PLANT REQUIREMENTS FOR MANUFACTURE OF FLAT GLASS

INTERNATIONAL COOPERATION ADMINISTRATION
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PLANT REQUIREMENTS

FOR MANUFACTURE OF FLAT GLASS

INTRODUCTION

Glass is one of the most common materials in everyday life the world over; and its history began long before man manufactured it artificially, when nature formed varieties of glass through volcanic action. One of the most common varieties thus formed was obsidian, which, during antiquity, man shaped into a wide variety of cutting tools and objects of adornment. Objects of this hard glossy material have been found all over the world, and before the Bronze Age, obsidian objects were articles of commerce.

During the period 1527-1415 B.C. the art of making hollow vessels seems to have been developed to a commendable degree. These hollow vessels were ingeniously molded by winding rods of hot, softened glass around a core of sand built up on a metal rod, or by dipping such cores several times in molten glass, thus increasing the wall thickness bit by bit.

About 1200 B.C. the Egyptians began pressing semi-liquid glass into open molds producing bowls, dishes, cups and similar objects which could not be made by the sand-core method. By placing various colored threads of glass in appropriate locations within the molds, it was possible to later reheat the object to a plastic state, thus softening the threads to a degree where it became possible to produce colorful, variegated patterns. It is believed that the Egyptians developed the art of glass making to a stage where they were the nucleus of glass manufacture, but at the same time the Chinese were making glass objects.

It is quite generally agreed that the Phoenicians, about 200 B.C., invented the blowpipe, probably the greatest discovery to advance the art of glass making. This discovery caused an industrial revolution which took objects made of glass out of the luxury class and made them necessities. Glass prepared without the aid of the blowpipe compares to pottery made before the invention of the potters' wheel.

The blowpipe has not changed in character from the day it was invented and consists today of the same hollow metal tube with a bulb at one end and a mouthpiece at the other. Yet this simple device, in the hands of a craftsman, makes possible the creation of an almost endless variety of hollow glass objects.

Relatively clear transparent glass was first produced about the beginning of the Christian era. An early name for such glass was "crystal" glass, for it closely resembled pure rock crystal in transparency. The term is still used to distinguish colorless glass from translucent and opaque varieties.

It was, however, during the middle and late 19th century that most countries began making "utility" glassware for ordinary domestic use, and while art forms didn't compare with the craftsmanship of former years, the volume of output increased tremendously.

Until 1900, manufacturing methods did not differ basically from what they had been during the previous 1500 years. Always a skilled trade, demanding rare dexterity and careful judgment, it was basically dependent on the individual worker, laboring under crude working conditions with a material inaccurately understood and imperfectly controlled.

The 20th century brought an enhanced understanding of glass technology, resulting in improved physical and chemical controls at all stages of the manufacturing process. Progress in the industry towards attaining a tremendous increase in output was further promoted by mechanization which improved quality, uniformity, increased productivity per man-hour, and decreased costs and selling prices. In addition to these factors, the industry greatly expanded due to the creation of a host of new products which were unknown before.

Glass manufacture is one of the truly basic industries. It is one of the three basic great industries -- wood, steel and glass. It is a most versatile creation and plays a role of ever increasing importance. It is a line of endeavor which may be commenced on an exceedingly modest scale, to produce simple articles of commerce, such as glass bottles and containers, where craftsmanship of a high order is not required.

GENERAL ASSUMPTIONS

1. Costs are based on 1954 prices in the United States. Labor rates are those prevailing in glassmaking centers in the United States.

2. Adequate and suitable water, sewage, electrical, and transportation facilities are available at the plant site.

3. The plant will operate an average of 22 eight-hour shifts per month.

4. Labor saving devices which would increase investment in capital out of proportion to the corresponding reduction of unit costs have not been included in the equipment requirements.

5. The necessary raw materials are available in suitable quantities, quality and at proper prices.

6. The market is available or can be readily developed; and the time for starting the proposed enterprise is favorable.

THE NATURE OF GLASS

Glass may be defined physically as a rigid, undercooled liquid having no definite melting point and a sufficiently high viscosity to prevent crystallization. Chemically, it is the union of the nonvolatile inorganic oxides resulting from the decomposition and fusing of the alkali and alkaline earth compounds, sand and other glass constituents.

Glass is an almost completely vitrified product with an exceedingly small amount of nonvitreous material in suspension. The mixture, or batch, from which glass is made contains silica (sand), soda, lime, potash, lead oxide, boric oxide, and cullet. It may also contain oxidizing agents, decolorizing agents, and coloring or opacifying materials.

Cullet, which is broken scrap glass, is almost always in large quantities, not only to reduce the cost of raw materials in the batch, but also because it actively assists in reducing the melting temperature and time. Ancient and modern developments in the industry have created hundreds of varieties of glass, yet it is noteworthy that silica, lime and soda still form over 90 percent of all glass constituents, the same as they did 3,000 years ago.

On the following page is a table supplied by Industrial and Engineering Chemistry giving the chemical composition of typical glasses. Quantities are expressed in percent of each constituent, assuming that the analysis of the cullet used closely approximates the average formula.

Chemical Composition of Glasses

No.	SiO_2	B_2O_3	Al_2O_3	Fe_2O_3	As_2O_3	CaO	MgO	Na_2O	K_2O	PbO	SO_3
1.	67.8		4.4			4.0	2.3	13.7	2.3		1.0
2.	69.4		3.5			7.2		17.3			
3.	70.5		1.9			13.0		12.0	1.9		
4.	71.5		1.5			13.0		14.0			
5.	72.88		0.78			12.68	0.22	12.69			
6.	72.9		0.7			7.9	2.8	15.0			
7.	72.68		0.5			12.95		13.17			0.44
8.	74.5		0.31			5.5	4.1	15.0			
9.	72.4		0.8			5.3	3.7	17.4			
10.	73.88	[illegible]	2.24		0.73			6.67			
11.	74.2	0.4			0.2	4.3	3.2	17.7			
12.	67.2				0.5	0.9		9.5	7.1	14.8	
13.	69.04	0.25				12.07		5.95	11.75		
14.	64.7	10.6	4.2			0.6		7.8	0.3		
15.	80.75	12.0			0.4	0.30		4.10	0.1		
16.	80.9	12.6	1.8					4.4			
17.	96.0	3.6									

Symbols

SiO_2	Silicon oxide
B_2O_3	Boron oxide
Al_2O_3	Aluminum oxide
Fe_2O_3	Ferric oxide
As_2O_3	Arsenic trioxide
CaO	Calcium oxide
MgO	Magnesium oxide
Na_2O	Sodium oxide
K_2O	Potassium oxide
PbO	Lead oxide
SO_3	Sulfur trioxide

1. Early Egyptian
2. Pompeian window
3. German window-blown
4. 19th Century window and bottle glass
5. Machine cylinder glass
6. Fourcault process glass
7. Polished plate
8. Owen bottle-machine
9. Electric light bulb
10. Lamp chimney
11. Tableware - lime crystal
12. Tableware - lead crystal
13. Spectacle
14. Laboratory
15. Corning Pyrex
16. Laboratory Pyrex
17. High silica

Commercial glasses generally fall into the following six classes:

1. Lime glass - the soda-lime-silica glass used widely for windows, transparent fixtures and most containers.

2. Lead glass - containing lead oxide, silica and alkali, which is used for decorative purposes and for some important optical purposes.

3. Vitreous silica - a glass made by fusing pure silica without a flux. It is both thermally and chemically resistant.

4. Borosilicate glass - boric oxide and silica combinations used for optical and scientific purposes.

5. Alkali silicates - soluble glasses used only as solutions.

6. Special glasses - colored and translucent glasses, safety and laminated glass and fibre glass.

Lime glass compositions excel all other compositions in production volume, being used in the manufacture of flat glass (window, plate, wire and figured) tableware and containers. The chief ingredients of which this type of glass is made range as follows:

SiO_2	69 to 72 percent
CaO	12.5 to 13.6 percent
Na_2O	13 to 15 percent

Products with these ratios do not require excessive melting temperatures and are sufficiently viscous so that they do not devitrify, yet they are not too viscous to be workable at reasonable temperatures.

Lead glasses are of great importance in optical work because of their high index of refraction and high dispersion. The brilliancy of good "cut glass" is due to the lead-bearing content of the composition. Lead glasses also possess high electrical resistance properties.

Vitreous glasses are characterized by possessing a low coefficient of thermal expansion and a high temperature softening point, thus imparting high thermal resistance and permitting the glass to be employed at temperatures above those possible for other types of compositions. This glass is also extraordinarily transparent to ultra violet radiation and is sometimes erroneously called quartz glass.

Borosilicate compositions usually contain from 10 to 12 percent B_2O_3 and from 80 to 83 percent silica. They have a low coefficient of thermal expansion, a superior resistance to shock, excellent chemical stability, and high electrical resistance. Ever increasing uses are being developed for this type of glass for food cooking utensils, laboratory glassware, chemical pipelines and high-tension insulators.

Alkali silicates have a range of composition from $Na_2O \cdot SiO_2$ to $Na_2O \cdot 4SiO_2$, and they are the only two-component glasses of commercial importance. The two ingredients are melted together and the product is commonly called sodium silicate. It is water soluble and is generally known as water glass. The product is quite widely used for fire-proofing purposes, for egg preservation, adhesives, and water-proofing compositions.

Special glasses range from relatively low cost decorative glasses to lenses for technical and scientific instruments which must meet exacting laboratory requirements. In this category may also be included fibre glass, laminated and shatter-proof glass, and specially tinted or colored glass.

RAW MATERIALS

The principal raw materials used for making glass are silica sand, soda ash, salt cake, limestone, a relatively smaller amount of lead oxide, potassium carbonate, saltpeter, borax, boric acid, arsenic trioxide, feldspar and a variety of metallic oxides, carbonates and other salts required for coloring. Appreciable quantities of coal, coke, wood, oil or gas are, of course, essential for fuel.

Sand for glass manufacture should be almost pure quartz. While deposits of suitable sand may be found in most countries of the world, the manufacturing plant location should be as close as possible to the sand deposit to keep transportation costs for this material as low as possible. The iron content of the sand should not exceed 0.04 percent, and it should not contain appreciable quantities of other detrimental impurities.

Feldspars provide a superior source of aluminum oxide because they are relatively cheaper than other materials, they are inherently purer, fuse excellently and are composed of glass-forming oxides. The alumina content serves to lower the melting point of the composition and retards devitrification.

Borax supplies both sodium oxide and boric oxide, and is used mainly for common glass containers. It combines high fluxing power with a lower coefficient of expansion and increases chemical durability. Borax is sufficiently low in price in most locations of the world to become the principal alkali material used.

Salt cake and other sulfates, such as ammonium and barium sulfates, are used to prevent troublesome floating scum from forming in melting furnaces.

Cullet is crushed scrap glass obtained from glass processing waste and defective production, as well as from the scrap market, as broken bottles. A batch of glass raw material may include cullet as low as 10 percent of the charge or as high as 80 percent.

Soda is the second most important glass making oxide next to silica. Its principal source is soda ash, Na_2CO_3 or sodium carbonate.

It may be realized from the above that there are but a few essential material items required to make glass. While, theoretically, a great many elements, inorganic salts and mixtures of various kinds can be made into glass by proper manipulation, comparatively few are really suitable for the manufacture of commercial products. In comparison with the total number of compositions available, those actually used are very limited. It is important to realize why this is true.

The reason is to be found in the fundamental nature of glass. Even very ancient glasses contained much the same ingredients which modern glasses contain, and it is more than a mere coincidence that analysis today of glasses formed centuries ago reveals that ancient and modern compositions are very similar.

From our modern point of view, suitable commercial compositions must satisfy the following stringent requirements:

1. The batch materials must be inexpensive and consistent with other prerequisites.

2. The materials must fuse and become fluid at a reasonable industrial temperature without generating gas to cause excessive frothing and bubble forming.

3. The glass must be sufficiently viscous so that it can be manipulated at temperatures above its freezing range, without devitrification, yet not so viscous that workability is sacrificed.

4. The glass must be sufficiently viscous in and below its freezing range that it will not devitrify in cooling.

5. The glass must be chemically stable and capable of resisting acid attacks.

6. The final product must possess the desired physical properties to cope with its intended application.

Emphasis should be directed toward fitting the composition to the manufacturing process and to the ultimate use. When, for illustration, the ancients attempted to lower the temperature of the melting range and to increase workability by using too much soda, the glasses produced disintegrated to mere fragments, which are now occasionally found. The glasses which have survived the centuries must represent the very best products of the ancient glassmakers, and the analysis of these long lasting specimens show them to contain almost exactly the same material constituents which our modern glass contains.

Expressed differently, from long experience glassmakers have found the best combinations of materials to use to achieve a particular final result, and they found that there are only three suitable basic ingredients to use -- silica, soda and lime. And these items are available in nearly all commercial centers of the world.

Because each material has its own peculiar characteristics, it should be purchased, stored, handled and mixed according to proven and accepted methods. There are three prerequisites: purity, proper physical condition, and low cost. Iron (Fe_2O_3) exceeding 0.015 percent cannot be tolerated in optical glass, and more than 0.04 percent in fine tableware is objectionable.

Materials should be thoroughly sifted just prior to their use to remove the foreign matter which nearly always seems to intrude. The sand should be dry and finely granular. Soda ash is a hygroscopic material; therefore, care should be exercised to store it in a manner that it won't pick up an excessive amount of moisture. Borax and boric acid should be stored away from elevated temperature areas. Hydrated lime should be kept dry and in a closed container.

MANUFACTURING METHODS

Glassmaking is, for the most part, a bulk process; large volumes of raw material must be handled. Until about three decades ago, the shovel, wheelbarrow, hand cart and manual labor predominated over all other types of material handling equipment. Until the turn of the last century, manufacturing processes were intermittent in nature, and individual factory production volume was rather small. Therefore, the problems now encountered in the United States, of handling enormous quantities of raw materials and finished products, did not exist.

Throughout the world today there still are a great many small or specialty glassmaking operations utilizing the manual material handling methods which have been employed for centuries. In the United States and other countries where hourly labor rates have risen to levels where they have become an exceedingly important factor in the cost of making glass, a wide range of mechanical material handling devices have been introduced. Also, many electronic and mechanical devices are employed in an endeavor to eliminate the human factor in quality control.

What has justified American glass manufacturers' investments of large sums of capital in highly mechanized plants has been: (1) the tremendous volume of production for specific items; (2) the necessity of eliminating the human element in process control so as to reduce the number of highly skilled operators required to turn out uniformly made products; and (3) the physical problems imposed where human effort instead of mechanical means are employed to handle and transport huge volumes of material.

Essentially, the process of making glass begins with the selection of raw materials which, when compounded in correct proportions, will produce the specific products desired. It is necessary to mix these materials in batch lots before they are ready for melting. The conversion of these raw materials into glass requires high temperature heat for melting, fluxing and fusing; therefore, fuel of some kind is required.

Most present day American glass manufacturers use gas or oil to supply the heat, but coal, coke and wood have been and still are being used in some parts of the world for fuel. The amount of time required to melt a batch of glass depends largely upon the size of the

batch; but irrespective of the batch size, the temperature of the heat within the melting furnace depends on the nature of the ingredients, and temperatures may range from about 1900 degrees Fahrenheit to close to 2900 degrees Fahrenheit.

There are several varieties of melting furnaces employed of both the pot and continuous melting types, and these furnaces range from the common inexpensive pot type that has been employed for centuries to the regenerative tank type continuous furnace constructed according to the individual glass manufacturers' specifications.

The centuries-old direct-fired-pot-type melting furnace is still used in small scale operations where table glassware and bottles of small volume production are hand fabricated. This type of furnace consists of a suitably constructed refractory brick-lined combustion chamber adequately insulated on the outside and suitably vented to remove the products of combustion.

Into this furnace one or more pots or crucibles containing the glass ingredients are placed. This type of furnace, of course, does not embrace any of the modern fuel conservation features, and is therefore suitable only where low cost fuel may be obtained or where competition is such that the cost of making the glass is of secondary importance. With furnaces of this type, care often must be exercised to divert objectionable elements, which the products of combustion of the fuel may contain, away from contact with the melting glass.

An improved type of pot furnace is the regenerative design, which may be constructed to accommodate from one to thirty pots containing as much as two tons of molten glass per pot. Essentially, the regenerative furnace embraces one or more pairs of fuel conservation chambers made of firebrick, laid checker-board fashion. The purpose which this design serves is that of utilizing what might otherwise become wasted heat. (Figure 1)

The operation of this furnace proceeds in two cycles. Hot gases leaving the combustion chamber pass through the checker-board brick work elevating the temperature of the chamber by leaving much of the heat which these hot gases contain. Periodically - usually at intervals of 20 to 30 minutes - these hot gases are switched from one to the other of a pair of conservation chambers.

While one chamber is being reheated, an air blast passes through the previously heated chamber to preheat and thereby intensify the temperature of the fuel used for combustion.

Such a design of furnace is, of course, much more efficient than a common pot-type both from the standpoint of fuel consumption and the standpoint of the pot handling conveniences which may be incorporated into the design. With this type of melting furnace, it is possible to melt a variety of different glass mixtures simultaneously, and the different batches may vary in quantities.

Where large quantities of glass of a particular composition are required, tank-type furnaces are usually employed. These furnaces are constructed to be used as both a holder type and a continuous type, and they may or may not be regenerative in operation. The holder-type furnace consists of a refractory brick lined tank over which hot gases pass to melt the charge, and it is therefore not considered to be the most efficient fuel consumer. It is used chiefly where sizeable quantities of glass of varying compositions are required, and where it is possible to utilize all of the glass of one composition before rechanging the furnace with a different composition. This type is still being employed by large producers of window glass. Such furnaces are constructed as large as 125 feet long, 30 feet wide, and 5 feet deep, holding when full, about 1,250 tons of molten glass.

In order to improve the fuel consumption efficiency of this type of furnace, the regenerative principle is employed. The regenerative feature incorporated into the design of holder tank furnaces operates the same way as does the pot-type described above.

The first continuous tank melting furnace was put into operation about 65 years ago, and during the following early years of operation of this type of furnace, a good deal of experimenting and redesigning was done to improve its fuel consumption efficiency by incorporating the regenerative principle.

Most of the modern regenerative continuous tank type furnaces are restricted to a maximum of about 1,000 tons capacity. The tank of this furnace consists of a refractory material elongated container covered with an arched roof of refractory material. The tank may

consist of but a single compartment, but more often it is divided into two or more dividing walls or bridges. Thus, the glass in different stages of melting flows from one compartment to the next through orifices of suitable dimensions to regulate the flow.

The name "doghouse" has been given to the area where the furnace is charged, and this area is followed by a rectangular area comprising nearly three-fourths the furnace length which is called the melting end. It is along both sides of the melting area that heat is admitted to the furnace.

The last section of the furnace is called the working end (Fig. 2) and usually is designed to accommodate the removal of molten glass from several accessible locations. Often, this area is semicircular in shape. This type of furnace is the most efficient thus far designed; however, its efficiency (heat utilized versus heat applied) does not exceed 25 percent, seldom reaches 15 percent, and may be considered to be a well operated furnace at 10 percent efficiency. About 80 percent of the fuel required is actually utilized in the melting cycle; the balance of 20 percent is either radiated or required to "hold" the temperature of the melt.

Various special features have been incorporated into the design of these furnaces by individual glassmakers, but to insure that the charge is properly melted and refined, most designs include some sort of "bridge-wall" to retard the flow of the melt.

When these continuous furnaces are first put into operation, the temperature is very gradually elevated over about a thirty-day period, or until all of the tank's contents and the furnace lining materials become thoroughly heat "soaked." The mixed batch of raw materials is then fed almost continuously into the dog-house end of the furnace, and flows automatically into the white-hot interior where the temperature ranges from 2,000 degrees Fahrenheit to 2,800 degrees Fahrenheit.

Melting takes place almost entirely by surface heat, from the incandescent gases flowing into the tank area from ports in the sidewalls, first from one side, then from the other, being reversed periodically. The crown of the furnace radiates downwards toward the glass batch.

The batch raw materials are more buoyant than the molten glass; therefore these raw materials float on the surface and come into direct contact with the hot gases. Once a furnace of this type commences operation, about five hours are required for raw materials to travel from the charging end to the working end of the furnace.

Several books have been published dealing with the technical and design aspects of furnaces and glass melting. Probably one of the most lucidly written books is Modern Glass Practice by Mr. S. R. Scholes, published in 1952 by Industrial Publications, Inc., 5 South Wabash Avenue, Chicago 3, Illinois.

Likewise, many excellent books have been published dealing with the technology of glass melting. Indeed it almost seems that nearly all authoritative information needed concerning glass and its manufacture is contained in the wealth of books and technical society proceedings published.

The aims of the melting process, by whatever means that may be utilized, are to produce glass that is free from visible bubbles and free from undesirable contamination, and glass that will result in marketing a clear, homogenous and commercially acceptable product. It is recommended, therefore, that while considering the potential possibilities of establishing a glass plant, one should devote a reasonable amount of study to the existing published literature concerning basic materials, types of furnaces, and melting techniques.

The context of the foregoing pages has dealt primarily with the process of obtaining molten glass and the materials and facilities necessary to produce whatever basic liquid raw glasses are required to produce certain finished items. The finished items could be window glass, tableware, bottles and other containers, optical glass, glass for electrical lighting fixtures, chemical laboratory equipment, or any product which can be made of ordinary glass.

The fabrication of each kind of finished product may be achieved by a variety of methods, depending on the volume of output required, the amount of capital investment justified for equipment and processing facilities, the quality of the ultimate product one proposes to manufacture, and the degree of craftsmanship available in the particular area where the enterprise is to be located.

Expressed differently, the methods used to manufacture any glass product may vary, and the most efficient or expedient method to utilize will depend on the circumstances and the conditions prevailing.

Window glass may be produced by "offhand blowing," casting, or one of the several rolling processes. The manufacture of "sheet," "flat," "plate," or window glass dates back to the early days of glassmaking, with plate glass, as we know it today, being a comparatively recent development. Although most flat glass is now manufactured by mechanical means, the original hand processes are still used.

There are two offhand processes, the "crown" and the "cylinder" process. In the crown process, about ten pounds of molten glass is gathered on the end of the blowpipe. This gathering is "marvered" to a spherical shape and is then blown to a sphere. The side of the sphere opposite the pipe outlet is flattened, and a "punty" with a piece of hot glass at its end is attached to the flattened portion.

The blowpipe is then cracked off, leaving a circular hole in the sphere. The sphere is then inserted through the "glory hole" of a furnace for reheating, after which the sphere is spun about the axis of the punty, thereby enlarging the hole until the sphere becomes a slightly convex circular sheet, of ununiform thickness, about sixty inches in diameter. When the spinning operation has been completed, the punty is broken off, leaving the slightly thicker center to form the "bull's-eye" which is a characterizing feature of windows glazed with crown glass.

The crown process is sometimes employed to make very thin glass sheets by inserting a small sphere into the glory-hole and rapidly revolving it until the spinning action flattens the sphere to a sheet 5 to 7 feet in diameter. The area at the circumference of the sheet may be reduced to a thickness of 3 thousands of an inch, with varying thicknesses toward the center. (Figure 3)

There are a number of variations of the cylinder process of sheet glassmaking. In the Belgian, French, and German methods, the length of the cylinder determines the length of the sheet, and the circumference determines the width. A blowpipe with a large bulb nose is used, and several gatherings are superimposed until a mass weighing about 60 pounds is obtained. A "parison" is formed by blowing and shaping the gathering in a hollowed out block, and, by elongation, the glass near the pipe nose is thinned to form the neck of the cylinder. When cool, the neck becomes sufficiently rigid to support the weight of the cylinder. (Figures 4 through 11)

The end of the parison at the bottom remains a thick gob of semi-liquid glass and therefore retains its heat. This portion of the parison is inserted into the furnace glory-hole for reheating and softening, and when it becomes sufficiently softened to work, it is held vertically in a pit with the soft end downward.

By the combination of blowing and swinging the mass in the pit, the cylinder is elongated from the neck downward. Several returns to the glory-hole for reheating may be necessary before the final length of the cylinder is obtained. When the final length is obtained, a hole is pierced in the lower end of the soft glass cylinder with a pair of shears; and after again returning the cylinder to the furnace for reheating, the cylinder is rapidly spun in the pit which enlarges the pierced hole to the diameter of the circumference of the cylinder.

The fully blown cylinder is then placed on a horizontal stand; either a wet string or a cold metal clamping device is wrapped around the glass at the blowpipe end, and with a sharp blow, the pipe comes free of the cylinder.

The Bohemian process is much like the above description, except that the length of the cylinder corresponds to the width of the final sheet; therefore, sheets of glass made by this process rarely ever measure over three feet square.

In all cylinder blowing processes, the cylinder is cracked lengthwise by drawing a red hot iron along the inside, or by touching the hot cylinder surface with a tight wet string.

The split cylinder is put into a hot oven where, by heating the cylinder to a softening point, the crack opens up. By passing a block of charred wood, held on the end of a long iron rod, backward and forward over the surface of the glass, what was a cylinder becomes a flat sheet of glass, measuring as much as five feet wide and seven feet long. When the sheet complies with commercial specifications for flatness, it is then pushed off onto a cooling table where it is trimmed to size and packed for storage or shipment.

BUILDING REQUIREMENTS

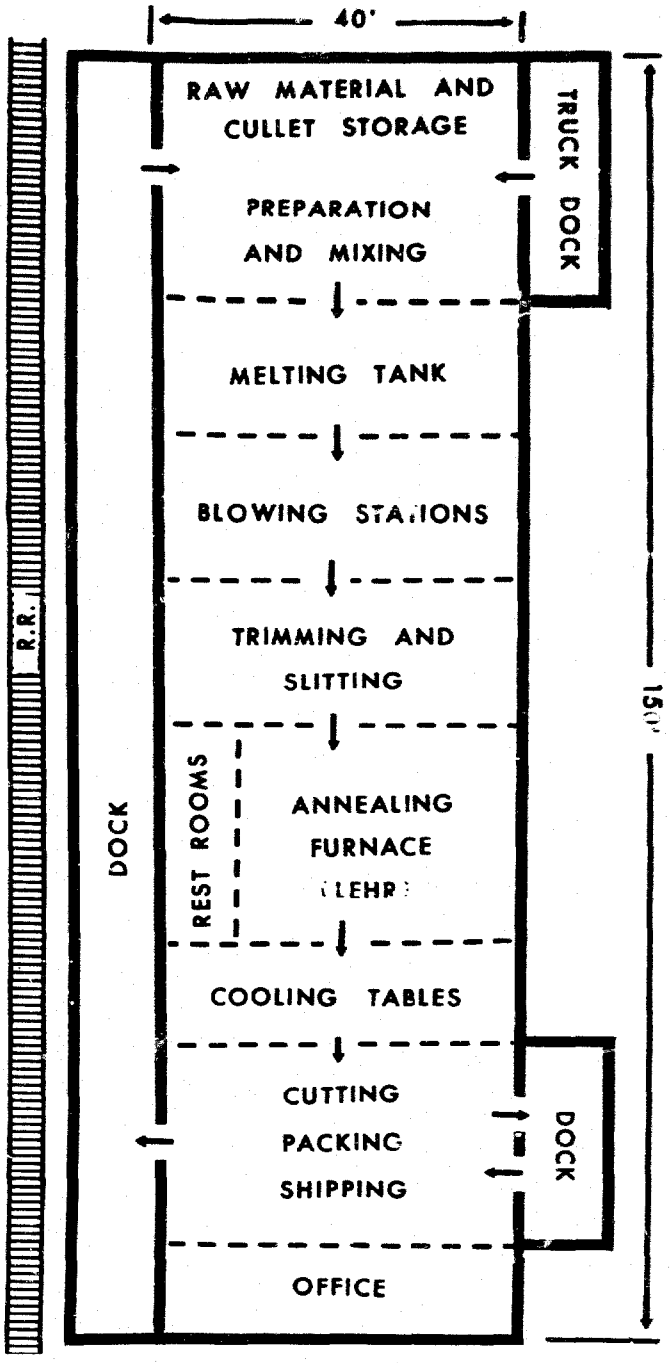
The type of construction for a building to house a glass manufacturing operation will depend a good deal on the climate where the plant is to be located. In warm and tropical climates, the building may be limited to merely a roof to afford protection from the rain, and fencing to protect the property from trespassers.

Such a structure, if constructed in the United States, would cost about $3.00 per square foot, including illumination, sanitation, and water supply.

The schematic floor plan which follows indicates an area 40 feet by 150 feet or 6,000 square feet. At $3.00 per square foot, this means a total estimated cost of $18,000 should be allowed for the building.

Since all operations are on the ground floor, it will be necessary to sink a pit at the blowing stations. It may be necessary to provide for drainage in order to keep the pit dry at all times. In a low area, this should be given careful study.

SCHEMATIC FLOOR PLAN AND FLOW CHART
FOR A SMALL FLAT GLASS PLANT



NOTES

1. PLANT MAY BE SERVED BY RAIL OR TRUCK OR BOTH ON EITHER SIDE OF BUILDING.
2. LAND AREA SHOULD BE AT LEAST 100' X 250' TO PERMIT OUTSIDE STORAGE AND ACCESS.
3. FUEL STORAGE PLACED IN ACCORDANCE WITH GOOD FIRE PREVENTION PRACTICE.
4. DOCKS SHOULD BE ROOFED AND HAVE SUBSTANTIAL FLOORS.
5. DETAILED DIMENSIONS NOT SHOWN BECAUSE ALL EQUIPMENT VARIES GREATLY IN SPACE REQUIRED.

EQUIPMENT REQUIREMENTS

Item	Number Required	Unit Cost	Estimated Total Cost	Actual Total Cost
Melting furnace	2	$ 8,000.00	$ 16,000.00	_____
Annealing furnace	1	5,500.00	5,500.00	_____
Platform scale	1	1,265.00	1,265.00	_____
Shovels	12	3.60	43.20	_____
Riddles	3	12.00	36.00	_____
Pyrometer	1	280.00	280.00	_____
Safety shoes	10	6.50	65.00	_____
Glassmakers tools			300.00	_____
Benches and storage racks			1,000.00	_____
Wheelbarrows	12	17.60	211.20	_____
Office equipment			700.00	_____
Cullet grinder			450.00	_____
Hand trucks	3	56.00	168.00	_____
Glory hole	2	500.00	1,000.00	_____
Burn-off torch			200.00	_____
Blow pipe	5	25.00	125.00	_____
Miscellaneous			1,000.00	_____
Invoice cost:			$ 28,343.40	_____
Export packaging, freight, cartage, insurance, etc.:			625.00	_____
Total cost:			$ 28,968.40	_____

LABOR REQUIREMENTS

A conventional offhand and unmechanized flat-glass plant in the United States with a melting capacity of five tons per day would require the following personnel:

Occupation	Direct Labor: Hourly Rate	Direct Labor: Number Required	Total Hourly Rate	Total Daily Wage	Actual Total Daily Wage
Gaffer	$ 3.00	3	$ 9.00	$ 72.00	_____
Blower	3.00	3	9.00	72.00	_____
Gatherer	2.40	2	4.80	38.40	_____
Cracker	1.65	1	1.65	13.20	_____
Mold holder	1.65	1	1.65	13.20	_____
Carry boy	1.65	2	3.30	26.40	_____
Total Daily Direct Labor Payroll:				$ 235.20	_____
Total Monthly Direct Labor Payroll: (22 working days per month)				$ 5,174.00	_____

Indirect Labor

Occupation	Hourly Rate	Number Required	Total Hourly Rate	Total Daily Wage	Actual Total Daily Wage
Superintendent	$ 4.00	1	$ 4.00	$ 32.00	_____
Clerks	1.50	2	3.00	24.00	_____
Total Daily Indirect Labor Cost:				$ 56.00	_____
Total Monthly Indirect Labor Cost: (22 working days per month)				$ 1,232.00	_____

REQUIREMENTS FOR MATERIALS, SUPPLIES AND FUEL

Materials and Supplies

The prices of material and supply items may vary slightly from day to day in source markets throughout the world; but over a full month's operation, the cost of such items may be averaged to provide the total material and supply cost for the total tonnage of acceptable finished products. The figures shown below are current American prices of materials delivered at glass making centers. The quantities shown are the estimated amounts required to produce one month's operation cycle for the capacity of the plant herein considered.

Item	Unit	Unit Price	Quantity	Estimated Daily Cost	Actual Daily Cost
Silica sand	16	$ .0026	11,643	$ 30.27	_____
Sodium oxide	16	.017	2,174	36.96	_____
Calcium oxide	16	.016	466	7.46	_____
Soda ash	16	.018	776	13.97	_____
Sundry	16	.035	466	16.31	_____
Total:			15,525	$ 104.97	_____
Days of operation				22	_____
Monthly material cost:				$ 2,309.34	_____

Fuel Costs

Each furnace consumes 325 gallons of fuel oil per day, and the lehr consumes 110 gallons. Thus, for two furnaces and the lehr, total oil consumption amounts to 760 gallons per day, or 16,720 gallons per month. The delivered price of fuel oil in most locations in the United States is 14¢ per gallon; hence the oil consumption for the operation under consideration would cost $2,340.80 per month, or $25.00 per ton of glass output. This means that one pound of glass would cost

$0.0125 for fuel; hence, the fuel cost of one square foot of glass would be 1.4 pounds X $0.0125 = $0.0175.

OVERHEAD RATE

Depreciation

Item	Estimated Cost	Actual Cost	Years Life	Annual Depreciation Estimated	Annual Depreciation Actual
Building	$ 18,000	_____	20	$ 900	_____
Melting furnace	16,000	_____	3	5,333	_____
Production equipment	11,640	_____	5	2,328	_____
Office equipment	700	_____	10	70	_____
Totals:	$ 46,340	_____		$ 8,631	_____

$$\text{Depreciation per month} = \frac{\$8,631}{12 \text{ months}} = \$720.00$$

Overhead Expenses (Per Month)

	Estimated	Actual
Power, Fuel, Water	$ 2,748	_____
Indirect Materials (not segregated; for office maintenance, etc.)	400	_____
Indirect Labor	1,232	_____
Insurance, Taxes, Interest	-	_____
Depreciation	720	_____
Total Overhead Expenses Per Month:	$ 5,100	_____

$$\text{Estimated Overhead Rate} = \frac{\text{Overhead}}{\text{Direct Labor Hours Per Month}} = \frac{\$5,100}{2,012} = \$2.53$$

$$\text{Actual Overhead Rate} = \frac{\text{Overhead}}{\text{Direct Labor Hours Per Month}} = _____ = _____$$

UNIT COST OF MANUFACTURE

In determining the unit cost of manufacturing, it has been assumed that the plant will operate at 85% of its potential, the monthly production being:

5 tons X 2,000 pounds X 85% X 22 days = 187,000 pounds, or

$$\frac{187,000 \text{ pounds}}{1.4 \text{ pounds per sq. ft.}} = 133,571 \text{ square feet per month}$$

		(Per Square Foot Acceptable) Estimated	Actual
Direct Labor			
$\frac{\$5,174 \text{ per month (page 18)}}{133,571 \text{ sq. ft. per month}}$	=	$ 0.039	_____
Materials			
$\frac{\$2,309.3x \text{ per month (p. 19)}}{133,571 \text{ sq. ft. per month}}$	=	0.0172	_____
Overhead			
$\frac{\$5,100.00 \text{ (p. 20)}}{133,571 \text{ sq. ft. per month}}$	=	0.038	_____
Total Manufacturing Cost Per Square Foot:		$ 0.0942	_____

CAPITAL REQUIREMENTS

Working Capital

			Estimated	Actual
Inventory:				
Direct material inventory (30 days)		$	2,298.34	_____
Work-in-process (2 days)			209.84	_____
Finished goods (2 days)			209.84	_____
Accounts Receivable (30 days)			14,025.00	_____
Expenses:				
Wages (direct)	5,174.00			
Salaries (indirect)	1,232.00			
Power, Fuel, Water	2,748.00			
			9,154.00	_____
Total Working Capital:		$	25,897.02	_____

Fixed Assets

		Estimated	Actual
Land		-	_____
Building	$	18,000	_____
Equipment		28,340	_____
Total Fixed Assets:	$	46,340	_____

Total Capital Required

Working Capital	$	25,897.00	_____
Fixed Assets		46,340.00	_____
Reserves (organizational expense, surveys, necessary operating reserves)		12,763.00	_____
Total Capital Required:	$	85,000.00	_____

SALES REVENUE

The average price received for single-strength glass is $0.105 per square foot. Allowing 15% of plant capacity for nonproductive time (vacations, shut-downs for repairs, returns, etc.), net production of marketable products will be:

2,000 lbs. X 5 tons daily X 85% X 22 days X 12 months = 2,244,000 lbs.

Since each square foot weighs 1.4 pounds, the annual output = 1,602,800 sq. ft.

Sales revenue = 1,602,800 sq. ft. X $0.105 = $168,300 per year.

PROJECTED PROFIT AND LOSS (one year)

		Estimated	Actual
Gross Sales: 1,602,800 sq. ft. X $0.105 =		$ 168,300	_____
Less: Returns & Allowances		-	_____
Net Sales		168,300	_____
Less: Cost of Manufacturing			
Materials	27,712		_____
Direct Labor	62,088		_____
Overhead	61,200		_____
Total		151,000	_____
Gross Profit on Sales		17,300	_____
Less: Distribution Expenses (2% of Sales)		3,366	_____
Operating Profit		13,934	_____
Less: Administrative Expenses (3% of Sales)		5,049	_____
Net Profit (before taxes, insurance, interest, and other undetermined expenses)		$ 8,885	_____

CONCLUSIONS

On the basis of the information herein presented, it may be safely concluded that it would be profitable to establish a flat glass plant in any country where the important factors are not less favorable than those herein assumed.

Some of the more important factors are:

(1) A market for at least 133,000 square feet of single-strength glass per month;

(2) Materials in proper quantity, quality, and price;

(3) Capital;

(4) Suitable labor.

All relevant factors should be carefully studied before any commitments are made.

Attention is also called to the fact that many other glass products can be made from molten glass in addition to the flat glass herein mentioned, for example, blown hollow ware and stemware. Some of these products will provide a much wider margin of profit than does flat glass.

In this connection, the average retail prices of a limited number of products, chosen at random, of a typical small plant, were found to run over $1.00 per pound. Some of the items checked at random were made for customers who owned the molds, the others being proprietary items.

It would be advisable to consider the possibility of manufacturing stemware and blown hollow ware, particularly if the market potentials are interesting.

* * *

A GLOSSARY OF COMMON GLASSMAKING TERMS

ANNEALING--A controlled reheating and cooling of a glass article to remove any stresses that may have been frozen in the glass as the article was shaped.

BATCH--The name given to the mixture of cullet and various raw materials which is fed into the tank.

BEAD-(1) An enlarged, rounded edge of a tumbler or other glass article, or any raised section extending around the article. (2) A small piece of glass tubing used around a lead wire.

BLANK--Any preliminary shape of glass which requires further forming or finishing.

BLOW MOLD--The metal mold in which a blown glass article is finally shaped.

BLOWER--Any workman who forms glass by blowing either by mouth or with compressed air.

BLOWN GLASS--Glassware shaped by air pressure, as by mouth blowing or by compressed air.

BLOW-PIPE--A long metal tube, on the end of which the workman gathers a gob of glass and through which he blows to expand or shape the glass.

CASTING--A process of shaping molten glass by pouring it into or on molds, tables, or rolls. Used in manufacture of plate glass and many other glass products.

CHECK--A surface crack in a glass article.

CONTINUOUS TANK--A glass furnace in which the level of glass remains constant because the feeding in of raw materials continuously replaces withdrawal.

CROWN GLASS--Flat glass produced by rapidly rotating molten glass at the end of a rod to form a thin, slightly curved sheet. The original method of flat glassmaking, it is now seldom used.

CRUCIBLE--A vessel or melting pot of some very refractory (difficult to melt) material.

CRYSTAL GLASS--A colorless glass containing a high percentage of lead oxide, highly transparent.

CULLET--Broken, or scrap, glass. Unlike broken pottery, broken glass can be remelted and used again.

DRAWN GLASS--Glass, in sheet, rod, tube, or filament form, made by continuous mechanical drawing or rolling operation.

ENGRAVING--The process of cutting figures and letters upon glass with fine copper wheels and an abrasive.

ETCH--To attack the surface of glass with hydrofluoric acid or other agent, generally for marking or decoration.

FINISHING--Process of cracking off, glazing, grinding and polishing glass after it has been blown, drawn or molded.

FIRE POLISHING--Making glass smooth, rounded or glossy by heating in a fire.

FLAT GLASS--A general manufacturing term covering sheet glass, plate glass, and various forms of rolled glass.

FLINT GLASS--The term is a long-standing trade designation which indicates a plain, dense, transparent glass of high lead content, such as is principally used for the manufacture of the finest decorative glass and tableware.

GAFFER--A master glassblower - an artisan skilled in the making of glass - head workman of a glass hand shop.

GATHER-(n.) The mass of glass picked up by the hand shop worker on the punty or blowing iron. (v.) To get glass from a pot or tank on the pipe or punty.

GLASS--An amorphous inorganic product of fusion, usually transparent or translucent, consisting ordinarily of a solution of silicates which has cooled to a rigid condition without crystallizing. Glass is typically hard, and has a conchoidal type of fracture. It may be colorless or colored, and range from transparent to opaque.

GLASS TANK--A melting unit which contains the molten glass and is constructed from refractory blocks.

GLORY HOLE--An opening giving access to the hot interior of a furnace and used to reheat the ware in hand working.

GOB-(a) A portion of hot glass delivered by a feeder. (b) A portion of hot glass gathered on punty or pipe.

HEAT-RESISTING GLASS--Glass able to withstand high thermal shock, generally because of low expansion coefficient.

LAMPWORKING--Forming glass articles from tubing and rod by heating in a gas flame.

LEAD GLASS--Glass containing a substantial proportion of lead oxide (PbO).

LEHR--The tunnel-shaped oven through which glass articles, after their formation by any of the numerous forming or shaping processes, are passed and subjected to a slow controlled cooling in order to eliminate internal stresses or tensions.

LIME GLASS--A glass containing a substantial proportion of lime, usually associated with soda and silica.

MARVERING--The process of rotating upon a polished iron (or sometimes wooden) slab the partially blown glass that is still soft and hot upon the end of a blow-iron. The glass is brought into a proper state of workability for shaping or forming.

MELT--A specific quantity of glass made at one time.

MELTING--The heating process by which the batch is completely converted into molten glass.

MOLD--A form (usually metal) in which glass is shaped.

MOLD-BLOWN GLASS--Molten glass is blown into a mold as distinct from off-hand manufacture.

OBSIDIAN--A highly siliceous natural glass often produced by volcanic action.

OFF-HAND PROCESS--While great strides have been made in the last few decades in the production of glass objects by mechanical means, the "off-hand" method is still used to create glass forms impossible by any other process.

OPAL--A white, semi-opaque glass, as distinct from brilliant colorless glass.

OPAQUE GLASS--Non-transparent and non-translucent. Produced by adding to the ingredients a fluorine (cryolite, fluorspar, or sodium silicate fluoride), which causes the formation of minute white crystals.

OPHTHALMIC GLASS--Glass used in spectacles, generally having specified optical and physical properties and quality.

OPTICAL GLASS--Glass of highest possible physical and chemical homogeneity, with extreme freedom from color and absorption. Used in the manufacture of lenses and prisms for cameras and other optical instruments.

PASTE MOLD--An iron mold lined with adherent carbon or with a paste usually made of beeswax, soap or resin which is placed in the hot mold and kept wet so that the revolving hot glass rides on a cushion of steam as it is blown and shaped.

POT--A one-piece refractory container for melting glass.

PRESS AND BLOW--A process of glass manufacture in which the preliminary form and the final shape is achieved by blowing.

PRESSED GLASS--Glassware made by dropping molten glass into a mold in which shape is imparted to it by the pressure of a plunger.

PRUNT--Small blobs of glass applied to the surface of a glass object into which seals, names or initials are impressed either as decoration or to provide identification.

PUMICE--A hardened, spongy or cellular volcanic glass froth used for smoothing and polishing.

PUNTY--An iron rod used for gathering and manipulating the hot glass - frequently used to hold the partly formed glass object.

SAND--A hard, granular rock material, finer than gravel, coarser than dust, and containing little or no organic matter. Glassmaking sands consist largely of silicon dioxide, or silica, and are found either as banks of loose sand or in the form of sandstone.

SANDBLASTING--Blowing fine quality sand onto glass to obtain a rough-textured and obscured sheet, and for deeply engraving patterns with the aid of protective stencils.

SHOP-(1) A unit group of workmen producing glassware. (2) Also, location of group and their tools and equipment at the furnace.

SODA-LIME-SILICA GLASS--Commonly known as "lime" glass. This is a term that is generally used to denote the oldest and most widely used type of glass. It can be melted in mass quantities in large tanks, thereby facilitating the production of low-cost articles such as bottles and food containers.

STEUBEN GLASS--Finest, handmade American glass for home use and decoration.

STRESS--Any condition of tension or compression existing within glass, particularly due to incomplete annealing, temperature gradient, or lack of homogeneity.

TEMPERED GLASS--Glass that has been rapidly cooled from near the softening point, under rigorous control, to increase its mechanical and thermal endurance.

TENSILE STRENGTH--The resistance of a material to breakage under the stress of pulling or stretching.

THERMAL ENDURANCE--The relative ability of glassware to withstand shock resulting from sudden changes in temperature.

TRANSLUCENT GLASS--Glass in which microscopic, colorless particles band light rays at all angles so that transmitted light is diffused and objects cannot be clearly seen through the glass.

TRANSPARENT GLASS--Permitting light to pass freely, without scattering and without noticeable absorption, so that bodies can be distinctly seen through the transparent material.

TUBING--Elongated hollow glass drawn to form such items as thermometers, laboratory apparatus, fluorescent lights, neon signs, and industrial pipe.

VISCOSITY--Resistance to flow, of a material - particularly a liquid or molten material. Molten glass is viscous.

VITREOUS--Of, relating to, or like glass. Obtained from glass. Resembling glass in some property, or having a glass-like appearance.

Fig. 1 - Gatherer is about to gather a gob of molten glass from the pot furnace.

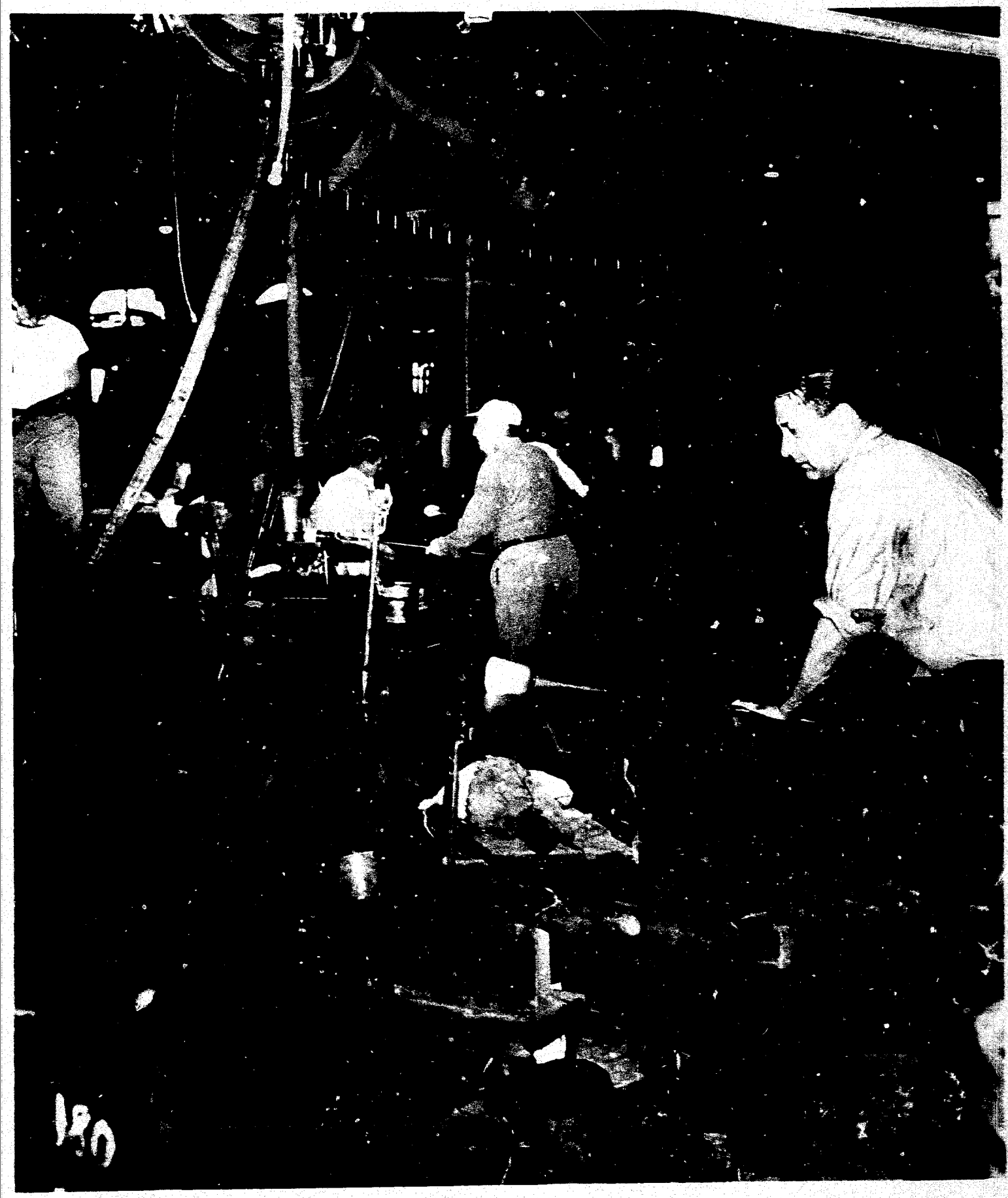


Fig. 2 - Gatherer marvers molten glass on steel marvering slab to chill surface in preparation for blowing. He then hands it to blower.

Grinding and polishing glass

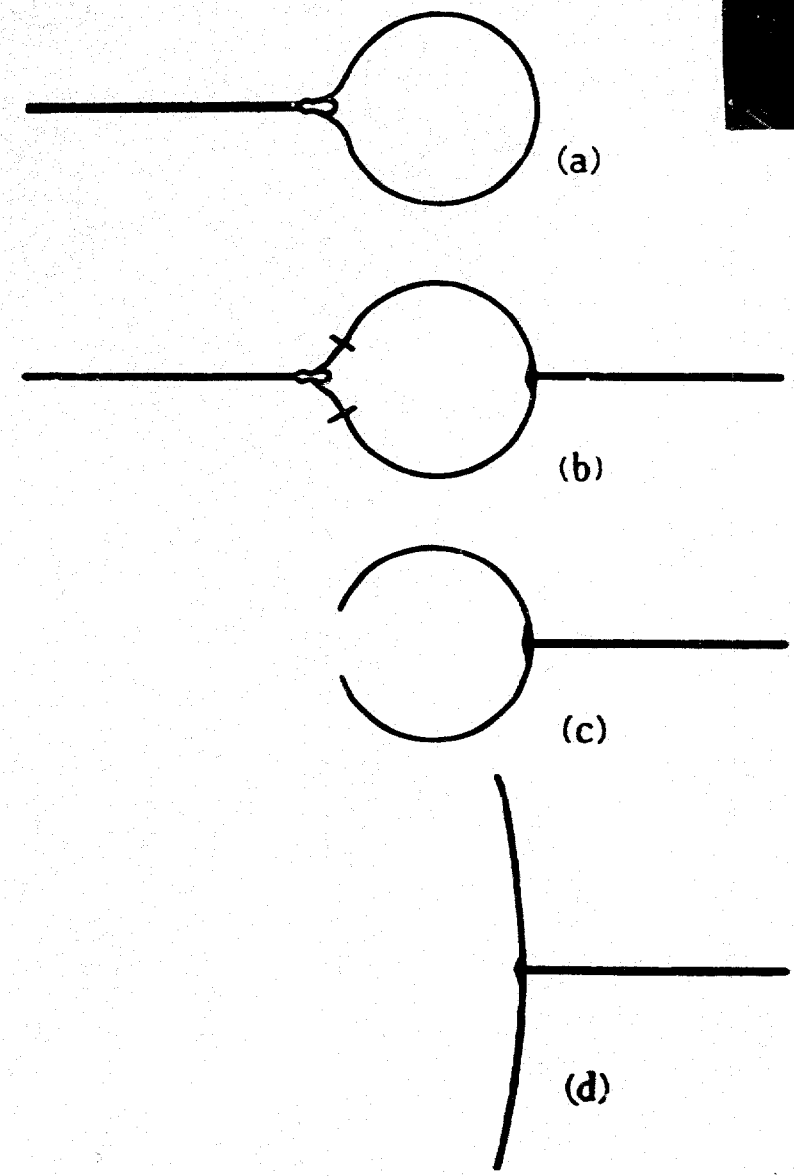


Figure 3 - The crown process for sheet glass (diagrammatic).

(a) Blowing of the sphere.
(b) Attachment of the punty.
(c) Removal of the blowing pipe.
(d) The glass spun into a disc.

BLOWING GLASS BY HAND.

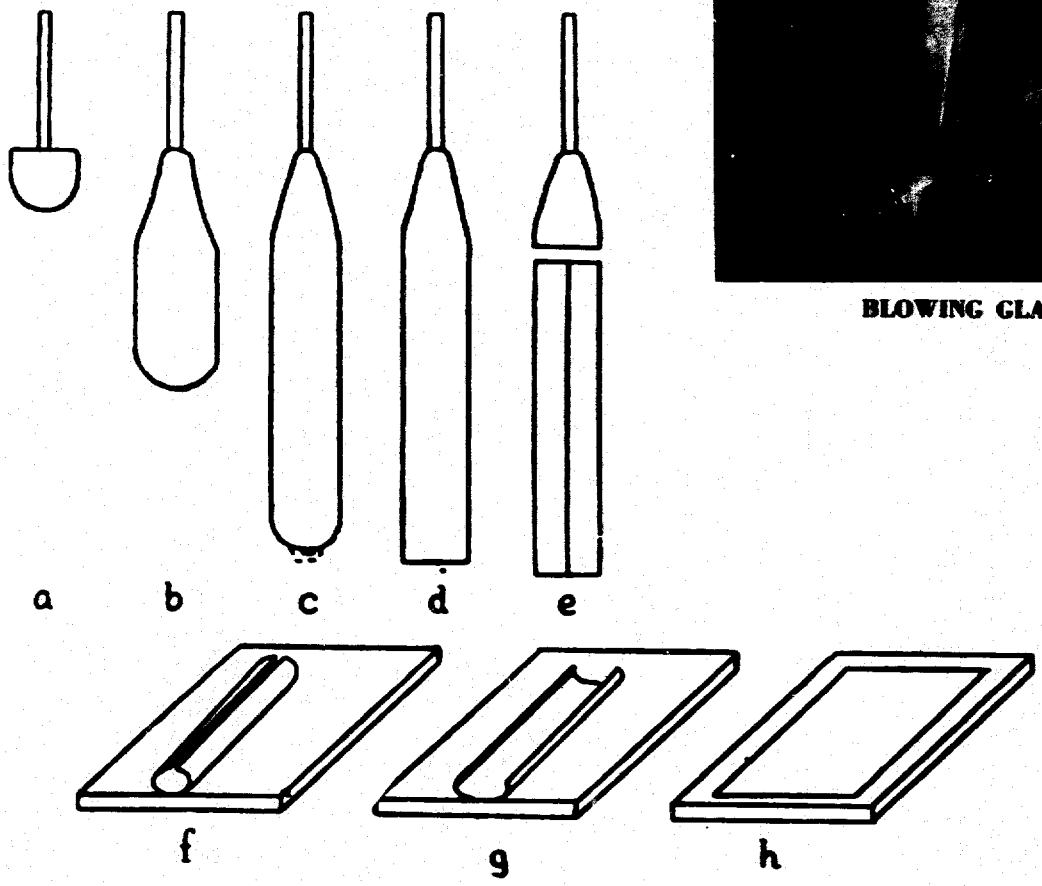


Figure 4 - Manufacture of sheet glass by the cylinder process (diagrammatic).

(a) The parison
(b) Formation of the neck of the cylinder
(c) The blown cylinder
(d) Cylinder with open end
(e) Cylinder removed from the pipe and split longitudinally
(f) First stage in flattening the cylinder
(g) Second stage in flattening the cylinder
(h) The flattened sheet

Figure 5 - Gathering

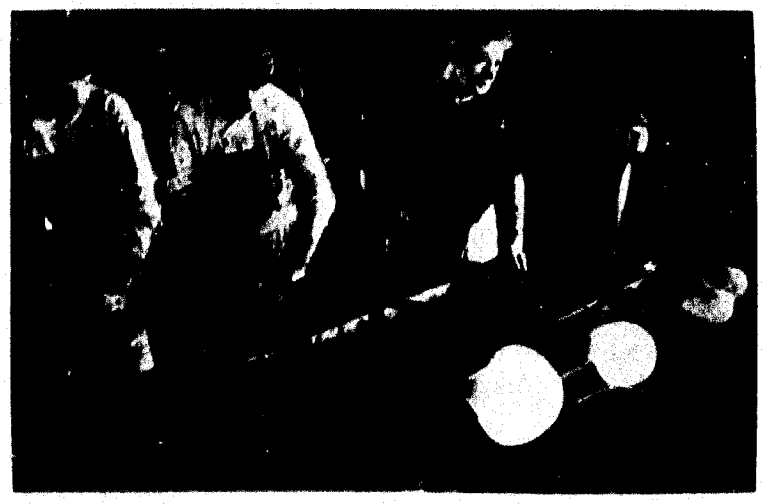


Figure 6 - Several stages of gathering in manufacture of sheet glass by cylinder process.

Figure 7 - Preparing parison in cylinder process.

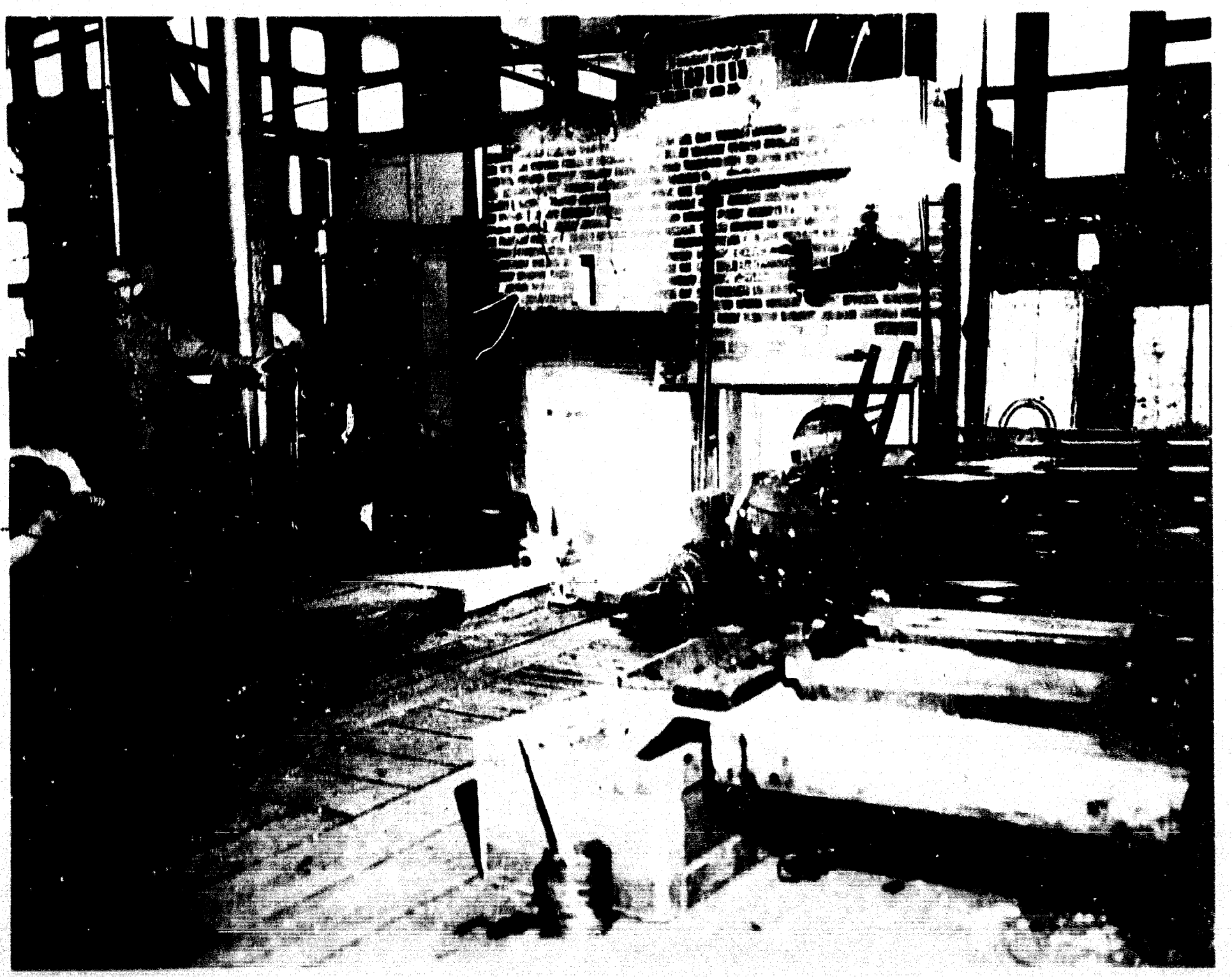


Figure 10 - Splitting cylinder.

Figure 11 - Flattening cylinder.

PLANT REQUIREMENTS REPORTS AVAILABLE

ABRASIVE WHEELS
ANIMAL FEED PELLETS
ASBESTOS - CEMENT SIDING
BRASS FOUNDRY
BUCKETS, PAILS AND PANS
BUILDING BRICKS
BUILDING HARDWARE
CERAMIC DINNERWARE
COARSE WRAPPING PAPER
CONCRETE BLOCKS & SLABS FOR WALLS
COTTON DRESSES
COTTONSEED OIL
FARM HAND TOOLS
FERTILIZER MIXING
FIBRE BOXES
FLAT GLASS
GLASS CONTAINERS
GRAY IRON JOBBING FOUNDRY
JOB MACHINE SHOP
KITCHEN EARTHENWARE
LEATHER TANNING
MEN'S HOSE
MEN'S UNDERWEAR
PAINT
PAINT AND VARNISH BRUSHES
PHOSPHATE PROCESSING
PLASTICS MOULDING
REFINED SUGAR
SANITARY WARE
SHELL BUTTONS
TERRY CLOTH
TWO-BURNER GAS PLATES
WALLBOARD