INDUSTRIAL OUTLOOK.

The Indian Glass Industry.*

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Raw Materials.

Chief Raw Materials.—All Indian glassware is of the soda-lime variety. Lead and potash glasses are not made on account of the high price of red lead, litharge, and potassium carbonate, none of which are strictly indigenous products: although red lead and litharge are made in Calcutta from Burma lead.

For the production of soda-lime glass the chief raw materials required are pure sand (silica), lime and soda ash (sodium carbonate), and also fireclay and fuel. All of these, with the exception of soda ash, are found in abundance in India, but unfortunately there is no place in the country where they are all found together in large quantities so that no particular district can be said to be favoured as a glass-manufacturing centre above all others.

In addition to the main raw materials enumerated above small quantities of special materials are required as oxidising, reducing, colouring, decolouring, and opacifying agents. These will be described in more detail later, but it may be mentioned here that nearly all of them have to be imported.

The process of manufacture consists of fusing together in suitable furnaces the sand, lime and soda ash and such small quantities of the special materials as are necessary for the particular type of glass being made. The sand (silica) which is acidic is decomposed at a much lower temperature in the presence of the sodium carbonate and lime than it would be in their absence. In general terms it may, however, be stated that the lower the alkali content the more durable the glass. The most resistant of all glass, *e.g.*, 'Pyrex', is practically pure fused silica and boric oxide, and the alkali content is only about 5 per cent.

Sand.—From the glass-maker's point of view the most objectionable impurity commonly found in sand is iron oxide; very small quantities of this material are sufficient to tint the glass green or straw coloured, and to spoil the much desired brilliancy. For the manufacture of the finest colourless glassware very pure sand containing not less than 99% silica and not more than 0·02% iron oxide is desirable. In addition, not less than 95% of the sand should pass a 30 mesh per inch sieve and be retained on a 100 mesh per inch sieve, as it is important that the sand should have a uniform grain size and not contain a large proportion of 'fines'. (Very fine sand is liable to be carried by gas bubbles to the surface of the glass where it forms 'stones' by reason of its comparative immunity there from the fluxing action of the alkalies.)

It is doubtful whether India possesses glass sand of this quality, but there are many deposits suitable for the manufacture of good decolourised glass, *i.e.*, sand in which the iron oxide content does not exceed 0·10% so that the green tint imparted to the glass is sufficiently pale to permit of decolourising by superimposing a pink tinge from small quantities of such materials as manganese dioxide or selenium. If the iron oxide content of the sand exceeds 0·10%, decolourising cannot successfully be carried out as the glass takes on a greyish hue and lacks brilliancy.

Much of the sand used by the industry is obtained from deposits of friable sandstone at Bargarh and Loghara near Naini in the United Provinces. A deposit with a good reputation is situated at Sawai Madhopur near Jaipur and is used by many of the Firozabad bangle-makers. There are also suitable deposits at Jaijon in the Hoshiarpur District, Jubbulpore and Madras. Glass sand can usually be improved by washing and screening but few Indian glass manufacturers do more to purify their sand than give it an elementary screening.

Lime.—Limestone is found in abundance in India and the glass industry suffers from no lack of excellent and cheap supplies of this material, either in its natural form or burnt to quicklime. Since most of the furnaces are pot furnaces, where

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* Continued from page 130.

the glass is melted in closed fireclay pots, quicklime or slaked lime (quicklime quenched with water) is usually used. Limestone, which has a less vigorous action than either quicklime or slaked lime, is used chiefly in tank furnaces where the glass is melted in contact with the flames and combustion products of the furnace and, therefore, usually reaches higher temperatures than when melted in glass pots. Pure quicklime contains 100% calcium oxide, pure slaked lime 75·7% and limestone 56%. As in the case of sand the most objectionable impurity is iron and this should not exceed 0·15% for good quality glassware, but for decolourised ware up to 0·30% iron is permissible. Many of the factories use lime from the enormous deposits at Katni, near Jubbalpore, in the Central Provinces.

Soda ash.—The third essential bulk raw material required for the manufacture of soda-lime glass, soda ash, is not produced in India in commercial quantities, and practically the whole of the supplies for the industry are imported. Small quantities of natural sodium carbonate are obtained from time to time from Lona Lake in the Central Provinces, but they are negligible compared with the demands of the glass industry.

Attempts have been made to manufacture soda ash in the country, notably at the Shri Shakti Alkali Works, Dhrangadra State, in Kathiawar and, during the War, by extracting sodium carbonate from *reh* deposits, but they have met with limited success. It is, however, understood that plans for the manufacture of soda ash on a large scale from the waste salt of the Khewra mines are nearing completion, so that it is probable that India will eventually have ample indigenous supplies of this material.

Fireclay.—India is fortunate in possessing large deposits of excellent fireclay admirably suited to the manufacture of glass. Most of the requirements of the industry are met by Messrs. Burn & Co., Jubbulpore, and Messrs. Bird & Co., Kumardhubi, but there are other suppliers, including Messrs. Burn & Co., Raniganj (silica and sillimanite) and Messrs. The Perfect Potteries, Jubbulpore. For use in the glass industry, fireclay is made into firebricks and blocks for the construction of the furnaces and annealing ovens. It is also shaped into glass pots or crucibles, for the pot furnaces, although at present most glass pots used in the industry are imported from Japan.

An essential requirement for fireclay refractories which are in contact with molten glass is that they must be chemically neutral—neither acidic nor basic—or they will rapidly be attacked by the glass. Silica, and lime or magnesia refractories are equally unsuitable for the purpose. In addition the refractories must be dense, mechanically strong and capable of resisting for long periods temperatures as high as 1,500° C. They should also have a very low coefficient of thermal expansion or contraction.

To comply with these exacting conditions the fireclay used, must contain such fluxing materials as lime, magnesia, potash and soda, in very small quantities only. It is not possible to dispense entirely with all of these 'impurities' as they are largely responsible for the plasticity of the clay. The clay should also be free from iron in appreciable quantities as, in the case of tank blocks, this will tend to dissolve into the glass. An analysis ‡ of a typical Jubbulpore clay given below shows that chemically, and as far as resistance to high temperature is concerned, these conditions are admirably met, and the clay there analysed compares well with similar English fireclays. Good as these refractories are, however, they will not withstand the corrosion at the glass level of high temperature tank furnaces for long, and for prolonged service super refractories must be employed in such places.

Sillimanite.—Much research work has been done during recent years on the subject of glass refractories and it is nowadays generally conceded that the substance which most satisfactorily fulfils the exacting requirements of glass tank service is

‡ Analysis of Jubbulpore Fireclay:

	%
Silica	68·25
Alumina	27·95
Iron oxide	1·10
Titanium oxide ..	1·66
Lime	0·50
Magnesia	0·20
Loss on ignition ..	0·20
	99·86

Fusion Test, Seger Cone 31/32 (1690° C./1710° C.)

the compound alumunium silicate corresponding to the formula $3Al_2O_3 \cdot 2SiO_2$, in the crystalline form known as sillimanite. This mineral, which is tough and strong, has a melting point of over 1800° C. and does not soften appreciably below this temperature; it has a very small coefficient of thermal expansion; it has great chemical stability and is neutral in composition.*

Another substance with the same chemical composition is kyanite, but this is not so satisfactory as a refractory as the coefficient of thermal expansion is much greater than in the case of sillimanite. Moreover, the hardness of kyanite is not the same along different planes. Kyanite can, however, by calcination at 1450° C., be converted to a substance known as 'mullite' which is very similar to sillimanite.

Massive sillimanite is very scarce throughout the world, and India is fortunate in possessing some of the few deposits of this super refractory so far discovered. Deposits of kyanite also exist in this country. The deposits of kyanite are described in the *Memoirs of the Geological Survey of India*, Vol. LII, Part II, and exist at Sona Pahar, Nongstoin State, Assam, near Shillong; at Pipra in Rewa State, Central India, about 100 miles from Mirzapore, and in the Banda District of the Central Provinces. There are deposits of kyanite at Singhbhum. Unfortunately, the sillimanite deposits are very inaccessible and the material is costly to mine. Moreover, it is extremely hard and the crushing costs are high, so that at present it is little used by Indian glass manufacturers: but small quantities of sillimanite refractories are made for the industry by Messrs. Burn & Co., Raniganj. Most of the sillimanite and kyanite mined is at present being exported raw, chiefly to America.

Fuel.—With the exception of a few charcoal and wood fired bangle furnaces, and the spangle glass furnaces at Panipat, all Indian glass furnaces are coal fired. Usually the coal is not gasified before burning but is 'direct fired' on the grates of the so-called 'Japanese' furnaces which are to be found in the great majority of the factories. As previously mentioned these furnaces are inefficient and for their successful operation they require good quality, long flame coal: the better qualities of coal from Jharia and Raniganj are, therefore, universally used. The price of coal at the factories varies enormously with their distance from the coal fields, but in all cases fuel is the most expensive of the cost items for the main raw materials, and the reduction of fuel charges by the introduction of better furnaces is one of the most obvious needs of the industry.

During the survey of the industry carried out by the Industrial Research Bureau in 1935–36 the average ratio of fuel burned in the furnaces to the batch materials melted was found to be 1·6 to 1. In modern glass furnaces a ratio of 0·8 to 1 is not uncommon.

Special Raw Materials: *Borax.*—This is frequently used in Indian glass batches, the acid boric oxide, replacing some of the silica. It is obtained from Tibet and used in comparatively small quantities.

Oxidising Agents.—In India the chief oxidising agent employed in glass manufacture is saltpetre. It is used in glass batches containing easily reducible substances which it is desired to keep in their oxidised form. The colouring effect of iron can be minimised by oxidising the iron to the less highly coloured ferric state. Saltpetre is added in small quantities to almost all Indian glass batches and is a common product of the country.

Reducing Agents.—The reducing agent commonly employed in the industry is carbon in the form of finely crushed coal. Reducing agents are added to glass batches containing materials which it is desirable to reduce in oxygen content. For instance, sometimes sodium sulphate (salt cake) is added as a partial substitute for soda ash to batches melted in the few tank furnaces which exist in India. When this is done a reducing agent is also added to reduce the sodium sulphate to sodium sulphite which is a more active fluxin-

* Chemical Analysis of Sillimanite :

	%
Loss on ignition ..	0·80
Silica	33·90
Titanium	1·72
Iron oxide	1·80
Alumina	61·18
Lime	0·51
Magnesia	Trace
Alkalies	Nil
	99·90

material. Reducing agents are employed in the production of colours from metallic oxides when the colouring agent must be present in a metallic state.

Colouring Agents.—The colouring of glass is accomplished by introducing certain metallic oxides and elements. The following is a list of colours commonly obtained in India, together with the colouring agents used. The colouring effect of these materials is usually very strong, and small quantities only are required to produce the desired effect. On the other hand, nearly all the materials have to be imported and are expensive.

COLOUR	COLOURING AGENT
Red	Selenium with or without cadmium sulphide
Yellow (Gold)	Cadmium sulphide
Yellow with a greenish Fluorescence	Uranium oxide
Aquamarine blue	Copper oxide or copper sulphate
Blue	Cobalt oxide
Green (Lemon)	Potassium dichromate and copper oxide
Green	Iron oxide
Violet	Manganese dioxide
Amber	Carbon (coal)
Yellow Amber	Sulphur

The production of good colours is a matter requiring considerable skill and experience and often depends upon the condition of the atmosphere inside the pot or tank. For instance, the colours produced by iron and manganese vary widely with the degree of oxidation. Some of the colouring agents such as manganese, nickel, chromium and iron form coloured silicates, others, such as selenium and carbon enter the glass in a colloidal form. The Firozabad bangle glass-makers are adepts at producing varied and beautiful colours, but nearly all of the ordinary blownware factories produce small quantities of simple coloured ware such as tumblers, vases, lamp-shades, globes, etc.

An iridescent effect is obtained by some glass-makers by spraying the article, whilst still hot, with ferric chloride, and the Firozabad bangle-makers frequently give a glistening silver appearance to their bangles by spraying them with silver nitrate.

Decolourising Agents.—The decolourising of Indian glass is accomplished by adding to the batch manganese dioxide (a product of India) or selenium (an imported element usually associated with sulphur). Both of these materials produce a pink colour when added in small quantities, and this serves to cover the familiar iron green tinge.

Opacifying Agents.—Indian batches for opal glass always contain fluorspar (calcium fluoride) and cryolite (sodium aluminium fluoride). The opal effect is caused by the fine colloidal dispersion which occurs in the glass when these materials are used. Both of these materials are imported.

Alkaline Rocks.—There are in India several large deposits of alkali containing rocks and minerals which are very suitable for the manufacture of glass. The chief of these are felspar, both albite (soda) and orthoclase (potash), and nephelene syenite. Analysis of these materials yields approximately 55/56% silica, 19/22% alumina and about 15% total alkalies, besides small quantities of iron, calcium, etc. It will readily be seen that their chief use is as a means of introducing cheap alkalies into the batch and so reducing the amount of costly soda ash required.

The chief difficulty experienced in using these materials on an economic scale is due to the large amount of alumina they contain, as alumina, when present in the glass batch in quantities exceeding 2 or 3 per cent., greatly increases the viscosity and so the founding temperature. In consequence, with the exception of a little felspar (for some reason unknown this is usually imported) which is generally added to opal batches to assist in promoting the opal effect, these materials are not at present used in the Indian glass industry, as the existing furnaces cannot maintain sufficiently high temperatures to found highly aluminous glasses.

The subject has been studied by Dr. V. S. Dubey and P. N. Agrawalla of the Benares Hindu University* who reached the conclusion that nepheline syenite is the most suitable indigenous rock for the partial substitute for soda ash in the Indian glass industry. (The ratio of alkalies to silica is higher in the case of nepheline syenite than in the case of felspar.) They suggested that it might be freed from iron by magnetic separation and used in glass batches in quantities equal to the silica content.

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* *Bulletin* No. 7 *of Indian Industrial Research.* "The Utilisation of Nepheline Syenite Rock as a Partial Substitute for Soda ash in the Glass Industry of India."

The chief deposits of felspar are at Ajmer, Kishengarh State, Rajputana, Bihar, Eastern Bengal and Madras. It is often found with mica. Nepheline syenite is available in large quantities in Kishengarh, and to a lesser extent in Kathiawar and Madras.

One of the methods of assisting the industry decided on after the survey by the Industrial Research Bureau was the publishing of a complete survey of the raw materials available in India. The geological work is being carried out by Dr. V. S. Dubey of the Benares Hindu University and the samples are being tested and classified at the Government Test House, Alipore, Calcutta.

Articles Manufactured—Value of the Industry—Manufacturing Process and Equipment—Composition of Indian Glass.

Articles Manufactured.—About 60% of the production of nearly all Indian glass works consists of oil lamp globes and chimneys. Next in numbers manufactured are blown stoppered glass bottles or jars used for the storage of food-stuffs. Hand-blown medical and other bottles are also made in large quantities. Cheap blown tumblers and a few pressed tumblers form an important line of production, but very little fancy or high class glassware is made.

A few works produce cheap laboratory ware such as beakers, phials, test-tubes and hand drawn glass tubing. Only one factory, the United Provinces Glass Works, Bahjoi, U.P., manufactures sheet-glass, the Fourcault drawing process being used. Generally speaking, the quality of Indian glassware is somewhat inferior to that of similar imported ware.

Value of the Industry.—In 1935–36 it was estimated that blownware and sheet-glass to the value of about Rs. 37 lakhs, and bangles to the value of Rs. 30 lakhs approximately were annually being produced in India. These estimates are probably conservative. The total value of imports of glassware in 1936–37 was Rs. 128 lakhs approximately.

Manufacturing Processes.—Nearly all Indian glassware is hand-blown. Very little pressed ware is made, and although three factories, the Allahabad Glass Works, Naini, United Provinces, the Bombay Glass Works, and the Calcutta Glass and Silicate Works, possess bottle blowing machinery, these are not at present in use. As previously mentioned most manufacturers melt their glass in direct fired pot furnaces, known colloquially as 'Japanese' furnaces.

Tank and Pot Furnaces.—There are two main types of glass furnaces, the tank furnace and the pot furnace. In the tank furnace the batch materials are melted in a large covered fireclay chamber, or tank, which forms part of the furnace itself. Gas (and sometimes oil) is introduced with a suitable supply of preheated air through the tank walls above the batch, and combustion takes place in contact with the glass. This type of furnace is suitable for the continuous production of large quantities of glass, raw materials being fed in at one end of the tank and glass withdrawn at the other. There are very few tank furnaces in India, where the average factory produces only two or three tons of glass daily.

The other type of furnace produces glass in fireclay pots or crucibles, the pots being enclosed in a fireclay pot chamber, or dome, into which the flames and products of combustion from the furnace proper are led. This type of furnace is intermittent in action and is capable of producing finer glass than the tank furnace, as when closed pots are used, the glass does not come into contact with the products of combustion.

The 'Japanese' Furnace.—The so-called 'Japanese' furnace universally used in India is a furnace of the second type. The coal is burned on an open grate below the pot chamber into which the flames and hot gases rise through a hole (the 'eye') in the centre of the chamber floor. The pots stand in a circle round the eye and the products of combustion pass away to the chimney through small flues in the walls of the pot chamber. In order that the flames may be caused to envelope the pots, the furnaces are operated with the maximum of draught. This results in enormous quantities of air in excess of the combustion requirements of the fuel being drawn through the furnace, which consequently can never attain really high temperatures. It also results in very high fuel consumption.

Modern glass furnaces, whether tank or pot furnaces, are all fitted with devices for utilising waste heat. These devices not only make for economy of fuel consumption but also ensure higher temperatures than are possible in direct fired furnaces. The coal is not burned completely in one operation, but it is first gasified in a 'producer' by burning it with a limited air supply, or with an injected mixture of steam and air, so that carbon monoxide and hydrogen are formed instead of carbon dioxide and water vapour. The gas is led to the furnace and combustion is completed in a convenient position (*e.g.*, over the batch mixture in a tank furnace, or in the 'eye' of a pot furnace) by means of a controlled supply of air pre-heated by the waste gases.

Regenerators and Recuperators.—There are two well-known air pre-heating devices, the regenerator and the recuperator. In regenerative systems the hot waste gases from the furnace are controlled by a two-way valve and are caused to pass alternatively through two sets of two chambers each filled with chequer brick work, before passing on to the chimney. When one set of these chambers has become sufficiently heated the valve is reversed and the waste gases are thereby caused to flow through the other two chambers, which previously had been passing the gas and air to the furnace. Simultaneously, the gas and air are now caused to pass through the preheated chambers before entering the furnace. When the original gas and air chambers are sufficiently heated the valve is again reversed, and the operation is repeated at about half hourly intervals throughout the working of the furnace. It will be seen that the method is intermittent and that flames are generated inside the furnace on alternate sides, as the flue openings, which are placed opposite to each other in the furnace, become alternately burners and waste gas outlets.

The other pre-heating device, the recuperator, consists essentially of a series of fireclay tubes which carry the waste gases from the furnace to the chimney flue. The incoming 'secondary' air is caused to flow round these tubes and so attains a considerable degree of preheat before entering the furnace. Opinions vary regarding the respective merits and demerits of the two systems, as in the case of the regenerator the heat is applied alternately from side to side of the furnace, while in the case of the recuperator there is danger of leakage in the recuperator tubes, although the combustion flames and products are always propagated in one direction. Actually, both systems are thoroughly tried and proved and one or other of them is essential to any modern furnace.

Usually, the regenerator is applied to the large glass tank furnaces as in such furnaces the alternating heating effect is not so pronounced on account of the great quantities of heat stored in the furnace walls and in the glass. The few tank furnaces which exist in India are made on this principle. The recuperator is ideal for small pot furnaces and it is astonishing to find no furnace fitted with this device in India.

The Industrial Research Bureau has designed a recuperative pot furnace of the size commonly found in India—9,800 lbs. pots—and the furnace will shortly be erected in Firozabad, United Provinces, where it is hoped to demonstrate its advantages.

Method of Manufacture.—The methods of manufacture practised by all Indian glass manufacturers in the production of hand-blown ware are substantially the same, so that a brief description of the manufacture of lamp globes, the chief line of production, will cover the manufacture of other blown articles in all except minor details.

The batch materials are weighed out, hand mixed and placed in the glass pots in the evening along with quantities of cullet (broken waste glass from the day's blowing). The fire is banked up and melting proceeds during the night. After melting is complete the glass is 'fined' for about an hour before using. During the fining period the temperature of the furnace is lowered slightly and the glass freed from bubbles as far as possible. To assist this process vegetable matter, such as potatoes, is sometimes thrown into the pots, but it is more usual to include in the batch small quantities of a volatile material such as arsenious oxide in order to liberate the 'seed' bubbles. After fining is complete the covers of the pots are removed and the glass allowed to cool to about 1,000° C. at which temperature it has a suitable viscosity for working.

When the glass is ready for "working out" a long iron blow pipe is inserted into the pot by the blower's mate and a portion of glass collected at the end. By blowing and swinging, this is formed into a small bulb. The pipe and bulb are then transferred to the blower who stands over a cast iron mould mounted in a small pit in the ground. The mould, which is in charge of a mould bay, is split down the middle and hinged so that it can be opened for the insertion of the bulb of glass. After closing the mould the glass is inflated by blowing to the shape of the interior of the mould. Sometimes moulds are lubricated during this process by the insertion of a sheet of paper along with the glass, carbon formed during the combustion of the paper acting as a lubricant.

After blowing the globes (globes are usually blown in connected 'strings' of two or more) are cracked off from the pipe and sent to the annealing lehr.

Annealing.—During the process of manufacture glass articles become strained and it is necessary to remove these strains by annealing, otherwise the glass will readily break in service. In India annealing is done by stacking the glass-ware in simple annealing kilns or lehrs, which are heated by small open fires built inside the kilns in one corner. The kilns are merely brick chambers about 10 × 6 × 6 feet with a filling door in the front wall and a chimney connected to the rear wall. The fire is tended through a special opening in one corner of the front wall.

When the kiln is full the filling door is closed and the temperature raised to about 500° C. The door is then opened and the fire drawn and the kiln allowed to cool down to room temperature, when the articles are removed for finishing and packing. This process of annealing is slow and there is a great deal of breakage during the filling and unloading of the kilns.

Modern glass works use continuous, gas heated lehrs which reduce breakage to a minimum. The glassware is loaded on an endless metal belt which runs through a gas-heated tunnel. The heating is under exact control and the temperature of annealing can be adjusted to the particular kind of glass passing through the lehr. After travelling through the heated portion of the tunnel the glass is subjected to controlled cooling as it proceeds on its journey to the discharge end of the lehr, and it is finally discharged cool enough to be handled.

Lehrs of this or similar types will eventually have to be used here if India is to hold her own as a glass producing country.

The Composition of Indian Glass.—The composition of glass is conventionally expressed in terms of the constituent oxides. The main constituents of a typical Indian blownware glass expressed in these terms and based on an average of seventeen batches are given below:

	%
Silica	74
Sodium oxide	17·4
Calcium oxide	6·8
Potassium oxide (from saltpetre)	1·4

A glass of this composition will be easy to melt but, on account of the high percentage of sodium oxide, will have a high coefficient of thermal expansion and, therefore, will be liable to crack when subjected to sudden temperature changes. Moreover, the glass will be slightly water-soluble even in cold water, and so will quickly loose its brilliance when exposed to the atmosphere. These characteristics are amplified by the potassium oxide present, as this material gives to glass similar properties as sodium oxide, although in a somewhat lesser degree.

Such a glass is quite unsuitable for the manufacture of medicine bottles, although in India similar glasses are sometimes so used.

The glass should contain more calcium oxide and less sodium and potassium oxides, as calcium greatly increases the hardness and decreases the solubility, although it increases the tendency towards devitrification and also increases the founding temperature somewhat. A glass containing about 12% of sodium and potassium oxides and about 12% of calcium oxide would be harder, cheaper and more durable, and could easily be melted in recuperative or regenerative furnaces, but such a glass could only be melted with the greatest difficulty in the existing direct fired pot furnances. It appears that the development of the Indian glass industry is largely bound up with the improving of the furnances and lehrs.