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Technical and Economic Features in the Utilization of Blast Furnace Slag in Glass Manufacture

By

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ABSTRACT

The object of this investigation was to find a more advantageous method for the disposal of blast furnace slag.

As a result of this investigation, a method was developed for the production of four types of glass: (1) A transparent aluminum glass, (2) an opaque black glass, (3) a translucent "opal" glass, and (4) a laboratory or "chemical" glass.

The optimum conditions for carrying out the various processes were determined.

The various objections to the use of slag for glass manufacture were discussed in detail and an explanation offered as to how these objections were overcome.

The transparent aluminum glass and the black opaque glass were made on a semi-commercial scale.

Drawings and specifications together with an estimate of the cost of the necessary equipment for commercial or large scale manufacture of the slag glasses are included. This data was supplied by the Simplex Engineering Company, and the Amsler-Norton Company.

The cost of the raw materials for producing the various slag glasses was determined and the results compared to various commercial glasses.

The physical and chemical properties of the various glasses were determined and the results compared with commercial glasses.

Various economic features were discussed with the point in view of determining the commercial feasibility of the process.

The results showed that there was a saving in the cost of the raw materials from 35 to 75 per cent and the glasses were of superior quality with respect to thermal endurance, chemical stability, tensile strength and resistance to breakage by impact. An additional advantage in the case of the black glass was the high gloss and true black color. An advantage possessed by all the slag glasses was their resistance to shattering when broken.

Technical and Economic Features in the Utilization of Blast Furnace Slag in Glass Manufacture

INTRODUCTION

Large quantities of blast furnace slag are produced as a by-product of the manufacture of pig iron. This slag while used to a considerable extent for railroad ballast, and for slag and Portland cement, is nearly worthless or at best brings a very low price. For example, the slag is quoted as low as $10.00, per car load.

In an effort to find a more advantageous method for the disposal of this slag, the writers became interested in the possibility of converting this material into glass.

Of the glasses developed only the transparent aluminum glass and the black glass are discussed in detail in this paper, the opal glass and the laboratory glass being only briefly treated.

The writers are indebted to Mr. C. E. Frazier, President Simplex Engineering Company, and to various officials of the Amsler-Norton Company, for their cooperation in the preparation of tentative plans for the layout of the slag glass plant and for estimates of the initial cost of the plant.

BIBLIOGRAPHICAL REVIEW

Several attempts have been made by different persons to make glass from blast furnace slag.

Parsons[1] developed a process in which fine blast furnace slag is digested with a solution of alkali metallic silicate to form calcium and magnesium silicates. These silicates are recovered by means of a centrifugal and are mixed with other material to form a glass making charge.

Parsons[2] also utilizes a basic slag, such as blast furnace slag, in glass manufacture by treating the slag with steam under a pressure of 150 pounds per square inch, thus converting the calcium sulphide of the slag into the hydrosulphide. The soluble calcium hydrosulphide is separated and the residue treated with sodium hydroxide to form a soluble sodium aluminate.

Enequist[3] employs a basic **soda** slag containing iron (Fe^{**}), with sand and other glass-making materials, to form a black glass or a "comparatively clear" glass for use as a glass or glaze.

Note: Among the various mixtures claimed by Enequist is one consisting of "Basic soda slag combined with basic lime slag, or alkaline earth slag, and a carbonate". Since the process patented by Enequist is based upon the utilization of a basic soda slag, it appears doubtful that his claim to the use of basic lime slag in some of his batches would seriously interfere with the process described. At any rate, Enequist's patent expires in 1939 and hence could not possibly be a factor after that date. The mixtures used in the two processes differ greatly. The dark color in the glass prepared by Enequist is attributed by him to ferrous silicates while the color in the black slag glass, discussed in this report is believed to be caused by the presence of sodium sulphide in the glass.

Two Russian chemists, I. I. Kitaigorodskii and I. P. Karev[4], have been working on the utilization of blast furnace slag in glass manufacture, simultaneously with the writers. These workers find that granulated blast furnace slag may be added to an ordinary glass batch in quantities up to 30 per cent of the weight of the batch, and that there is an improvement in the quality of the glass on addition of the slag.

Kitaigorodskii and Karev state further that glass containing 30 per cent of its weight of blast furnace slag was composed of 70 per cent silicic acid, 3.2 per cent alumina, 16 per cent calcium oxide, and 10 per cent sodium oxide. The batch used to obtain this glass was made up of the following materials, expressed as parts by weight;

Sand	1000
Sodium Sulfate	275
Soda	160
Slaked Lime	180
Charcoal	10

The same workers find[5] that a batch containing 30 per cent of its weight in blast furnace slag gives a black or orange glass when soda is used and a clear glass when sodium sulphate is used. They state that a high-grade glass can be made at a considerable saving by using blast furnace slag in the batch.

Kitaigorodskii and Karev apparently began with an ordinary glass batch and attempted to add slag to this batch, rather than beginning with slag and adding other glass-making materials to secure a batch of the desired composition. The main objection to such a procedure is that the quantity of slag which may be used in the batch is reduced in proportion to the lime present in the batch at the beginning. The batch given by them contains considerable slaked lime. The quantity of slag which may be used in the batch is limited by the calcium oxide content of the glass, hence a batch containing lime would not allow the addition of as much slag as could be used in a batch containing no lime. As a whole, the work of these men verified in several respects the results secured by the writers.

OVERCOMING OBJECTIONS TO THE USE OF SLAG IN GLASS MANUFACTURE

The use of an impure waste material, such as blast furnace slag, in a glass-making charge naturally presents certain difficulties which must be overcome. Examination of the work reported in the scientific literature by other investigators show that most of them have resorted to some preliminary treatment of the slag in order to overcome the objections to its use in glass production. The objections to such preliminary treatment of the slag are obvious.

Blast furnace slag consists primarily of lime, silica, and alumina. Lime and silica are essential in glass-making, while alumina is known to impart certain desirable properties to glass in which it is present. A study of the composition of blast furnace slag suggested the conversion of all the slag into glass without any preliminary chemical treatment. Certain of the difficulties encountered in the conversion and the manner in which they were overcome are discussed below.

Composition Of The Slag:

While slag is composed of certain of the materials used in glass manufacture, the proportions in which these materials are present is not that desired in the glass batch. The lime is much too high, while the silica is entirely too low.

In order to secure a mixture of the desired composition, other glass-making materials, chiefly sand and soda, were added to the slag. The addition of sand to the mixture served to increase the silicon content and the addition of soda materially reduced the melting point of the glass and improved its working qualities. The lime content of the batch was, of course, reduced in proportion to the sand and soda added to the mixture.

Impurities in the Slag:

If slag is to be used in a glass batch, consideration must be given the impurities present in the slag. These impurities consist chiefly of sulphur and iron, together with small amounts of magnesium and titanium. The magnesium and titanium may be ignored, but the sulphur and iron must be taken into account in the development of a process for converting the slag into glass.

Sulphur:

Experimental work showed that the development of transparency in slag glass is dependent upon the removal of the sulphur of the slag. Unless this sulphur is removed, an opaque glass results. This property of the sulphur of the slag for imparting a black color to glass serves as the basis for making both a transparent and a black glass from the slag.

It was found that the addition of a small amount of arsenic trioxide (AS_2O_3) to the glass mixture brought about liberation of the sulphur as a volatile sulphide of arsenic when the charge was heated in the glass furnace and that a transparent glass resulted. Small quantities of this material, therefore, were added to the mixture from which it was desired to produce a transparent glass.

It was found, on the other hand, that a true, jet-black glass could be prepared from blast furnace slag simply by stabilizing the sulphur of the slag in the glass as sodium sulphide (Na_2S). To produce such a glass, then, the arsenic trioxide was omitted from the charge and care was taken to prevent oxidation of the sulphur. When sodium sulphate was used as a scum remover in the batch, it was found necessary to counteract the oxidizing action of the sulphate on the sulphur of the slag by the addition of a very small amount of coke to the batch. Failure to counteract this oxidizing action of the sulphate results in the formation of a brown or greenish-brown glass.

Iron:

Both free iron and iron oxide are present in small quantities in blast furnace slag. According to information supplied by The Carnegie Steel Company, Pittsburgh, Pennsylvania, the iron existing as oxide in granulated slag shows little variation, usually being between 0.20 and 0.30 per cent, while the iron present in the free condition usually varies from 0.40 to 0.80 per cent, but may run as high as 1.50 per cent in some samples.

If a transparent glass is desired, steps must be taken to oxidize the iron of the slag and to keep it in the ferric condition until the glass leaves the furnace. The color imparted to glass by iron in the ferric condition is not so objectionable as that imparted by iron in the ferrous condition.

Experimental work indicated that the addition of a little more arsenic trioxide than was actually necessary to remove the sulphur of the slag served to oxidize the iron of both the slag and the sand, and to produce a transparent glass having a pale green color. In the production of black slag glass, such oxidation is not desirable.

Examination of the figures given above for the percentage of iron occuring in slag suggests the use of a magnetic separator for preliminary treatment of the slag to remove the free iron. Since the major portion of the iron in slag exists as metallic iron and since practically all of the variation in total iron content of the slag is due to variation in the percentage of metallic iron, such preliminary treatment of the slag might prove feasible. Magnetic treatment of the slag should give a product having a low, practically constant iron content.

Variation in Composition of the Slag:

When slag is considered as a raw material for glass manufacture, the question immediately arises as to the variation in chemical composition of the slag and the effects of this variation on any process developed for converting the slag into glass.

According to the Carnegie Steel Company, a typical analysis of blast furnace slag from standard basic iron is as follows:

	Per Cent by weight			
SiO_2	36.62	35.56	36.18	36.13
Al_2O_3	14.14	12.96	12.68	14.25
CaO	43.28	46.03	45.69	43.76
MgO	3.14	3.51	3.13	3.51
S	1.58	1.71	1.69	1.63
MnO	1.41	.67	.97	1.00
Fe - as oxide	.20	.20	.20	.20
Fe - metallic	.40	.47	.37	.47

Variations in the analysis of the slag are reported as follows:

SiO_2	34.00 to 38.00	per cent
Al_2O_3	12.00 to 14.00	depending on ore
CaO	42.00 to 48.00	
MgO	1.00 to 5.00	
S	1.25 to 2.00	
MnO	.50 to 2.00	
Fe - as oxide	.10 to .40	
Fe - metallic	.20 to 1.00	

In connection with the variation in the analysis of the slag, it is reported that the iron existing as oxide does not show much variation, usually being around 0.20 to 0.30, but the metallic iron, on the other hand, may show a wide variation, usually from 0.20 to 1.00. The variation in iron is reported as often being between 0.4 and 0.8 per cent.

Aside from the iron, which has already been discussed, the only components of the slag whose variation would materially affect the properties of the glass are the lime and silica.

The variation in lime content of blast furnace slag is given above as from 42.00 to 48.00 per cent. In other words, the variation above or below the average percentage for lime does not exceed 3.00 per cent of the weight of the slag. Since the percentage of slag in the mixture for the transparent glass is 39.4 and that in the mixture for the black glass is 32.3, the maximum variation in the amount of lime in the two mixtures should not exceed 1.2 per cent and 1.0 per cent, respectively, of the weight of the charge.

The variation in silicon content of the slag is given as from 34.00 to 38.00 per cent. By a procedure similar to that used for lime, it is reasoned that the maximum variation in silica content should not exceed 0.8 per cent of the weight of the charge for the transparent glass and 0.6 per cent of the weight of the charge for the black glass.

It is not believed that in a cheap glass to be used for sky lights, tiles and similar purposes where hardness and strength were important, that the variation of iron, lime, silica, etc., would be of importance nor that it could be detected. In order to prove this point, glass was made from several different slags, and the various glasses compared. Examination of the green transparent glasses showed that the variation in the shade of the green transparent glasses was too slight to be detected. The physical properties were also strictly comparable. This was also true in the case of the black glass. Consequently, the conclusion was reached that variation in the slag would be of slight if any importance as far as the slag glass was concerned.

PRODUCTION OF SLAG GLASS ON A LABORATORY SCALE

Transparent Aluminum Glass

Apparatus:

A small gas-fired furnace was constructed for fusing the mixture and carrying out the necessary reactions. The use of natural gas and preheated compressed air made possible a temperature as high as 2700°F. with this furnace.

For the preliminary laboratory work, a small fire clay crucible having a capacity of about 30 grams of mixture was used. Later, larger crucibles were employed, the largest size used in the laboratory work holding up to 700 grams of mixture.

The temperature of the furnace was determined by means of a calibrated optical pyrometer.

The melted glass was poured on a previously-heated piece of sheet steel and rolled with an iron pipe or was poured into a small metal mold and molded into a disk.

MATERIALS AND GENERAL PROCEDURE:

Analysis of Raw Materials:

Analyses of the raw materials used in the batch are given in Table I below:

TABLE I

Analysis of Raw Materials

Per cent by weight—dry basis

	Slag No. 1	Slag No. 2	Sand No. 1	Sand No. 2	Sand No. 3
SiO_2	37.55	37.45	97.72	94.53	99.57
Fe_2O_3	1.41	3.57	1.10	.32	.09
Al_2O_3	11.38	11.18	.64	4.18	.13
TiO_2		.47		1.02	
CaO	46.27	45.47	.65	.38	.08
MgO	.23				
S	1.23	1.01			
Ign. loss					
Undetermined	1.93	.85			
Total	100.00	100.00	100.11	100.43	100.00

Slag No. 1 was a granulated slag furnished by the Woodward Iron Company, Birmingham, Alabama, and Slag No. 2 was an ungranulated slag supplied by the same company.

Sand No. 1 was a washed sand secured from the Flomaton, Alabama, plant of the Roquemore Sand and Gravel Co. This was an ordinary building sand and was considered representative of most Alabama sands.

Sand No. 2 was a washed sample from the property of Judge Brewer, Opelika, Alabama. This sand, it will be noted, contained a low percentage of iron.

Sand No. 3 was secured from the Mohawk Sand Deposit belonging to Dr. W. G. Meharg, Anniston, Alabama. This sand was believed to be a typical glass sand.

The soda ash employed contained 58.5 per cent Na_2O.

Sodium sulfate of U. S. P. grade was used for the early work on the transparent glass. Later, calcined salt-cake of the grade ordinarily used for glass manufacture was adopted for the work. This salt cake was supplied by the Grasseli Chemical Company, Birmingham, Alabama, and contained 97.61 per cent Na_2SO_4, 1.56 per cent H_2SO_4, and 1.07 per cent NaCl.

The arsenic trioxide used contained 0.25 per cent non-volatile material, 0.20 per cent antimony trioxide, and 0.01 per cent iron.

Composition of the Batch:

Most glasses contain from 65 to 75 per cent silica, from 8 to 18 per cent alkali, and up to 20 per cent calcium oxide, together with smaller amounts of other substances. Considerable alumina is present in many glasses.

Addition of sand to the slag in the ratio of approximately eight parts of sand to seven parts of slag served to reduce the lime content to an amount corresponding approximately to the upper limit for this material and to increase the silica content to the desired amount. It is known in this connection that the presence of alumina in the charge makes possible the use of a batch having relatively high lime content without undesirable effects on the properties of the glass (Hodkin and Cousen, "Textbook of Glass Technology", Van Nostrand Company, 1925).

It was found that a satisfactory glass could be made using ordinary building sand (Sand No. 1). The use of a higher grade sand, however, gave a product of higher quality and one having very little color.

Soda ash was added to the batch to supply the desired alkali.

As is frequently done in glass practice, calcined saltcake was added to the mixture to prevent the formation of a scum consisting of fine particles of uncombined silica.

The addition of arsenic trioxide, as stated above, is essential in removing the sulphur of the slag and in oxidizing the iron in the mixture. Arsenic trioxide is often used as a firing agent in glass manufacture. Its use here, however, is dependent upon an entirely different principle. The arsenic trioxide reacts with the sulphur of the slag to form a volatile sulphide or arsenic, which escapes with the flue gases. The amount of arsenic trioxide required in the charge is dependent upon the quantities of iron and sulphur present in the mixture. Slight excesses of the trioxide should have no appreciable effect upon the glass.

The composition of the mixture found to be satisfactory in the laboratory was as follows:

	Per cent by weight dry basis
Slag	39.4
Sand	45.8
Soda ash	8.8
Salt cake, calcined	4.9
Arsenic trioxide	1.1
Total	100.0

The sand used in the mixture given above was Sand No. 1, containing 1.10 per cent Fe_2O_3. A pale green almost colorless glass was produced from Slag No. 1 and Sand No. 3, using only 0.3 per cent arsenic trioxide.

This mixture gave a pale green, transparent glass which was free from scum and had an unusually high luster. The glass had good working properties.

Fineness of the Charge:

The speed with which the reactions take place in the glass furnace is determined in part by the size of the particles of various materials making up the charge, especially by the size of the particles of sand. The sand is usually screened to between 20 and 40 mesh. Any particles of sand larger than 20 mesh are likely to delay the reactions unreasonably and such particles also tend to cause the formation of scum. On the other hand, particles of sand much smaller than 40 mesh may cause the charge to foam excessively as it melts.

Runs were made in the laboratory using sand which had been ground to such fineness that none of it was held by a 40-mesh screen, 14.7 per cent was held by a 60-mesh screen, and 63 per cent was held by a 100-mesh screen.

This degree of fineness was found very satisfactory for the laboratory work in that only a short time was required for the necessary reactions to take place. Some foaming resulted but no difficulty was experienced in keeping the charge inside the crucible.

Runs were also made with sand of the fineness usually used in glass-making (20.40 mesh), and very satisfactory results were obtained.

Course of a Run:

From 30 to 700 grams, depending on the size of the crucible used, were placed in the fire clay crucible hot from the previous run. The average temperature of the crucible and furnace at this time was about 1200°F. The crucible was filled about two-thirds full of charge.

The burner was then turned on and the temperature of the furnace rapidly increased. Fusion began in from 15 to 30 minutes.

During the first 20 or 30 minutes, arsenic sulphide escaped from the charge in considerable quantity. A glass tube inserted into the charge collected the arsenic sulphide as a yellow deposit on the inner wall of the tube. As the furnace became hotter, sulphur dioxide, resulting from the decomposition of the salt cake, was liberated from the charge.

The furnace reached a temperature of 2500°F. in from 30 minutes to an hour. The temperature was then gradually increased to around 2600°F., at which point it was maintained until the glass was poured.

At the end of from one to three hours, depending upon the weight of the charge, fining was found to be complete; the glass was reasonably free of bubbles, fusion was complete, transparency had developed, and the glass was uniform in texture. The glass was poured on a previously-heated piece of sheet steel and rolled with a hot iron pipe.

In most cases the glass was allowed to cool to a dull red in the air and was then quickly transferred to the electric annealing furnace, which had previously been heated to the desired annealing temperature.

Calculated Composition of the Glass:

An attempt to analyze the slag glass showed so much difficulty that it was believed more accurate results could be obtained by calculating the composition of the glass. The composition of a glass made from the mixture given on page 13, using Slag No. 1 and Sand No. 1, is as follows:

	Per cent by weight
SiO_2	65.26
CaO	20.30
Na_2O	7.94
Al_2O_3	5.24
Fe_2O_3	1.16
MgO	.10
Total	100.00

The theoretical yield from the dry mixture is 91.2 per cent, with 8.8 per cent of the charge passing off as gas. For the purpose of this calculation, it is assumed that there is no volatilization of the sodium. It is further assumed that the loss of sulphur is balanced by the arsenic remaining in the glass.

The substitution of a good grade of glass sand for the lower grade building sand gives considerable reduction of the iron content of the glass. The use of Sand No. 3 in the mixture given on page 13, for example, gives a glass having the following composition:

	Per cent by weight
SiO_2	66.27
CaO	20.04
Na_2O	7.95
Al_2O_3	4.99
Fe_2O_3	.65
MgO	.10
Total	100.00

Still further reduction of the iron content of the glass could be obtained, no doubt, by passing the slag through a magnetic separator, thus removing the iron present in the slag in the free condition.

Molecular Composition of the Glass:

Authorities on glass technology agree that there is a definite ratio in which the oxide should be present in the glass, if the product is to be stable and durable. Most authorities are agreed[6] (Hodkin and Cousen, "Textbook of Glass Technology, Van Nostrand Company, 1925, p. 59), that the ratio in which the oxides are present should approximate the "trisilicate" ratio in which the ratio of acids to bases is 3 to 1. While the molecular composition of common glasses varies considerably from this trisilicate ratio in some instances, most of them approach it very nearly.

Using the calculated composition given above as a basis, the transparent slag glass has a molecular ratio of $6S10_2$, 0, $7R_20$, 2 R0. The relative amount of basic oxides in somewhat higher than is demanded by the trisilicate ratio. However, the ratio of basic oxides to acid oxides compares rather favorably with the ratio of basic oxides to acid oxides employed in several batches for window glass and pressed glass, as reported by Hodkin and Cousen (see p. 101).

The ratio of RO molecules (i. e. CaO) to R_2O moecules (Na_2O) is somewhat higher for the transparent slag glass than the ratio ordinarily employed for soda lime glasses. This ratio was somewhat reduced on a semi plant scale. In the case of the black slag glass this ratio is closely comparable to many window and pressed glasses as reported by Hodkin and Cousens[6]. Incidently Hodkin and Cousen state that the presence of alumnia allows the replacement of a portion of the alkali by lime with consequent improvement in the glass. This may partly account for the beneficial effects of the slag.

DETERMINATION OF OPTIMUM OPERATING CONDITIONS:

Amount of Arsenic Trioxide:

The development of transparency in slag glass depends upon the removal of the sulphur of the slag. Glass made from slag from which the sulphur has not been removed is opaque. Further, the color of slag glass depends somewhat upon the state of oxidation of the iron present. Ferrous iron, for example, produces a dark green brown to brownish-yellow color in glass, depending upon the amount present, while ferric iron produces a green to light greenish yellow color, depending upon the quantity present in the glass.

The presence of sodium sulphate has some effect on the elimination of sulphur particularly on prolonged heating, the resulting glass being brown to dark green in color depending upon how much of the color was removed. As previously explained, however, it is considered advisable to add a definite amount of arsenic trioxide, which quickly and easily removes the sulphur and hence leads to an accurate control of the resulting color.

The amount of arsenic trioxide necessary to remove the sulphur and oxidize the iron was found to vary considerably. The amount of oxidizing agent necessary to oxidize the iron and keep it oxidized until it leaves the furnace, however, is dependent upon the amount of iron in the slag and sand and also upon the reducing action of the furnace gases. Ordinarily from 0.5 to 1.0 per cent trioxide is sufficient. With a high grade sand, the quantity required should be near the minimum, and in some cases may be as low as 0.3 per cent.

Temperature of Heating:

A temperature of 2500°F. to 2600°F. was found to be most satisfactory for the laboratory work. Lower temperatures failed to bring about complete fusion and fining of the glass, while higher temperatures tended to cause corrosion of the crucible and furnace walls. Glass made at a temperature of 2500°F. to 2600°F. was of uniform texture and was practically free of bubbles or "seed".

Time of Heating:

The time necessary for the proper reactions to take place and for the removal of bubbles and fining of the glass at the temperature given above was from one to three hours, depending upon the weight of the charge. A much longer time would be required, of course, for large-scale work.

Rate of Heating:

The rate of heating used in the laboratory work was very rapid. Some runs were made using a slow rate of heating, but no advantages were evident with the slower rate.

ANNEALING:

Determination of Upper Annealing Temperatures:

The upper annealing temperature (the temperature above which there is danger of loss of shape) of the glass was determined by supporting sheets of glass 2.5 inches long and one-eighth of an inch thick on fire clay supports set two inches apart in an electric furnace. The temperature of the furnace was then slowly raised until the glass began to sag. This temperature, 1200°F., was determined by means of a calibrated base-metal thermo-couple and was recorded as the upper annealing temperature of the glass.

Selection of a Suitable Annealing Temperature:

It was believed that a temperature 100°F. below the upper annealing temperature would avoid danger of loss of shape and of devitrification, hence at temperature of 1100°F. was selected as the proper annealing temperature.

Pieces of glass several inches long, two inches wide, and from 1/8 to 1/4 of an inch thick were shown by a polarizing microscope to be well annealed after being held at 1100°F. for ten minutes and then slowly cooled to room temperature. Larger pieces would require a longer time for annealing.

Rate of Cooling:

The rate of cooling the glass after it has been annealed should be as rapid as possible without causing strains to be set up in the glass. The rate at which the glass could be cooled would depend upon the size of the piece annealed, heavy, thick pieces requiring slower cooling than smaller pieces.

METHODS AND RESULTS OF TESTING THE GLASS:

Luster:

Slag glass possesses a much higher gloss or luster than does ordinary glass such as is used for bottles, windows, some tableware, etc.

Hardness:

The slag glass has a hardness of from 6 to 6.5 on Moh's scale of hardness. Window glass is given a hardness of 5.5 in Kraus and Hunt's Mineralogy.

Specific Gravity:

The average specific gravity of a number of the samples was found to be 2.600.

Tensile Strength:

The apparatus available for determining the tensile strength of the glass made it necessary to use only small threads of the glass for the tests. The diameters of these threads were very carefully determined by means of a micrometer and the tensile strength of the threads was carefully measured by means of a thread-breaking machine of the type used in testing textiles. It is not believed that the high conversion factor resulting from the small diameter of the threads led to any considerable error.

The results of tests made to determine the tensile strength of the transparent slag glass are given below in Table II.

TABLE II

Tensile Strength of Transparent Slag Glass

Pounds per square inch, as determined on rods of 0.025 to 0.035-inch diameter		
Sample No.	Glass from Slag No. 1	Glass from Slag No. 2
1	10,815	21,875
2	14,726	19,270
3	7,897	8,000
4	23,331	19,875
5	11,679	9,365
6	18,887	
7	19,375	
Average	15,257	15,677

The tensile strength of a number of samples of laboratory glass rods determined with exactly the same apparatus, was from 10,000 to 12,000 pounds per square inch.

It is believed that the impurities such as iron, aluminum, titanium, etc., are responsible for the high tensile strength. The unusual toughness of the glass was noticed long before the tensile strength was determined.

Crushing Strength:

Considerable difficulty was encountered in determining the crushing strength of the glass with the apparatus available. The crushing strength, as determined by crushing small pieces of the glass in a small hydraulic press, varied from 50,000 pounds per square inch to 143,000 pounds per square inch with different samples.

Resistance of the Glass to Breakage on Impact:

A simple test devised to determine the resistance of the glass to breakage on impact showed the slag glass to offer exceptional resistance to such breakage.

A steel ball weighing 5.45 grams was allowed to fall vertically on 1-inch squares of the glass. The test was applied to samples of common glasses as well as to the slag glass. A great number of these tests were made on each type of glass. The results of the tests are summarized in Table III.

TABLE III

Comparative Resistance of Transparent Slag Glass and Commercial Glasses to Breakage on Impact.

Sample	Fall of Ball	Percentage of Samples Breaking
Double-Strength Window Glass, 1/8" thick	2 ft.	73.
Plate Glass 3/16" thick	2 ft.	60
Transparent Slag Glass 3/16" thick	2 ft.	None
Transparent Slag Glass 3/16" thick	4 ft.	None
Transparent Slag Glass 3/16" thick	6 ft.	50.

Note: It is apparent from these tests that the percentage breakage of the slag glass is lower at 6 feet than the plate glass is at 2 feet. A considerable number of the slag glass samples resist breakage at 7 or even 8 feet.

Linear Coefficient of Expansion:

The linear coefficient of expansion of the transparent slag glass made from Slag No. 1 and Sand No. 1, determined in the usual way with rods about 787 millimeters long and a temperature increase of about 68°C., was found to be 0.0000081.

According to Hodkin and Cousen, soda-lime glasses have a linear coefficient of expansion varying from 0.000011 to 0.000008, while laboratory glasses vary from 0.0000055 to 0.0000075.

Thermal Endurance:

The ability of a glass to withstand sudden changes in temperature without breaking is known as its thermal endurance. This property depends upon several physical properties of the glass, the most important of which are (1) thermal conductivity, (2) thermal expansion, and (3) tensile and crushing strength.

A high thermal conductivity, a low coefficient of expansion, and a high tensile and crushing strength favor a high thermal endurance.

The slag glass has a high tensile strength and a relatively low coefficient of expansion, both properties implying a high thermal endurance. The thermal conductivity was not determined, because of lack of equipment. The composition of the slag glass, however, indicates that its thermal conductivity should be high. It follows that a high thermal endurance is to be expected of the slag glass.

Tests made in the laboratory by subjecting samples of slag glass and commercial glasses (bottle and window) of comparable size and thickness, to sudden temperature change (heated to 100°C. and quenched in water at 15°C.) gave the following results:

	Per cent Cracked
Commercial Glasses—Av. of 6 tests	33.3
Slag Glasses—Av. of 12 tests	16.6

Resistance to Corrosion:

The resistance of a glass to corrosion is usually determined by studying the action of boiling water, boiling hydrochloric acid, and boiling alkali upon it. Hodkin and Cousen (Textbook of Glass Technology Van Nostrand Company, 1925, p. 56) discuss the effect of these reagents upon several glasses.

A number of samples of the slag glass made from Slag No. 1 and Sand No. 1 were subjected to treatment with these reagents. For the sake of comparison, the results of the tests on the slag glass are given in Table IV, beside data given by Hodkin and Cousen for two grades of chemical glass.

TABLE IV

Resistance of Slag Glass to Corrosion

Reported as loss in weight in milligrams per square decimeter			
	Chemical Glass A	Chemical Glass B	Slag Glass
Water test:			
300 cc. of distilled water boiled to 100 cc. in 2 hours	0.6	6.2	none
Alkali tests			
(1) 2N caustic soda at 100°C. for 3 hours	283.8	364.0	6.5
(2) N/10 caustic soda at 100°C. for 3 hours	61.8	111.3	0.8
Hydrochloric acid test:			
250 cc. constant-boiling acid evaporated to 100 cc. in 1.5 hours	8.3	5.4	0.5

SUMMARY OF THE PROPERTIES OF THE TRANSPARENT SLAG GLASS

The transparent slag glass is characterized by a high luster, almost colorless to dark green color, a high tensile strength, a relatively low coefficient of expansion, a good thermal endurance, an excellent resistance to breakage by impact, and a remarkable resistance to corrosion by boiling water, hot sodium hydroxide and boiling hydrochloric acid. The glass is much superior to ordinary soda lime glass with respect to its tensile strength, resistance to breakage by impact, toughness, thermal endurance and resistance to corrosive agents.

As for the working properties of the transparent slag glass, the preliminary indications in the laboratory were to the effect that these properties were satisfactory. Runs made later on a semi-plant scale, however, indicated that the glass is better suited to rolling and pressing than to blowing.

Note: The discussion given above concerning the laboratory preparation of transparent slag glass is based largely upon "A Transparent Aluminum Glass from Blast Furnace Slag", C. A. Basore, Engineering Experiment Bulletin No. 3, Alabama Polytechnic Institute. The general outline and most of the material given above has been adopted from this bulletin.

BLACK GLASS

Apparatus:

The apparatus used for making the black slag glass was identical to that used for making the transparent glass. A description of this apparatus is given on page 11.

RAW MATERIALS AND GENERAL PROCEDURE:

Analysis of Raw Materials:

Analyses of the various raw materials used in the laboratory production of black glass are given in Table V below.

TABLE V

Analysis of Raw Materials for Black Glass

	Results reported as per cent by weight		
	Granulated Slag	Ungranulated Slag	Sand
SiO_2	37.55	37.45	96.96
Fe_2O_3	1.41	3.57	.86
Al_2O_3	11.38	11.18	.79
TiO_2		.47	
CaO	46.27	45.47	.37
MgO	.23		.19
S	1.23	1.01	
Na_2O and K_2O			.52
Undetermined	1.93	.85	.31
Total	100.00	100.00	100.00

The soda ash employed contained 58.5 per cent Na_2O.

The calcined saltcake used was supplied by the Grasseli Chemical Company, Birmingham, Alabama, and contained 97.01 per cent sodium sulphate, 1.56 per cent sulphuric acid, and 1.07 per cent sodium chloride. This saltcake was of the grade ordinarily used for glass manufacture.

The slag used was the same as that used in the laboratory work on the transparent slag glass and was supplied by the Woodward Iron Company, Birmingham.

The sand was from the Montgomery plant of the Roquemore Sand and Gravel Company. This sand was a washed building sand.

COMPOSITION OF THE CHARGE

Removal of Scum and Stabilization of Sodium Sulphide in Glass:

In order to secure a mixture of the desired composition, sand was added to the slag. A good grade of building sand was found to be entirely satisfactory for this purpose. Addition of soda ash appreciably lowered the melting point of the mixture and materially improved the working properties of the glass.

A mixture consisting of 30 parts of slag, 40 parts of sand, and 21 parts of soda ash gave a glass that appeared to have sufficient fluidity and satisfactory working properties. Considerable scum, however, was formed with this mixture.

Sodium sulphate is generally used in glass practice to prevent the formation of scum consisting of finely divided particles of uncombined silica. Sodium sulphate does not react with the silica until a high temperature is reached and thus it serves to take into combination the fine particles of sand which have escaped attack by the soda ash and have been carried to the surface of the melt by the escaping gases. Sodium sulphate, then, was added to the charge in the form of calcined saltcake as a scum remover.

The decomposition of sodium sulphate creates an oxidizing atmosphere within the melt. Unless some reducing agent is added to the charge to counteract the oxidizing effect of the sodium sulphate, part of the sulphur of the slag is oxidized and escapes with the flue gases. As stated above, the sulphur of the slag must be held in the glass as sodium sulphide (Na_2S) if the glass is to be black. Carbon in the form of coke was added to the charge and was found to counteract the action of the decomposing sodium sulphate on the sulphur of the slag.

The composition of the mixture found to be satisfactory in the laboratory was as follows:

	Per cent by weight dry basis
Slag	32.5
Sand	44.2
Soda ash	13.6
Salt cake	8.8
Coke	1.1
Total	100.0

The mixture given above yielded a jet-black glass of very high luster that was free of scum. The glass poured and worked well, remaining soft for some time. Since the product was intended primarily for pressed ware, no lengthy working range was considered essential.

Note: It was found later, while producing the glass on a semi-plant scale, that a more satisfactory product with better working properties was obtained by slightly increasing the alkali content of the batch over that given above.

Fineness of the Charge:

The sand was screened so that it all passed a 20-mesh screen and was all held by a 40-mesh screen.

In the runs in which solidified slag was used and no effort was made to use the waste heat of the slag as it comes from the blast furnace, granulated, slag ground in a Broun Pulverizer was used. It should be mentioned in this connection that granulated slag may be used in the charge without any grinding.

Course of a Run:

A convenient quantity of the mixture (100 to 750 grams) was placed in a fire clay crucible in the furnace. The temperature of the furnace was rapidly increased, reaching 2600°F. in from 40 to 60 minutes. The temperature was then slowly raised to around 2650°F. and held at this point until the glass was poured.

At the end of 2 to 3.5 hours, depending upon the weight of the charge, the glass was thoroughly fused, combination of the silica with the alkali was complete, and the glass was uniform in texture and was reasonably free of bubbles. The glass was either poured onto a steel plate and rolled with an iron pipe or was poured into a small iron mold and molded into a disk, cooled to a dull red, and placed in the annealing furnace.

Calculated Composition of the Glass:

The composition of the black glass, as calculated from the composition of the mixture given on page 21, is as follows:

	Per cent by weight
SiO_2	63.01
CaO	17.32
Na_2O	12.81
Al_2O_3	4.61
Na_2S	1.11
Fe_2O_3	.96
MgO	.18
Total	100.00

The theoretical yield is 87.3 per cent, with 12.7 per cent of the mixture passing off as gas. The calculation is made on the basis of granulated slag. It is assumed that there is no volatilization of the sodium and that all of the sulphur of the slag remains in the glass.

Molecular Composition of the Glass:

Calculated on the basis of the chemical composition given above, the molecular ratio for the black glass is $6SiO_2$, $1.2R_2O$, $1.8RO$, $0.3R_2O_3$. A general discussion of molecular ratio is given on page 15 of this report.

DETERMINATION OF OPTIMUM OPERATING CONDITIONS:

Temperature:

With the mixture given on page 22, it was found that a temperature of 2500°F. or less was too low to bring about complete attack of the silica by the alkali.

A temperature of 2600°F. to 2700°F., on the other hand, was found to be satisfactory. Glass made at this temperature was free of scum and bubbles. A temperature of 2600°F. to 2700°F., then, was adopted for the remainder of the laboratory work.

Note: It was found in the semi-plant work that it was advisable to increase the alkali content of the glass somewhat, thus lowering the temperature necessary for its fusion.

Time of Heating:

The time of heating found satisfactory for the laboratory work varied from 2 to 3.5 hours, depending upon the weight of the charge.

Rate of Heating:

The rate of heating used for the laboratory work was very rapid, being limited only by the capacity of the furnace used. Runs made at a slower rate showed no advantage over runs made at the rapid rate, so the rapid rate of heating was adopted for the laboratory work.

ANNEALING:

Determination of Upper Annealing Point:

The upper annealing point of the black glass was determined in exactly the same manner as was the upper annealing temperature for the transparent glass. This point was found to be 1250°F. for the black glass.

Selection of a Suitable Annealing Temperature:

A point 100° F. below the upper annealing temperature proved to be satisfactory for annealing the transparent glass. The glass had no tendency to lose its shape at this temperature.

Since the composition of the black glass did not differ greatly from that of the transparent glass, a similar procedure was adopted for the annealing of the black glass. A temperature 100°F. below the upper annealing temperature of 1250°F., or 1150°F., was adopted for annealing the black glass.

The time required for proper annealing of the glass depends, of course, upon the size of the piece to be annealed. With pieces ⅛ to ¼ inch thick, ten minutes apparently is sufficient time for the relief of internal strains in the glass.

Since strained or unannealed glass has the property of rotating a plane of polarized light, the polarizing microscope or a variation of it is usually used for determining whether or not glass is free of strain. The opaque character of the black glass, however, did not permit the use of such a method and apparatus was not at hand for the development of an alternative method. Simple tests and observations coupled with the experience gained in previous work on the transparent glass had to be relied upon for determining when the glass was free of strain.

Rate of Cooling:

As with the transparent glass, the rate of cooling the glass after it has been annealed is dependent upon the thickness or size of the piece that has been annealed.

METHODS AND RESULTS OF TESTING THE GLASS:

Luster:

The black glass made from blast furnace slag possessed an unusually high luster. Smooth surfaces of the glass were almost mirror-like in appearance.

Hardness:

The hardness of the black glass on Moh's scale was found to be 5.5 to 6.0.

Specific Gravity:

The black glass was found to have a specific gravity of 2.608.

Tensile Strength:

The tensile strength of the black slag glass was determined in the same manner as was that of the transparent glass.

The results of the tests to determine the tensile strength of the black glass are given below in Table VI.

TABLE VI

Tensile Strength of Black Slag Glass

Sample	Tensile Strength lbs. per sq. in.	Sample	Tensile Strength lbs. per sq. in.
1.	14,327	9.	20,430
2.	22,000	10.	25,600
3.	25,510	11.	18,135
4.	16,840	12.	22,010
5.	15,350	13.	14,140
6.	15,820	14.	18,665
7.	19,490	15.	17,120
8.	11,251		

Average Tensile Strength — 18,500 lbs. per sq. in.

Resistance of the Black Glass to Breakage on Impact:

The same test used for determining the resistance of the transparent glass to breakage on impact was applied to the black glass. For the sake of comparison, the results obtained by testing the black glass are tabulated below in Table VII beside results obtained by applying the same test to several samples of other glasses.

TABLE VII

Resistance of Black Slag Glass to Breakage on Impact

Sample	Fall of Ball	Percentage of Samples Breaking
Double-strength window glass, 1/8 in. thick	2 ft.	73
Plate Glass, 3/16 in. thick	2 ft.	60
Transparent slag glass, 1/8 to 3/16 in. thick	2 ft.	None
Black slag glass, 1/8 to 3/16 in. thick	2 ft.	None
Transparent slag glass, 1/8 to 3/16 in. thick	3 ft.	None
Black Slag Glass, 1/8 to 3/16 in. thick	3 ft.	None
Transparent slag glass, 1/8 to 3/16 in. thick	4 ft.	None
Black slag glass, 1/8 to 3/16 in. thick	6 ft.	43

Crushing Strength:

Considerable difficulty was experienced in determining the crushing strength of the glass with the equipment at hand. A number of tests were made to determine this value, however, and the values obtained with the various samples are given below in Table VIII. These values are believed to be low, but roughly approximate the correct value.

TABLE VIII

Crushing Strength of Black Slag Glass

Cross-Sectional Area of Sample	Pounds Pressure Employed	Crushing Strength (lbs. per sq. in.)
0.063 sq. inches	3,750	60,000
0.250	15,600	62,400
0.200	8,700	43,500
0.070	3,400	48,600
0.025	2,500	100,000

Linear Coefficient of Expansion:

The coefficient of linear expansion of the glass was determined in the usual way, using rods of glass about 30 inches long and temperature changes of 60°C. to 90°C., and was found to be 0.00001757. This figure is believed to be high.

Resistance to Corrosion:

The resistance of the glass to corrosion was determined by measuring the loss in weight per unit surface area when the glass was subjected to the action of (1) boiling water, (2) hot caustic soda, and (3) boiling hydrochloric acid.

The results obtained with the black slag glass are given below beside values given by Hodkin and Cousen for two grades of chemical glass in Table IX.

TABLE IX

Resistance of Black Slag Glass to Corrosion

Reported as loss in weight in milligrams per square decimeter

	Chemical Glass A	Chemical Glass B	Slag Glass
Water test:			
300 cc. of distilled water boiled to 100 cc. in 2 hours	0.6	6.2	2.4
Alkali Test:			
2N caustic soda at 100°C for 3 hours	283.8	364.0	48.2
Acid Test:			
250 cc. constant-boiling hydrochloric acid evap. to 100 cc. in 1.5 hours	8.3	5.4	9.4

Summary of the Properties of the Black Slag Glass:

The results of the tests outlined above indicate that the black glass has a jet-black color, a very high luster, a high tensile strength, a fairly high coefficient of expansion, and excellent resistance to breakage on impact and to corrosion by water, acid and alkali. The resistance to breakage by impact is better at a height of six feet than window glass is at two feet.

NOTE: The results obtained in making the black glass on a semi-plant scale indicate that the alkili should be increased over the amount used in the laboratory. Such an increase in the alkali would tend to cause some variation in the properties of the glass from the values given above, but it is doubtful that a small increase in the alkali content would cause much variation from the values obtained by testing the glass made in the laboratory.

A CHEAP CHEMICAL GLASS

Certain experiences encountered in the work on the transparent slag glass led to the belief that a cheap chemical glass would be prepared from this material. An effort was made, therefore, to produce from blast furnace slag a glass having sufficient thermal endurance to be used as one of the cheaper grades of laboratory ware, cooking ware, etc.

It was found that the use of a batch based upon the mixture used for the transparent aluminum glass, with boron trioxide added in the form of borax, gave a glass that compared well with the cheaper grades of chemical glass now on the market. The batch finally adopted had the following composition:

Slag	31.1 per cent
Sand	38.3
Salt cake	9.4
Arsenic trioxide	0.8
Borax	17.7
Magnesia	2.7
Total	100.0

The slag used in this mixture was the granulated Slag No. 1 given in Table I.

Since it was desired to keep the iron content of the glass as low as possible, Sand No. 3 (Table I) from the Mohawk Sand Deposit was used.

The salt cake was the calcined grade ordinarily used for glass manufacture. The borax was the ordinary commercial grade ($Na_2B_4O_7$. 10 H_2O). The magnesia (Mg0) was calcined.

The borax was used both to lower the melting point and improve the properties from the working standpoint and to supply boron trioxide for improving the thermal endurance of the product.

A small amount of Mg0 was added to this mix in the form of Magnesite.

Assuming that there was no volatilization of sodium from the melting batch, the glass from the mixture given above had the following composition (calculated):

SiO_2	59.73	Al_2O_3	4.30
CaO	17.25	Fe_2O_3	0.56
Na_2O	8.36	MgO	3.24
B_2O_3	6.56		
		Total	100.00

A temperature of 2500°F. to 2600°F. was found satisfactory for melting and fining the glass in the laboratory.

The resulting glass had a linear coefficient of expansion of 0.0000055. Hodkin and Cousen ("Textbook of Glass Technology", Van Nostrand Company, 1925, p. 26) state that the thermal coefficient of expansion for ordinary laboratory glassware varies from 0.0000055 to 0.0000075, while Pyrex glass has a coefficient of expansion of 0.0000032 (19°C. to 350°C.)

The glass showed good thermal, mechanical, and chemical endurance and was pale green in color.

The cost of raw materials for the slag mixture given above should be considerably below that of the mixture ordinarily used for the production of chemical glasses, while the product from the slag mixture is decidedly superior in several respects to the lower grades of chemical glass.

OPAL GLASS

It was found that an opal glass could be produced from blast furnace slag by the addition of the mineral Apatite or of tricalcium phosphate to the batch, indicating that an opal glass can be prepared from slag at a low cost of raw materials.

The mixture found satisfactory in the laboratory had the following composition:

	Per cent by weight
Slag	30.7
Sand	35.8
Salt cake	10.7
Soda ash	9.0
Apatite	12.8
Arsenic trioxide	1.0
Total	100.0

This mixture, when fused and fined in the glass furnace at a temperature of 2400°F. to 2500°F., gave a glass that was transparent and was pale green in color.

Opalescence was developed in the glass by carefully reheating the product to 1500°F. or 1600°F. after it had been removed from the glass furnace and had been allowed to cool somewhat. Proper temperature control during the reheating proved very important.

The finished product was very striking in appearance, being opalescent and having a banded appearance. The opalescence was attributed to precipitated decomposition products of the apatite (or of the phosphate).

PRODUCTION OF THE GLASS ON A SEMI-PLANT SCALE

Transparent Aluminum Glass

As already mentioned, a number of runs of the transparent glass were made on a scale much larger than that used in the laboratory. These runs were made in the plant of the L. J. Houze Convex Glass Company, Point Marion, Pennsylvania. A discussion of these semi-plant runs is given below.

Apparatus:

The apparatus used for the semi-plant work consisted of a small pot furnace having a capacity of around 100 pounds of charge.

The apparatus available was not entirely satisfactory, for it was only with difficulty that a temperature as high as 2500°F. could be obtained. In fact, the maximum temperature obtained during the course of some of the runs was less than 2400°F. The temperatures were obtained by means of a calibrated optical pyrometer.

In some cases the glass was poured on a previously heated piece of steel and rolled, as in the laboratory work. In other cases the glass was pressed. Several attempts were also made to blow the glass.

Satisfactory annealing equipment was available at the plant for annealing the slag glass.

The Batch:

Since the temperature available, with the apparatus at hand for the larger-scale work was considerably lower than that obtainable with the laboratory equipment, the melting point of the first run was reduced by the addition of borax to the batch. The resulting mixture had the following composition:

	Per cent by weight
Slag	38.4
Sand	43.8
Soda ash	9.7
Salt cake	4.5
Arsenic trioxide	1.0
Borax	2.6
Total	100.0

This mixture fused readily and gave a product that flowed freely, pressed well, rolled well, and was free of "seed".

In view of the results obtained with the borax-containing mixture, it was believed that a satisfactory product could be obtained with the mixture used for the laboratory work. A batch was prepared, therefore, having approximately the same composition as the mixture used in the laboratory work, except that the arsenic trioxide was reduced. This mixture had the following percentage composition by weight:

Slag	39.6
Sand	46.1
Soda ash	8.9
Salt cake	4.9
Arsenic trioxide	0.5
Total	100.00

This mixture gave a product that was pale greenish-yellow in color, was practically free of bubbles, and contained no scum. The glass worked well so far as rolling and pressing were concerned, but was not satisfactory for blowing.

The slag employed in the mixture was a representative sample from blast furnaces operated by the Carnegie Steel Co., Pittsburgh, Pa. An analysis of this slag is almost identical to the granulated slag used in the laboratory work. The sand was washed and was comparable to the sand used in the laboratory work. The soda ash, salt cake, and arsenic trioxide were of the grade ordinarily used in glass practice.

Course of a Run:

From 30 to 50 pounds of batch were placed in the pot, the gas turned on, and the furnace allowed to increase in temperature as rapidly as it would. The limited temperature available with the furnace made this rate of temperature increase rather slow. About twelve hours were required for the proper fusing and fining of the glass.

The glass was removed from the furnace at the completion of the melting process and was pressed or rolled into plates. In some instances, attempts were made to blow the product.

The glass was placed in the annealing furnace and annealed at 1100°F. It was noted in this connection that the glass must be transferred to the annealing furnace by the time the last, dull red color is leaving the cooling product if cracking is to be prevented.

Properties of the Product:

The glass made as explained apparently was of good quality and was similar to that made in the laboratory.

BLACK GLASS

As was the case with the transparent glass, several runs of the black glass were made on a semi-plant scale in the plant of The L. J. Houze Convex Glass Company.

The apparatus and equipment used was the same as that used for the transparent glass.

The Batch:

The slag, sand, soda ash, and salt cake used for the production of black slag glass on a semi-plant scale were the same as were used for the transparent glass.

Black glass produced on a semi-plant scale from the mixture used for the laboratory work could not be properly fused and fined at the temperature available with the equipment on hand for this work. The batch which gave good results in the laboratory at temperatures a little above 2600°F. produced a product that was stiff and contained many bubbles at the lower temperature, 2400°F., available with the semi-plant equipment.

In order to reduce the temperature necessary for melting the product, the alkali in the batch was increased by the addition of 1.5 pounds of soda ash to 30 pounds of the mixture used for the laboratory work. The resulting batch had the following composition:

	Per cent by weight dry basis
Slag	30.8
Sand	42.1
Soda ash	17.7
Salt cake	8.4
Coke	1.0
Total	100.0

This mixture fused readily at the temperature of the furnace and gave a product that was practically free of bubbles. The glass from this mixture was easily pressed or rolled, but could be blown only with difficulty.

Course of a Run:

The course of a run of the black slag glass was practically the same as that given for a run of the transparent glass.

From 30 to 50 pounds of batch were charged into the furnace and heated for about twelve hours, at the end of which time the molten glass was pressed or rolled, transferred to the lehr, and annealed at a temperature of 1100°F.

Composition of the Glass:

The mixture given above, would yield a glass of the following composition:

	Per cent by weight
SiO_2	61.04
CaO	16.77
Na_2O	15.53
Al_2O_3	4.47
Na_2S	1.08
Fe_2O_3	0.93
MgO	0.18
Total	100.00

It is assumed for the calculation of the composition of the glass that there is no volatilization of the sodium and that all of the sulphur of the slag remains in the glass as sodium sulphide.

Properties of the Glass:

The increase in the sodium oxide content of the glass indicated above, would of course, make some slight changes in the properties of the glass. Preliminary tests indicated that the glass was practically identical to that made in the laboratory.

Summary and Conclusions—Semi-Plant Work:

The semi-plant work indicated that both a transparent glass and a black glass could be made readily under conditions strictly comparable to the manufacture of commercial glasses. The effect of variations in the process has been studied and an effort made to determine the optimum conditions.

Results obtained in the semi-plant work as well as in the laboratory work, indicated that the composition of the batch may be varied considerably to meet the particular requirements of a given plant.

The glasses in appearance and color were identical with those made in the laboratory. Preliminary tests indicated that the physical properties of these glasses were similar to those made in the laboratory.

PROPOSED PLAN FOR THE PRODUCTION OF THE GLASS ON A COMMERCIAL SCALE:

An investigation has been made to determine the proper general lay-out and approximate initial cost of a small plant for making the slag glass. As a result of this investigation, tentative plans for the general lay-out and estimates of the initial cost of equipment and buildings have been obtained for two types of small plants; (1) a 45-ton continuous-tank plant, and (2) a 8-ton day-tank plant. The two types of plants are discussed below.

CONTINUOUS-TANK PLANT:

Proposed Lay-Out and Equipment:

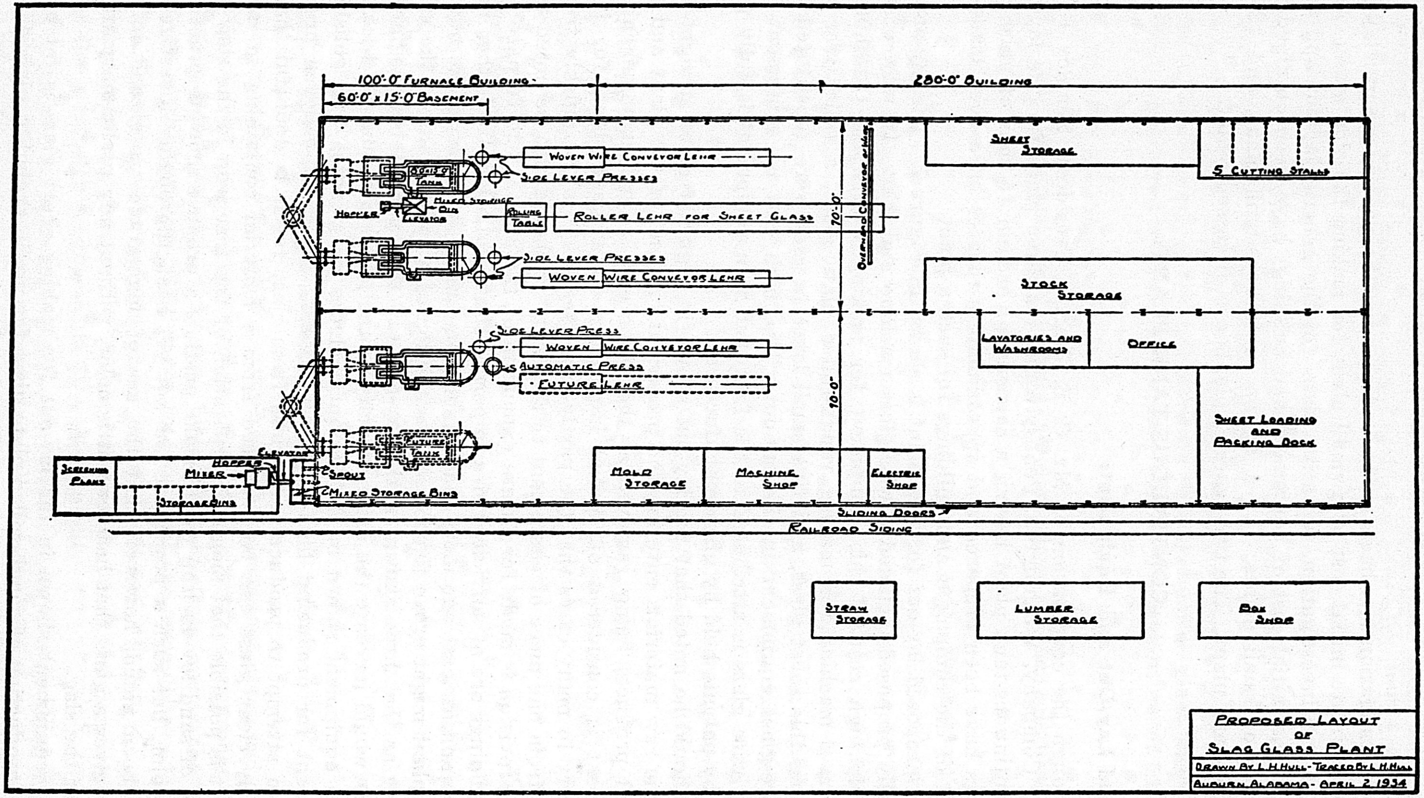
Through the cooperation of Mr. C. E. Frazier, President, Simplex Engineering Company, Washington, Pennsylvania, tentative plans for the lay-out of a continuous-tank plant having a capacity of around 45 tons of glass per 24 hours have been prepared and approximate estimates have been made of the cost of the equipment and buildings for such a plant.

The proposed lay-out for this plant is shown in Figure I. The lay-out as originally proposed included a wire-glass machine and lehr. In view of the relatively high cost of this equipment for making wire glass ($100,000), however, a machine for making rough-rolled plate glass, a roller lehr for annealing this sheet glass, and five small lever presses were substituted for the wire-glass equipment in the lay-out. The high cost of equipment for making wire glass is attributed to the fact that such equipment is fully protected by patents held by glass manufacturers.

It should be noted that the lay-out shown in Figure I gives straight-line flow, the raw materials entering the process at one end of the plant and the finished products being removed at the other end. Such arrangement of equipment is considered of special importance in a glass plant, for it is necessary in many cases that the partly-processed material be quickly transferred from one piece of equipment to the next. It should also be noted that ample provision is made for future expansion of the plant. The furnace and lehr buildings are of sufficient size to permit the installation of another tank furnace and at least one more lehr at such time as an increase in the output of the plant might prove feasible. The addition of a fourth tank of the same capacity as the three shown in the lay-out (15 tons per 24 hours approximately) would increase the daily capacity of the plant to around 60 tons.

The equipment shown in the lay-out includes no grinding and polishing equipment for producing high-grade plate glass. It is not believed practicable to attempt to produce such glass from slag, for it is doubtful that a perfectly clear glass can be produced from a material containing so much iron. It is possible that magnetic separation of the free iron in the slag and the use of sand low in iron would make possible a product showing practically no color, but such a procedure has not yet been thoroughly investigated. It has been noted, however, that the use of high-grade glass sand in the charge gives a glass that has very little color, without any preliminary treatment of the slag.

The equipment shown in the lay-out for making sheet glass is intended for the production of rough-rolled plate glass for use in skylights, glass doors, etc. The slag glass has a natural high luster that is not dimmed by rolling.



100'-0" Furnace Building
60'-0" x 15'-0" Basement
280'-0" Building
Woven Wire Conveyor Lehr
Side Lever Presses
Tank
Mixed Storage Bin
Hopper
Elevator
Rolling Table
Roller Lehr for Sheet Glass
70'-0"
Overhead Conveyor
Side Lever Presses
Woven Wire Conveyor Lehr
Sheet Storage
5 Cutting Stalls
Stock Storage
Lavatories and Washrooms
Office
Side Lever Press
Woven Wire Conveyor Lehr
Automatic Press
Future Lehr
70'-0"
Sheet Loading and Packing Dock
Future Tank
Elevator
Hopper
Screening Plant
Mixer
Storage Bins
Spout
Mixed Storage Bins
Mold Storage
Machine Shop
Electric Shop
Sliding Doors
Railroad Siding
Straw Storage
Lumber Storage
Box Shop
Proposed Layout of Slag Glass Plant
Drawn By L. H. Hull - Traced By L. H. Hull
Auburn, Alabama - April 2, 1934

Figure I

Since the slag glass is much more suited to rolling and pressing than to blowing, no glass-blowing equipment is included in the lay-out.

The plant shown in Figure I is intended for the production of rough-rolled plate glass and pressed ware. Ample pressing equipment is included in the lay-out for the production of a wide variety of pressed articles, such as table-ware, ash trays, glass tile, photographic trays, vases, ornamental pieces, etc.

The three tanks shown in the lay-out make possible the production of three glasses. It is doubtful that a batch producing glass suitable for rolling would be entirely satisfactory for the production of glass for pressing. It follows that one furnace should probably be used for the production of transparent glass for rolling, a second furnace for the production of transparent glass for pressing, and the third furnace for the production of black glass for pressing. The glass produced in the furnace should be determined by the demands of the market. Adjustment of the composition of the batch to produce a product with the desired rolling or pressing qualities should be a simple matter.

It is not believed that the number of furnaces should be less than three for a plant of 45-ton capacity. The substitution of one or two larger furnaces for the three 15-ton furnaces shown in the lay-out would sacrifice flexibility of operation. The flexibility of operation possible with a continuous tank furnace is limited, at best.

The estimates of the cost of the various equipment and buildings and the basis upon which each estimate is made are as follows:

Cost of Equipment:

3	15-ton Continuous Tanks; including stacks, pyrometer equipment, tank-cooling facilities, fuel piping, ladle tracks, batch storage bins, and facilities for feeding batch to tanks (Estimate of Simplex Company)	$ 75,000
3	Conveyor Lehrs for pressed ware and other articles (Estimate of Simplex Company)	$ 30,000
1	Rolling Machine (Estimate of writers, based upon estimate of Amsler-Morton Company for similar machine for smaller plant)	$ 9,000 to $ 12,000
1	Roller Lehr for sheet glass (Estimate of writers, based upon estimate of Amsler-Morton Company for similar machine for smaller plant)	$ 26,000 to $ 30,000
	Batch Mixing Plant and Raw Materials Storage (Estimate of Simplex Company)	$ 30,000
1	Press (Estimate of Simplex Company)	$ 7,500
5	Small Lever Presses (Estimate of Amsler-Morton Company)	$ 12,500
	Molds (Estimate of Simplex Company)	$ 5,000 to $ 15,000
	Machine Shop Equipment for repair work only (Estimate of Simplex Company)	$ 10,000
	Other Shop Equipment, including Carton-Gluing Machine (Estimate of Simplex Company)	$ 10,000

Cutting Tables (Estimate of Simplex Company)	$ 1,500
Air Compressors, Mold-Cooling Fans, and other equipment (Estimate of Simplex Company)	$ 25,000
Railroad Sidings, Sewerage, Electric Wiring for yard, Fence, Time Office, Watchman Quarters, and incidentals (Estimate of Simplex Company)	$ 25,000 to $ 35,000
Total, Equipment	$266,500 to $293,500

Cost of Buildings:

The estimates given below for the cost of the buildings for the 45-ton plant are those supplied by the Simplex Engineering Company.

The furnace building proper is really a one-story steel building with basement. The cost of this building with a reinforced concrete floor designed to support a live load of 250 pounds per square foot is estimated to cost $5.00 per square foot of area. This estimate includes 18 gauge standard galvanized roofing, 22 gauge galvanized steel siding, the necessary steel sash, doors, hardware, downspouts, etc., in fact a complete building, including foundations.

The balance of the buildings, that is, the lehr building, raw materials storage, box shop, etc., are estimated to cost $2.00 per square foot of area. This estimate includes foundations, reinforced concrete floor, 18 gauge galvanized steel roofing, 22 gauge galvanized steel siding, steel sash, doors, etc.

The approximate cost, then, of all the buildings would be as follows:

100 ft. by 140 ft. Furnace Building	$70,000
280 ft. by 140 ft. Lehr Building	$78,400
Additional amount for Storage Racks, Cutting Stalls, Offices, Mold Storage, Machine Shop, and Electric Shop	$10,000
Additional amount for Lavatories and Washroom	$ 1,300
80 ft. by 20 ft. Building for Screening Plant, Raw Materials Storage, etc.	$ 3,200
30 ft. by 20 ft. Building for Straw Storage	$ 1,200
60 ft. by 20 ft. Building for Lumber Storage	$ 2,400
60 ft. by 20 ft. Box Shop	$ 2,400
Total, Buildings	$168,900
Total, Buildings and Equipment, Erected	$435,400 to $462,400

Operating Requirements:

According to the Simplex Engineering Company, the continuous tank furnaces shown in the layout require from 8,000,000 to 12,000,000 B.t.u. to melt and fine each ton of glass, depending on the composition of the batch. It is believed that around 10,000,000 B.t.u. should be required to melt and fine one ton of slag glass in these furnaces. If natural gas having a heating value of 1,000 B.t.u. per cubic foot were used for fuel, the gas required for melting and fining one ton of slag glass should be around 10,000 cubic feet.

Should the glass plant be located sufficiently near the source of slag from the blast furnaces, it might prove possible to utilize the heat present in the slag as it leaves the blast furnace, thus effecting a saving in fuel requirements for the tank furnaces. Numerous runs of glass were made in the laboratory in an effort to determine the possibility of utilizing this waste heat of the molten slag and the results obtained on a laboratory scale indicate that such a saving in fuel may be possible. All of the raw materials except the slag were charged into the laboratory furnace hot from the previous run. Molten slag was then poured into the glass furnace on top of the raw materials already in the furnace and the heating process was begun. Fusion began readily and the fusing charge was stirred once or twice with a glass rod. The resulting glass was satisfactory, the slight variation in properties being attributed to the difficulty of introducing the proper quantity of slag into the furnace on so small a scale.

Except for the cost of raw materials, and the possible saving in fuel through utilization of the waste heat of the slag, as discussed above, the operating costs of the slag glass plant would be comparable to those of any plant of the same capacity making glass by the commonly-used processes and producing finished products similar to those proposed for the slag glass plant. It should be noted in this connection that the labor requirements for the slag glass plant would be relatively low, for the simple rolling, pressing, and annealing operations proposed for the plant would require much less labor than those carried out in many glass plants.

DAY TANK PLANT:

Proposed Lay-out and Equipment:

The Amsler-Morton Company, Pittsburgh, Pennsylvania, has cooperated in the preparation of plans for the general lay-out and of estimates of the initial cost for a day-tank plant having a capacity of around 8 tons of glass per 24 hours.

The lay-out proposed for this plant is shown in Figure II. Both the drawing of the general lay-out and the estimates of the cost of the various pieces of equipment are based upon information supplied by the Amsler-Morton Company.

As in the case with the 45-ton plant discussed above, the lay-out of the plant shown in Figure II is based upon the principle of straight-line flow.

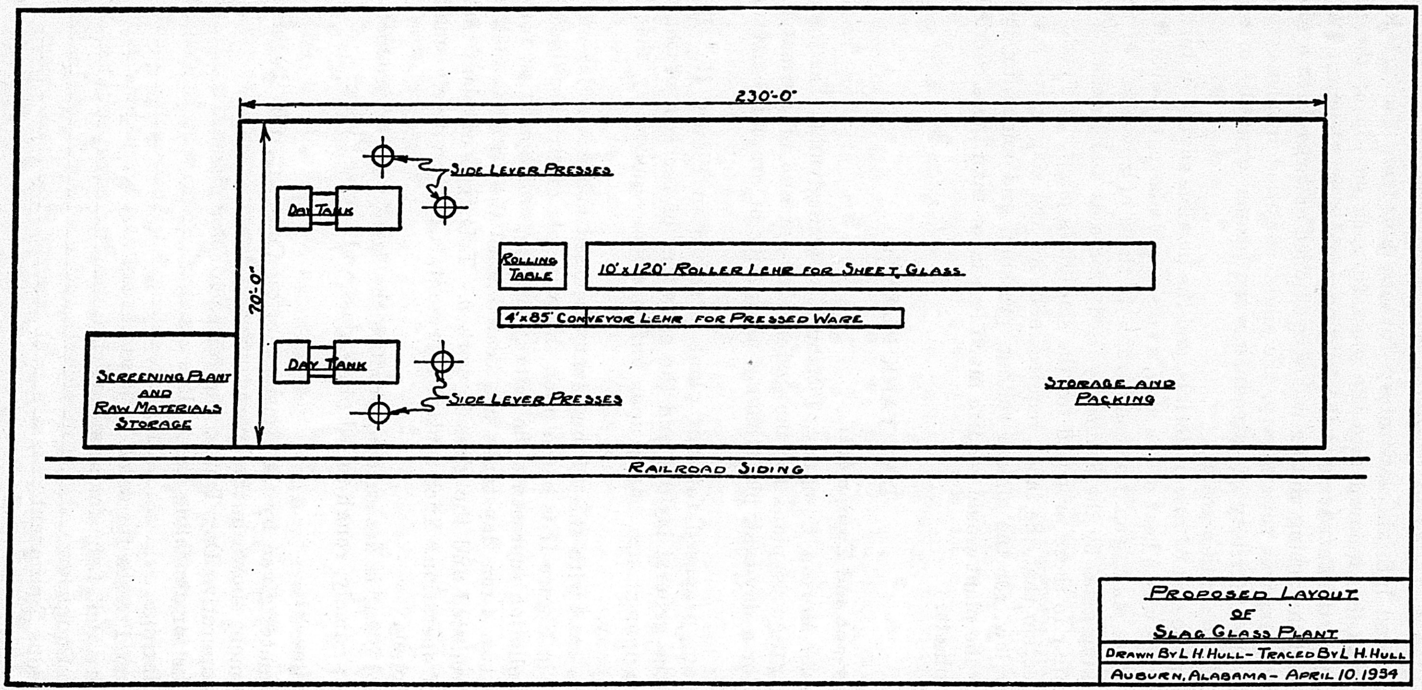
This installation represents the intermittent type of operation for a glass plant. The two 4-ton day tanks are heated until the batch is melted, then the heat is reduced and the glass is worked. This type of plant makes for flexibility of operation. Such a plant represents a comparatively small initial outlay of money.

The 8-ton plant is designed to produce the same kind of products as the 45-ton plant; namely, rough-rolled plate glass and pressed ware.

Cost of Equipment:

The estimates given by the Amsler-Morton Company, for the initial cost of the equipment shown in the lay-out are as follows:

2	4-ton Recuperative Day Tanks, one for each color glass	$10,000
1	Roller Lehr for annealing sheet glass	$22,000
1	Rolling Machine	6,500
4	Small Lever Presses for small articles	10,000
1	Woven-wire Belt Lehr for small articles	10,000
	Screening Equipment	1,500
	Miscellaneous Equipment	10,000
	Total, Equipment	$70,000



230'-0"
70'-0"
Side Lever Presses
Day Tank
Rolling Table
10' x 120' Roller Lehr for Sheet Glass
4' x 85' Conveyor Lehr for Pressed Ware
Day Tank
Side Lever Presses
Screening Plant and Raw Materials Storage
Storage and Packing
Railroad Siding
Proposed Layout of Slag Glass Plant
Drawn By L. H. Hull - Traced By L. H. Hull
Auburn, Alabama - April 10, 1934

Figure II

Cost of Building:

The 70 ft. by 230 ft. building shown in the lay-out is estimated by the Amsler-Morton Company to cost $40,000. This estimate is for a steel building with reinforced concrete floor, complete foundations, 18 gauge galvanized steel roofing, 22 gauge galvanized steel siding, and the necessary steel sash, doors, hardware, etc.

The total cost of the building and equipment is as follows:

Cost of Building	$ 40,000
Cost of Equipment	70,000
Total	$110,000

Operating Requirements:

According to information supplied by the Amsler-Morton Company, the day tank furnaces shown in the lay-out require around 20,000,000 B.t.u. per ton of glass melted. If natural gas having a heating value of 1,000 B.t.u. per cubic foot were used for fuel, around 20,000 cubic feet of gas would be required per ton of glass melted.

The relatively high fuel requirement of the day tank is the chief objection to its use. The figures given above show the day-tank plant to require approximately twice as much fuel per ton of glass melted as is required by the continuous-tank plant. As was mentioned above, it is possible that some saving in fuel requirement could be realized by utilizing the waste heat of the slag as it leaves the blast furnace.

With the exception of the cost of raw materials and the possible saving in fuel by utilizing the heat of the slag, the operating costs of the plant should approximate those of any plant of the same capacity making similar products.

ADVANTAGES FROM USE OF SLAG

The advantages derived from the use of slag in the glass batch appear to be twofold. First, a saving in cost of raw materials and possibly of fuel is realized, and second, a glass of superior quality is produced. These two advantages offered by the process for utilizing blast furnace slag in glass manufacture are discussed below.

Saving in Cost:

The usual value placed upon granulated blast furnace slag by the companies producing it as a by-product of the manufacture of pig iron is around $10.00 per carload. The Carnegie Steel Company, for example, quotes granulated slag at this price. This amount is so much less than the cost of the materials entering into the usual glass batch that considerable saving is realized by using this slag in the glass mixture.

In order that the saving in cost of raw materials possible through the use of slag in the glass mixture might be placed on a numerical basis, estimates of the cost of raw materials necessary to produce one ton of glass from the slag mixtures and from a number of the commonly-used glass batches have been prepared. These estimates are as follows:

Cost of Raw Materials for One Ton of Transparent Slag Glass:

The composition of the mixture found satisfactory on a semi-plant scale was as follows:

Slag	39.6
Sand	46.1
Soda ash	8.9
Salt cake	4.9
Arsenic trioxide	0.5
Total	100.0

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

879 lbs. Slag @ $0.25 per ton	$0.11
1023 lbs. Sand @ $2.00 per ton	1.02
197 lbs. 58% Soda ash @ $1.25 per cwt.	2.46
109 lbs. Salt cake @ $15.00 per ton	.82
11 lbs. Arsenic trioxide @ $0.045 per lb.	.50
Total	$4.91

Cost of Raw Materials for One Ton of a Transparent Aluminum Glass Approximating in Composition the Transparent Slag Glass:

A batch having the following composition would produce a glass of approximately the same composition as the transparent slag glass:

Sand	47.6
Limestone	28.5
Kaolin	11.6
Soda ash	7.9
Salt cake	4.4
Total	100.0

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1190 lbs. Sand @ $2.00 per ton	$1.19
712 lbs. Limestone @ $4.00 per ton	1.42
290 lbs. Kaolin @ $15.00 per ton	2.18
197 lbs. 58% Soda ash @ $1.25 per cwt.	2.46
109 lbs. Salt cake @ $15.00 per ton	.82
Total	$8.07

Cost of Raw Materials for One Ton of Transparent Glass from Commonly-Used Batches:

I. Window Glass:

A commonly-used batch for window glass given by Hodkin and Cousen ("Textbook of Glass Technology", Van Nostrand Company, 1925, p. 101) has the following composition:

Sand	1000
Soda ash	260
Salt cake	60
Limestone	370
Total	1690

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1440 lbs. Sand @ $2.00 per ton	$1.44
374 lbs. 58% Soda ash @ $1.25 per cwt.	4.68
86 lbs. Salt cake @ $15.00 per ton	.65
533 lbs. Limestone @ $4.00 per ton	1.07
Total	$7.84

II. Machine-Made Bottles:

A batch given by Hodkin and Cousen (p. 101) for machine-made bottles has the following composition:

Sand	1000
Soda ash	375
Limespar	175
Total	1550

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1520 lbs. Sand @ $2.00 per ton	$1.52
570 lbs. Soda ash @ $1.25 per cwt.	7.12
266 lbs. Limespar @ $4.00 per ton	.53
Total	$9.17

III. Pressed Ware:

A batch given by Hodkin and Cousen for cheap pressed ware has the following composition:

Sand	1000
Soda ash	400
Limespar	180
Arsenic trioxide	1
Selenium	0.03
Total	1581.03

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs, ignoring the selenium, are as follows:

1500 lbs. Sand @ $2.00 per ton	$1.50
600 lbs. 58% Soda ash @ $1.25 per cwt.	7.50
270 lbs. Limespar @ $4.00 per ton	.54
1.5 lbs. Arsenic trioxide @ $0.045/lb.	.07
Total	$9.61

Cost of Raw Materials for One Ton of Black Slag Glass:

The mixture used for the semi-plant work and found satisfactory was as follows:

Slag	30.8
Sand	42.1
Soda ash	17.7
Salt cake	8.4
Coke	1.0
Total	100.0

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

724 lbs. Slag @ $0.25 per ton	$0.09
789 lbs. Sand @ $1.50 per ton	.74
416 lbs. 58% Soda ash @ $1.25 per cwt.	5.20
197 lbs. Salt cake @ $15.00 per ton	1.48
23.5 lbs. Coke @ $6.00 per ton	.07
Total	$7.58

Cost of Raw Materials for One Ton of Common Black Lime Glasses:

A batch given by Hodkin and Cousen (p. 116) has the following composition:

Sand	1000
Soda ash	330
Limespar	150
Cobalt oxide	1
Manganese dioxide	220
Total	1701

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1340 lbs. Sand @ $1.50 per ton	$ 1.01
442 lbs. 58% Soda ash @ $1.25 per cwt.	5.53
201 lbs. Limespar @ $4.00 per ton	.40
1.34 lbs. Cobalt oxide @ $1.35 per lb.	1.81
421 lbs. 70% Pyrolusite @ $45.00 per ton	9.47
Total	$18.22

Another batch given by Hodkin and Cousen (p. 116) for black lime glass has the following composition:

Sand	1000
Soda ash	330
Limespar	200
Cobalt oxide	53
Manganese dioxide	200
Total	1783

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1280 lbs. Sand @ $1.50 per ton	$ 0.96
422 lbs. 58% Soda ash @ $1.25 per cwt.	5.28
256 lbs. Limespar @ $4.00 per ton	.51
67.0 lbs. Cobalt oxide @ $1.35 per lb.	91.53
366 lbs. 70% Pyrolusite @ $45.00 per ton	8.23
Total	$106.51

A third batch given by Hodkin and Cousen (p. 116) for black glass has the following composition:

Sand	1000
Potash	250
Soda ash	100
Limespar	130
Manganese dioxide	230
Total	1710

The approximate quantities of these materials necessary to produce one ton of glass and their approximate costs are as follows:

1330 lbs. Sand @ $1.50 per ton	$ 1.00
333 lbs. Potash, 80% K_2CO_3, @ $0.07/lb.	23.31
133 lbs. 58% Soda ash @ $1.25 per cwt.	1.66
173 lbs. Limespar @ $4.00 per ton	.35
437 lbs. 70% Pyrolusite @ $45.00 per ton	9.83
Total	$36.15

Summary of Cost of Raw Materials:

A summary of the cost of raw materials shows the comparative cost of the materials necessary to produce one ton of the slag glasses and the various commercial glasses to be as follows:

I. Transparent Glasses:	Cost of Materials
A. Transparent Commercial Glasses	
Aluminum Glass	$8.07
Window Glass	7.84
Machine-Made Bottles	9.17
Cheap Pressed Ware	9.61
B. Transparent Slag Glass	4.91

II. Black Glasses:

A. Black Commercial Glasses	
Cheapest Black	18.22
Medium-Priced Black	36.15
Expensive Black	106.51
B. Black Slag Glass	7.58

It is evident from the estimates given above that the saving in cost of raw materials is roughly from 37 to nearly 50 per cent in the case of the transparent glass and, if the most expensive black is omitted from the calculation, from 60 to 80 per cent in the case of the black glass. Comparable savings in the cost of raw materials are possible also in the case of the opal and chemical slag glasses.

Saving in Fuel:

Attempts to utilize the waste heat of the slag as it leaves the blast furnace have not been made on a scale of sufficient size to make possible even a rough estimate of the possible saving in fuel resulting from such a procedure.

II. Superior Quality of the Slag Glass:

Note: It is well recognized in glass making that as the CaO-Na_2O ratio increases, the strength, chemical stability and other desirable properties of glass increase. Hence it is important to call attention to the fact that this ratio maintained in the slag glasses is closely comparable to that maintained in ordinary window or plate glass, i.e., in general from one to one and one-half parts of CaO to one part Na_2O. In other words, the slag glasses and the commercial glasses are compared under the same conditions as far as possible.

The superior quality of the slag glasses is shown by the results of testing the glass, as has already been discussed. Briefly reviewing the most important of these properties, we find them to be as follows:

Appearances:

All of the slag glasses possess a natural high gloss which is not dimmed by pressing or rolling. This gloss is of particular interest in the black glass, for the high luster of the jet-black glass is strikingly beautiful.

Several persons having knowledge of glass technology have commented upon the fact that the black slag glass is a true black, rather than the purple or greenish color shown by most so-called black glasses.

Hardness:

The hardness of slag glass varies from between 5.5 and 6.0 to 6.5 on Moh's scale, depending upon the type, while window glass has a hardness of 5.5.

Tensile Strength:

The average tensile strength of the slag glass is around 15,000 pounds per square inch, as compared to 2,000 to 10,000 pounds per square inch for most glasses as reported by Hodkins and Cousen.

Coefficient of Expansion:

The linear coefficient of expansion of the slag glass varies from 0.0000055 to 0.00001757, depending upon the type. The average window glass has a coefficient of 0.000011.

Durability and Resistance to Breakage:

The slag glass shows a remarkable thermal, chemical, and mechanical durability as compared to the common glasses. Identical tests show the slag glasses to have greater durability than the common glasses in almost every instance.

The slag glass is much the superior of common glasses with respect to thermal endurance, tensile strength, resistance to breakage by impact, and resistance to chemical corrosion. An added advantage is the fact that on breaking, the slag glass has little tendency to splinter.

DISTRIBUTION OF GLASS PLANTS

Of the 263 plants engaged in making glass from raw materials in the United States (Census of Manufacturers, 1929) only 11 are located within the Southern states. Alabama has one establishment; Arkansas, 3; Louisiana, 3; South Carolina, 1; Tennessee, 2; and Florida, 1. The bulk of the remainder of the 263 plants are concentrated in Pennsylvania, Ohio, Illinois, Indiana and West Virginia. According to Tyler's Chemical Engineering Economics, Pennsylvania has 32 per cent. Ohio 10.8 per cent, West Virginia 16.2 per cent and Illinois and Indiana 18.6 per cent.

The relationship between the total capacity of the 11 plants in the South and the total capacity of all the plants in the United States, is not known. It is known, however, that the average capacity of the 11 plants located in the ten Southern states is much below the average for the United States. Except for a very small percentage, the glass consumed in the territory mentioned above is shipped relatively long distances from the glass centers of the United States. At a maximum not more than 11/263 or 4.2 per cent of the glass made in the United States is made in the South, while the population of the Southern states mentioned is probably close to 20 per cent of the total population of the country.

From the standpoint of markets for the finished products of slag glass, the South or middle West outside of the glass manufacturing districts appear to be in a very favorable position. The great saving in transportation costs on glass manufactured and sold in these areas should give a plant located in this area a distinct advantage. In other words, slag glass plants so situated should be able to bring about a double saving, i.e., a saving not only in the raw materials, but also in freight rates.

FACTORS IN THE LOCATION OF A SLAG GLASS PLANT

Any locality offering a supply of raw materials, fuel and labor and offering a ready market for the finished products may be considered a possible location for a slag glass plant. Since approximately 86 per cent of the weight of the mixture used for producing transparent slag glass and around 73 per cent of the weight of the mixture used for producing black glass, consists of slag and sand, it is obvious that the slag glass plant should be located within reasonable proximity of plentiful supplies of these two materials. As previously stated, one advantage of the process is the fact that sand of the purity of glass sand is not necessary. Ordinary building sand is satisfactory.

The fuel and power supply is a second consideration of importance. Since natural gas is always used as a fuel, the availability of this or a similar gas supply is important.

The labor supply is an item of some importance. In a typical slag glass plant probably it would be necessary to bring in a relatively few skilled operators from the glass centers of the East. A large part of the labor would be unskilled.

Transportation facilities of course would be of importance in supplying the finished products to those districts which would constitute the natural market for these goods. Probably the chief dependence would be rail, although cheap water transportation might be of considerable importance.

A study of the relation of a slag glass industry to other industries is interesting. As already discussed, the slag glass plant is directly dependent upon the iron industry and its production of blast furnace slag as a by-product. A source of sand is also essential.

An industrial center providing iron and steel products, refractories, etc., also would be of advantage.

A location providing a plentiful supply of technical service for plant maintenance and repair as well as an abundant labor supply also is of importance.

A location favoring the markets for the finished products is worthy of consideration.

In conclusion, it would appear that most of the Eastern, Midwestern or Southern steel centers would be good locations for the manufacture of slag glass. The absence of other glass plants in the vicinity might offer an additional advantage. From this standpoint, Birmingham, Alabama, would have a special advantage.

SUMMARY

1. A method has been developed for the utilization of blast furnace slag in glass manufacture.
2. Four types of glass have been prepared from the slag. These consist of a transparent aluminum glass, a black opaque glass, a chemical or laboratory glass, and an opal glass.
3. The optimum conditions for making the glasses have been studied.
4. The transparent glass and the black glass have been made on a semi-commercial scale.
5. The difficulties in the use of slag as a raw material for glass manufacture have been discussed and an explanation offered as to how these difficulties are eliminated.
6. Tentative plans for the lay-out of two types of commercial plants suitable for making slag glass have been prepared and estimates have been made of the initial cost of the installation.
7. The properties of the various glasses have been determined. The slag glasses are superior to the commercial glasses in several definite respects.

8. The distribution of glass plants in the United States, as well as market conditions have been discussed.
9. The raw material costs for the slag glasses have been calculated and the results compared to a number of commercial glasses. The results show a saving of raw materials from 35 to 75 per cent in the case of the slag glasses.
10. The slag glasses are superior to ordinary soda lime glass with respect to thermal endurance, tensile strength, resistance to breakage by impact and resistance to chemical corrosion. The superior tensile strength and resistance to breakage by impact are particularly noticeable. The resistance to breakage by impact is two to three times as great as ordinary soda lime glass.

NOTE: In the above comparison of the properties of slag and commercial glasses, it should be noted that in the slag glasses the ratio of sodium oxide to calcium oxide was comparable to that employed in the commercial glasses (window plate, bottle, etc.). In other words, the two glasses were compared under approximately the same conditions.

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