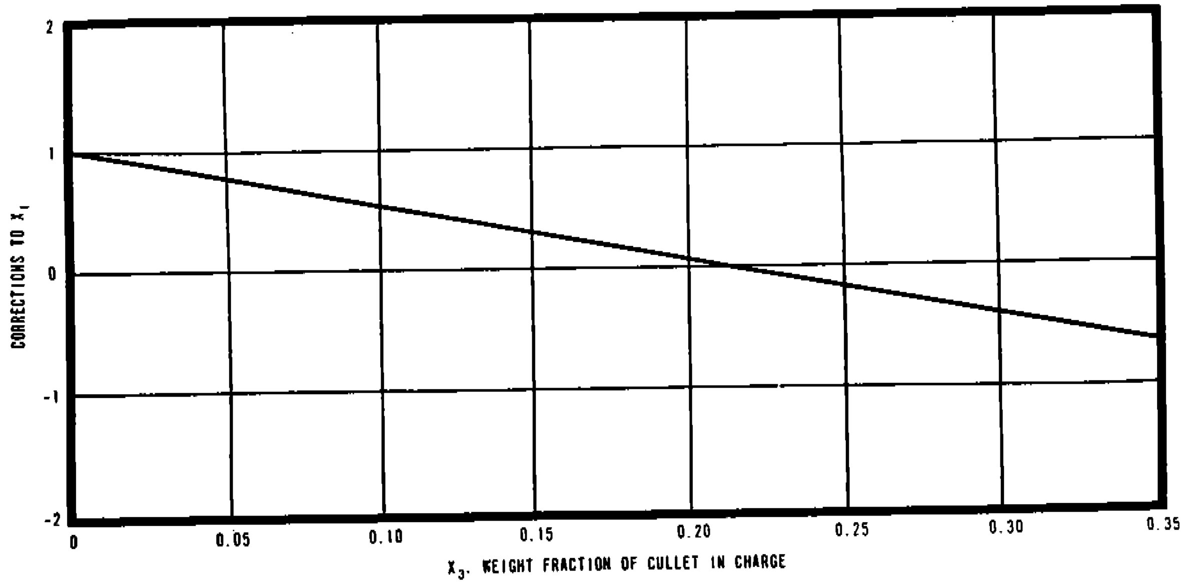


Figure 594. Correction to particulate emissions for cullet content of the batch charge.

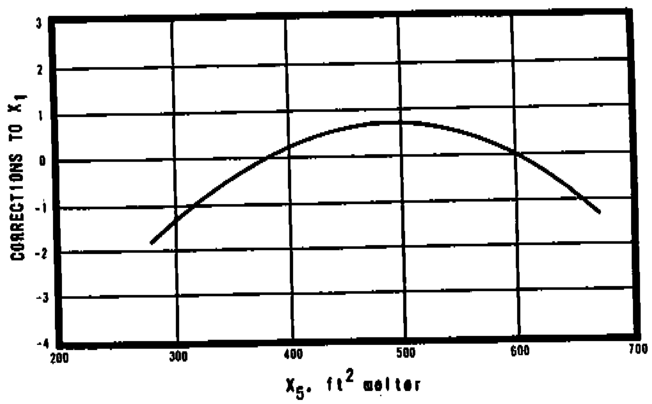


Figure 595. Correction to particulate emissions for melter area.

throughout the batch (Wilson, 1960). Fluxing materials such as salt cake appear more effective, since the unmelted batch does not usually travel so far in the melter tank before it melts. Moisture content of the batch is normally increased to about 2 percent by weight. If the moisture content exceeds 3 percent, batch ingredients adhere to materials-handling equipment and may cake in storage bins or batch cans.

Other batch preparation methods have been employed on a limited-production or experimental basis to reduce dust carryover from soda-ash glass manufacture. One method involves presintering the batch to form cullet and then charging only this cullet to the furnace. Advantages claimed are faster melting, better batch control, less seed formation, reduced clogging in the checkers, and lower stack losses (Arrandale, 1962). A Dutch oven doghouse cover also reduces dust carryover by sintering the top of the floating dry batch before it enters the melter. This method is probably not as efficient as is complete presintering in reducing dust carryover.

Other methods include: (1) Charging briquets, which are made from regular batch ingredients by adding up to 10 percent by weight of water; (2) charging wet batches containing 6 percent moisture, which are made by first dissolving soda-ash to form a saturated solution and mixing this solution with sand and the other dry materials; (3) charging the dry batch (Submerged) in the melter; (4) enclosing batch feeders (Fabrizio, 1961); and (5) installing batch feeders on opposite sides of end port, regenerative furnaces and charging alternately on the side under fire.

Checkers

The design concept of modern regenerative furnaces, with its emphasis on maximum use of fuel, is also indirectly committed to reducing dust carryover. All things being equal, less fuel burned per ton of glass means less dust entrainment by hot combustion gases and flames flowing across the surface of the melting glass. Although container furnaces constructed over 15 years ago required over 7,000 cubic feet of natural gas per ton of glass at maximum pull rates, container furnaces built today can melt a ton of glass with less than 5,000 cubic feet of natural gas.

While several design changes are responsible for this improvement, one of the most important is the increase in checker volume. The ratio of checker volume (cubic feet) to meter area (square feet) has been rising during the years from about 5 in earlier furnaces to about 9 today. Enlarged checkers not only reduce fuel consumption and particulate formation but also present a more effective trap for dust particles that are expelled from the melter. Source tests conducted by a large glass-manufacturing company indicated that over 50 percent of the dust carryover from the melter is collected by the checkers and gas passages instead of entering the atmosphere.

Of course, the economics connected with regenerative furnace operation dictates the checker volume. The law of diminishing returns operates where capital outlay for an added volume of checkers will no longer be paid within a specified period by an incremental reduction in fuel costs. Checkers have been designed in double-pass arrangements to recover as much as 55 percent of the heat from the waste gases (Sharp, 1954). Although dust collects within checkers by mechanisms of impingement and settling, the relationship among various factors influencing dust collection is unknown. These factors include: Gas velocity, brick size, flue spacing, brick setting, and brick composition. Checkers designed for maximum fuel economy may not necessarily have the highest collection efficiency. Further testing will be necessary in order to evaluate checker designs. Checkers designed for maximum heat exchange contain maximum heat transfer surface per unit volume, a condition met only by smaller refractories with tighter spacing. Heat transfer surfaces can be computed by the method given in Trinks (1955). Since gas velocities are also highest for maximum heat transfer, less dust collects by simple settling than by impingement. Dust collection is further complicated in that smaller brick increases the potential for clogging.

To prevent clogging in the checkers and ensure a reasonable level of heat transfer, checkers should be cleaned once per month or more often; an adequate number of access doors should be provided for this purpose (Spain, 1956b). Compressed air, water, or steam may be used to flush fine particles from the checkers. Virtually nothing can be done to remove slag after it has formed. Checkers can be arranged in a double vertical pass to reduce overall furnace height and make cleaning easier. Access doors should also be provided for removing dust deposits from the flues.

Preheaters

Further reductions in fuel consumption to reduce dust emissions may be realized by installing rotary, regenerative air preheaters in series with the checkers. Additional benefits include less checker plugging, reduced maintenance, and increased checker life. Rotating elements of the preheater are constructed of mild steel, low-alloy steel, or ceramic materials. Preheaters raise the temperature of the air to over 1,000°F, and the increased velocity of this preheated air aids in purging dust deposits that block gas passages of the checkers. Exhaust gases passing through the opposite side of the preheater are cooled below 800°F before being exhausted to the atmosphere. A heat balance study of a plate glass, regenerative furnace shows a 9 percent increase in heat use by the installation of a rotary, regenerative air preheater (Waitkus, 1962). To maintain heat transfer and prevent re-entrainment, dust deposits on the preheater elements must be removed by periodic cleaning. Ductwork and valves should be installed for bypassing rotary air preheaters during the cleaning stage.

Refractories and insulation

Slagging of the upper courses of checkerwork can be alleviated in most cases by installing basic (high alumina content) brick in place of superduty firebrick (Robertson et al., 1957). Basic brick courses extend from the top downward to positions where checker temperatures are below 1,500°F. At this temperature, firebrick no longer "wets" and forms slag with dust particles. Dust usually collects in the lower courses of firebrick in the form of fine particles that are easily removed by cleaning. Although basic brick costs 3 or 4 times as much as superduty firebrick, some glass manufacturers are constructing entire checkerworks of basic brick where slagging and clogging are most severe. In some instances, basic refractories are replacing fireclay rider tiles and rider arches in checker supports (Van Dreser, 1962). A word of caution, basic brick is no panacea for all ills of checkers. Chemical composition of the dust should be known, to determine compatibility with the checkers (Fabrianio, 1961).

Regenerative furnaces can be designed to consume less fuel and emit less dust by proper selection and application of insulating refractories. A heat balance study of a side port, regenerative furnace shows that, in the melting process, glass receives 10 percent of heat transfer from convection and 90 percent from radiation. Of the radiation portion of heat transferred, the crown accounts for 33 percent (Merritt, 1958). Since heat losses through the uninsulated crown can run as high as 10 percent of the total heat input, there is need for insulation at this spot.

Most crowns are constructed of silica brick with a maximum furnace capacity restricted to an operating temperature of 2,850°F (Sharp, 1955). Insulation usually consists of insulating silica brick backed with high-duty plastic refractory. Furnaces are first operated without insulation, so that cracks can be observed. Then the cracks are sealed with silica cement, and the insulation is applied.

Insulation is needed on the melter sidewall and at the port necks to prevent glassy buildup caused by condensation of vapors. Condensate buildup flows across port sills into the melter and can become a major source of stones.

While insulation of sidewalls shows negligible fuel reduction for flint glass manufacture, it does show substantial fuel reduction for colored glasses. The problem in manufacturing colored glass is to maintain a high enough temperature below the surface to speed the solution of stones and prevent stagnation. Insulation on sidewalls raises the mean temperature to a point where stones dissolve and glass circulates freely.

Six inches or more of electrofusion cast block laid over a clay bottom in a bed of mortar (Baque, 1954) not only saves fuel but is also less subject to erosion than is fireclay block.

Insulation is seldom needed on the refining end of the furnace since refiners have become cooling chambers at today's high pull rates. Nose crowns, however, are insulated to minimize condensation and drip (Bailey, 1957). Checkers are sometimes encased in steel to prevent air infiltration through cracks and holes that develop in the refractory regenerator walls during the campaign.

Combustion of fuel

Furnace size also has an effect upon use of fuel, with a corresponding effect on the emissions of dust. Large furnaces are more economical than are small furnaces because the radiating surface or heat loss per unit volume of glass is greater for small furnaces.

Slightly greater fuel economy may be expected from end port furnaces as compared with side port furnaces of equal capacity. Here again, the end port furnace has a heat loss advantage over the side port furnace because it has less exposed exterior surface area for radiating heat. Side port furnaces can, however, be operated at greater percentages in excess of capacity since mixing of fuel with air is more efficient through several smaller inlet ports than it is through only one large inlet port. In fact, end port furnaces are limited in design to the amount of fuel that can be efficiently mixed with air and burned through this one inlet port (Spain, 1955). As far as dust losses are concerned, there are only negligible differences between end port and side port furnaces of equal size. Reduced fuel consumption to reduce dust carryover can also be realized by increasing the depth of the melter to the maximum consistent with good-quality glass. Maximum depths for container furnaces are 42 inches for flint glass (Tooley, 1953) and about 36 inches for amber glass and emerald green glass.

Dust emissions as well as fuel consumption can also be reduced by firing practice. Rapid changes in pull rates are wasteful of fuel and increase stack emissions. Hence, charge rates and glass pull rates for continuous furnaces should remain as constant as possible by balancing loads between the glass-forming machines. If possible, furnaces should be fired on natural gas or U.S. Grade 3 or lighter fuel oil. Particulate emissions increase an average of about 1 pound per hour when U.S. Grade 5 fuel oil is used instead of natural gas or U.S. Grade 3 fuel oil, and opacities may exceed 40 percent white.

Combustion air should be thoroughly mixed with fuel with only enough excess air present to ensure complete combustion without smoke. Excess air robs the furnace of process heat by dilution, and this heat loss must be overcome by burning additional fuel. Volume of the melter should be designed for a maximum fuel heat release of about 13,000 Btu per hour per cubic foot.

Furnace reversals should be performed by an automatic control system to ensure optimum combustion. Only automatic systems can provide the exact timing required for opening and closing the dampers and valves and for coordinating fuel and combustion airflow (Bulcraig and Haigh, 1961). For instance, fuel flow and ignition must be delayed until combustion air travels through the checkers after reversal to mix with fuel at the inlet port to the melter. Furnace reversals are usually performed in fixed periods of 15 to 20 minutes, but an improvement in regenerator efficiency can be realized by programming reversal periods to checker temperatures measured optically. Reversals can then occur when checker temperatures reach preset values consistent with maximum heat transfer (Robertson et al., 1957).

An excellent system for controlling air-to-fuel ratios incorporates continuous flue gas analyzers for oxygen and combustible hydrocarbons. With this system, the most efficient combustion and best flame shape and coverage occur at optimum oxygen with a trace of combustible hydrocarbons present in the flue gas. Sample gas is cleaned for the analyzers through water-cooled probes containing sprays. The system automatically adjusts to compensate for changes in ambient air density. Fuel savings of 6 to 8 percent can be accomplished on furnaces with analyzers over furnaces not so equipped (Gunsaulus, 1958).

Combustion of natural gas in new furnaces occurs efficiently when the oxygen content of the flue gases in the exhaust ports is less than 2 percent by volume. As the campaign progresses, air infiltration through cracks and pores in the brickwork, air leakage through valves and dampers, increased pressure drop through the regenerators, and other effects combine to make combustion less efficient. To maintain maximum combustion throughout the campaign, pressure checks with draft gages should be run periodically at specified locations (Spain, 1956a). Fuel savings can also be expedited by placing furnace operators on an incentive plan to keep combustion air to a minimum.

Electric melting

Although melting glass by electricity is a more costly process than melting glass by natural gas or fuel oil, melting electrically is a more thermally efficient process since heat can be applied directly to the body of the glass.

Electric induction systems installed on regenerative furnaces are designed to increase maximum pull rates by as much as 50 percent. These systems are called boosters and consist of several water-cooled graphite or molybdenum electrodes equally spaced along the sides of the melter 18 to 32 inches below the surface of the glass. Source test results indicate that pull rates can be increased without any appreciable increase in dust carryover or particulate emissions. Furnace temperatures may also be reduced by boosters, preventing refractory damage at peak operations.

Furnace capacity increase is nearly proportional to the amount of electrical energy expended. A 56-ton-per-day regenerative furnace requires 480 kilowatt-hours in the booster to melt an additional ton of glass, which is close to the theoretical amount of heat needed to melt a ton of glass (Tooley, 1953).

Electric induction can also be used exclusively for melting glass on a large scale. Design of this type of furnace is simplified since regenerative checkerworks and large ductwork are no longer required (Tooley, 1953). One recently constructed 10-ton-per-day, all-electric furnace consists of a simple tank with molybdenum electrodes. A small vent leads directly to the atmosphere, and dust emissions through this vent are very small. The furnace operates with a crown temperature below 600°F and with a thermal efficiency of over 60 percent. Glass quality is excellent, with homogeneity nearly that of optical glass. After the first 11 months of operation, there was no apparent wear on the refractories (Peckham, 1962). First costs and maintenance expenses are substantially lower than for a comparable-size regenerative furnace. An electric furnace may prove competitive with regenerative furnaces in areas with low-cost electrical power.

Baghouses and centrifugal scrubbers

Air pollution control equipment can be installed on regenerative furnaces where particulate emissions or opacities cannot be reduced to required amounts through changes in furnace design, control of raw materials, and operating procedures. Regenerative furnaces may be vented by two types of common industrial control devices--wet centrifugal scrubbers and baghouses.

Figure 596 shows a low-pressure, wet, centrifugal scrubber containing two separate contacting sections within a single casing. Separate 50-horsepower, circulating fans force dirty gas through each section containing two to three impingement elements similar to fixed blades of a turbine. Although the collection efficiency of this device is considered about the highest for its type, source tests show an overall efficiency of only 52 percent. This low efficiency demonstrates the inherent inability of the low-pressure, wet, centrifugal scrubbers to collect particulates of submicron size.

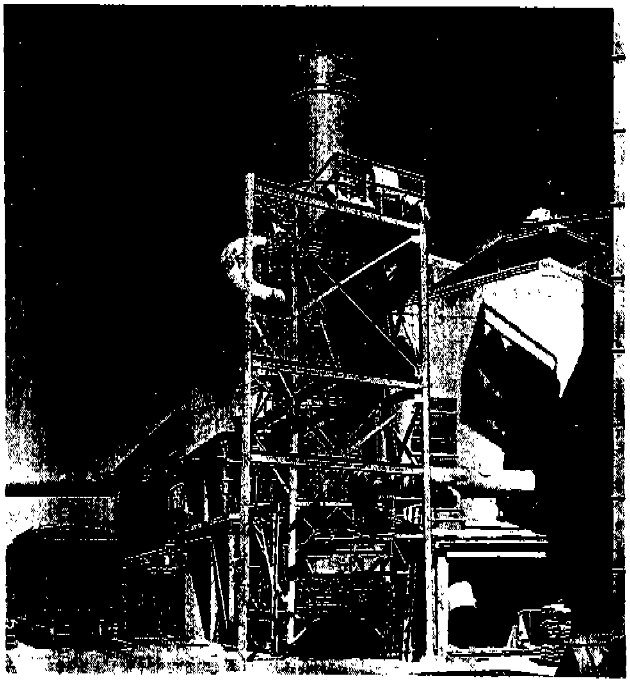


Figure 596. Wet, centrifugal-type scrubber controlling emissions from a glass-melting furnace (Thatcher Glass Co., Saugus, Calif.).

On the other hand, baghouses show collection efficiencies of over 99 percent. Although baghouses have not as yet been installed on large continuous, regenerative furnaces, they have been installed on small regenerative furnaces. One baghouse alternately vents a 1,800-pound- and a 5,000-pound-batch regenerative furnace used for melting optical and special glasses used in scientific instruments. Bags are made of silicone-treated glass fiber. Off-gases are tempered by ambient air to reduce the temperature to 400°F, a safe operating temperature for this fabric.

Another baghouse, although no longer in operation, vented a 10-ton-per-day regenerative furnace for melting soda-lime flint glass. Stack gases were cooled to 250°F by radiation and convection from an uninsulated steel duct before entering the baghouse containing orlon bags.

To determine the feasibility of using a cloth filtering device on large continuous, regenerative furnaces, a pilot baghouse was used with bags made of various commercial fabrics. An air-to-gas heat exchanger containing 38 tubes, each 1-1/2 inches in outer diameter by 120 inches in length, cooled furnace exhaust gases before the gases entered the pilot baghouse. The baghouse contained 36 bags, each 6 inches in diameter by 111 inches in length, with a 432-net-square-foot filter area. A 3-horsepower exhaust fan was mounted on the discharge duct of the baghouse.

When subjected to exhaust gases from amber glass manufacture, bags made of cotton, orlon, dynel, and dacron showed rapid deterioration and stiffening. Only orlon and dacron bags appeared in satisfactory condition when controlling dirty gas from flint glass manufacture and when the dirty gas was held well above its dew point. This difference in corrosion between amber and flint glass was found to be caused by the difference in concentrations of sulfur trioxide (SO_3) present in the flue gas.

To reduce the concentration of SO_3 from amber glass manufacture, iron pyrites were substituted for elemental sulfur in the batch, but this change met with no marked success. Stoichiometric amounts of ammonia gas were also injected to remove SO_3 as ammonium sulfate. Ammonia injection not only failed to lessen bag deterioration but also caused the heat exchanger tubes to foul more rapidly.

In all cases, the baghouse temperature had to be kept above the dew point of the furnace effluent to prevent condensation from blinding the bags and promoting rapid chemical attack. At times, the baghouse had to be operated with an inlet temperature as high as 280°F to stay above the elevated dew point caused by the presence of SO_3.

Additional pilot baghouse studies are needed to evaluate orlon and dacron properly for flint glass manufacture. Experiments are also required for evaluating silicone-treated glass fiber bags in controlling exhaust gases from regenerative furnaces melting all types of glass.

Information now available indicates that glass fiber bags can perform at temperatures as high as 500°F, well above the elevated dew points. They are virtually unaffected by relatively large concentrations of SO_2 and SO_3, and there is less danger from condensation. One advantage of glass fiber is that less precooling of exhaust gases is required because of the higher allowable operating temperatures. Reverse air collapse is generally conceded to be the best method of cleaning glass fiber bags, since this material is fragile and easily breaks when regular shakers are installed.

Furnace effluent can be cooled by several methods: Air dilution, radiation cooling columns, air-gas heat exchangers, and water spray chambers. Regardless of the cooling method selected, automatic controls should be installed to ensure proper temperatures during the complete firing cycle. Each cooling method has its advantages and disadvantages. Dilution of offgases with air is the simplest and most troublefree way to reduce temperature but requires the largest baghouse. Air-to-gas heat exchangers and radiation and convection ductwork are subject to rapid fouling from dust in the effluent. Automatic surface-cleaning devices should be provided, or access openings installed for frequent manual cleaning to maintain clean surfaces for adequate heat transfer. If spray chambers are used, severe problems in condensation and temperature control are anticipated.

GLASS-FORMING MACHINES

From ancient times, bottles and tableware were made by handblowing until mechanical production began in the decade preceding the turn of the century with the discovery of the "press and blow" and the "blow and blow" processes. At first, machines were semiautomatic in operation. Machine feeding was done by hand. Fully automatic machines made their appearance during World War I and completely replaced the semiautomatic machines by 1925. Two types of automatic feeders were developed and are in use today. The first type consists of a device for dipping and evacuating the blank mold in a revolving pot of glass. The second type, called a gob feeder, consists of an orifice in the forehearth combined with shears and gathering chutes (Tooley, 1953).

Glass container-forming machines are of two general types. The first type is a rotating machine in which glass is processed through a sequence of stations involving pressing, blowing, or both. An example of this type of machine is a Lynch machine. A second type is used in conjunction with a gob feeder and consists of independent sections in which each section is a complete manufacturing unit. There is no rotation, and the molds have only to open and close. An example of this type is the Hartford-Empire Individual Section (I.S.) six-section machine shown in Figure 597. Mechanical details and operations of various glass-forming machines for manufacturing containers, flat glass, and tableware are found in the Handbook of Glass Manufacture (Tooley, 1953).

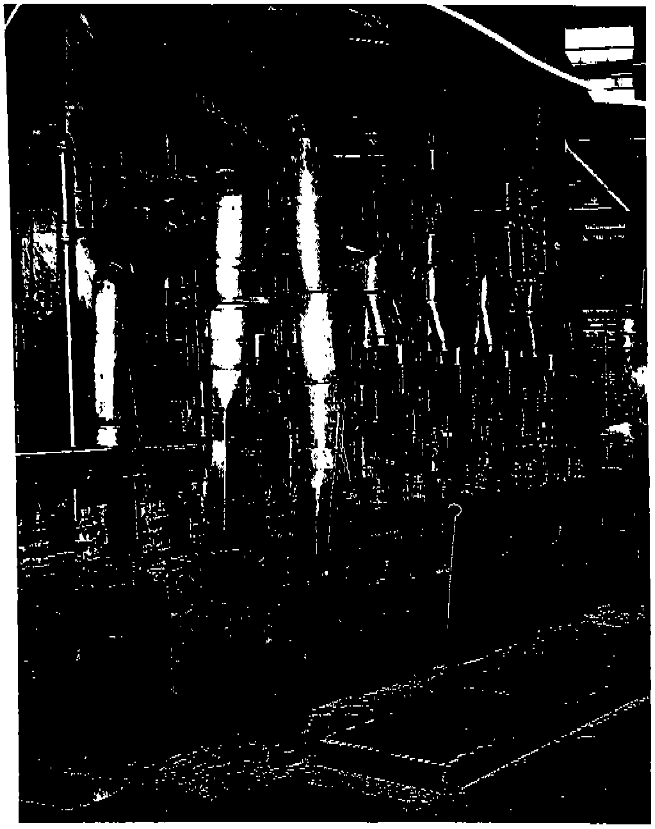


Figure 597. Hartford-Empire I.S. six-section glass-forming machine. (Thatcher Glass Co., Sangus, Calif.).

The Air Pollution Problem

Dense smoke is generated by flash vaporization of hydrocarbon greases and oils from contact lubrication of hot gob shears and gob delivery systems. This smoke emission can exceed 40 percent white opacity.

Molds are lubricated with mixtures of greases and oils and graphite applied to the hot internal surfaces once during 10- to 20-minute periods. This smoke is usually 100 percent white in opacity and exists for 1 or 2 seconds. It rapidly loses its opacity and is completely dissipated within several seconds.

Air Pollution Control Methods

During the past decade, grease and oil lubricants for gob shears and gob delivery systems have been replaced by silicone emulsions and water-soluble oils at ratios of 90 to 150 parts of water to 1 part oil or silicone. The effect has been the virtual elimination of smoke. The emulsions and solutions are applied by intermittent sprays to the delivery system and shears only when the shears are in an opened position.

Lubricating properties of silicone-based emulsions appear in some respects superior to those of soluble oil solutions. Gob drop speeds are increased by 20 to 25 percent. Apparently, the gob rides down the delivery chute on a cushion of steam. Heat from the gob breaks the silicone emulsion, forming an extremely stable resin, a condensation product of siloxane, which acts as a smooth base for the cushioning effect of steam. This resin is degraded in a matter of seconds and must be reformed continuously by reapplying the silicone emulsion.

While graphite gives no apparent advantages to emulsions, a combination of water soluble oil and silicone emulsion appears to be most effective (Singer, 1956). Oil aids the wetting of metal surfaces with silicone and coats metal surfaces, retarding rust formation. Sodium nitrite is also helpful in inhibiting rust when added to silicone emulsion. Water for mixtures must be pure, and in most cases, requires treatment in ion exchangers or demineralizers.

Water treatment is most critical for soluble oil to prevent growth of algae and bacteria. Oil solutions form gelatinous, icicle-like deposits upon drying on the surfaces of pipes and arms of the I. S. machine. These particles should not be allowed to fall into the mold. Optimum results are obtained by flood lubrication of the delivery system to the maximum amount that can be handled by a runoff wire or blown off by air. Dry lubrication of delivery systems has been tried on an experimental basis by coating the metal contact surfaces with molybdenum disulfide or graphite.

Although future developments in the application of emulsions to molds look promising, present practice still relies upon mixtures of hydrocarbon greases, oils, and graphite. Silicone emulsions and soluble oils eliminate smoke, but several difficulties must be overcome before they can be widely used for mold lubrication. Water emulsions with their high specific heat cause excessive cooling if they are not applied evenly to the mold surfaces by proper atomization. Fine sprays meet with wind resistance, and these sprays cannot be effectively directed to cover the shoulder sections of some molds. Because of the low viscosity of water emulsions, the emulsions are very difficult to meter through existing sight oil feeders. One company has equipped its machine with individual positive-displacement pumps for each nozzle. Invert-post cross-spraying is found to be most effective in giving a uniform coating to the molds of I. S. machines (Bailey, 1957).

Rotating machines are much easier to lubricate than are individual section machines. Emulsion sprays are most effective on rotating machines when mounted at the point of transfer of gobs from the blank mold to the blow mold.

FRIT SMELTERS

INTRODUCTION

Ceramic coatings are generally divided into two classes, depending upon whether they are applied to metal or to glass and pottery. In the case of metal, the coating is widely referred to in this country as porcelain enamel. The use of the term vitreous enamel seems to be preferred in Europe. Glass enamel is sometimes used interchangeably with both terms. On the other hand, the coating applied to glass or pottery is known as ceramic glaze.

Ceramic coatings are essentially water suspensions of ground frit and clay. Frit is prepared by fusing various minerals in a smelter. The molten material is then quenched with air or water. This quenching operation causes the melt to solidify rapidly and shatter into numerous small glass particles, called frit. After a drying process, the frit is finely ground in a ball mill, where other materials are added. When suspended in a solution of water and clay, the resulting mixture is known as a ceramic slip. Enamel slip is applied to metals and fired at high temperatures in a furnace. Glaze slip is applied to pottery or glass and fired in a kiln.

Raw Materials

The raw materials that go into the manufacture of various frits are similar to each other whether the frit is for enameling on steel or aluminum or for glazing. The basic difference is in the chemical composition.

The raw materials used in enamels and glazes may be divided into the following six groups: Refractories, fluxes, opacifiers, colors, floating agents, and electrolytes (Andrews, 1961). The refractories include materials such as quartz, feldspar, and clay, which contribute to the acidic part of the melt and give body to the glass. The fluxes include minerals such as borax, soda ash, cryolite, fluorspar, and litharge, which are basic in character and react with the acidic refractories to form the glass and, moreover, tend to lower the fusion temperatures of the glasses. These refractory and flux materials chiefly comprise the ingredients that go into the raw batch that is charged to the smelter.

Materials falling into the other four groups are introduced later as mill additions and rarely exceed 15 percent of the total frit composition.