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ROLE AND EFFECTS OF SILICA SAND ON THE QUALITY OF GLASS

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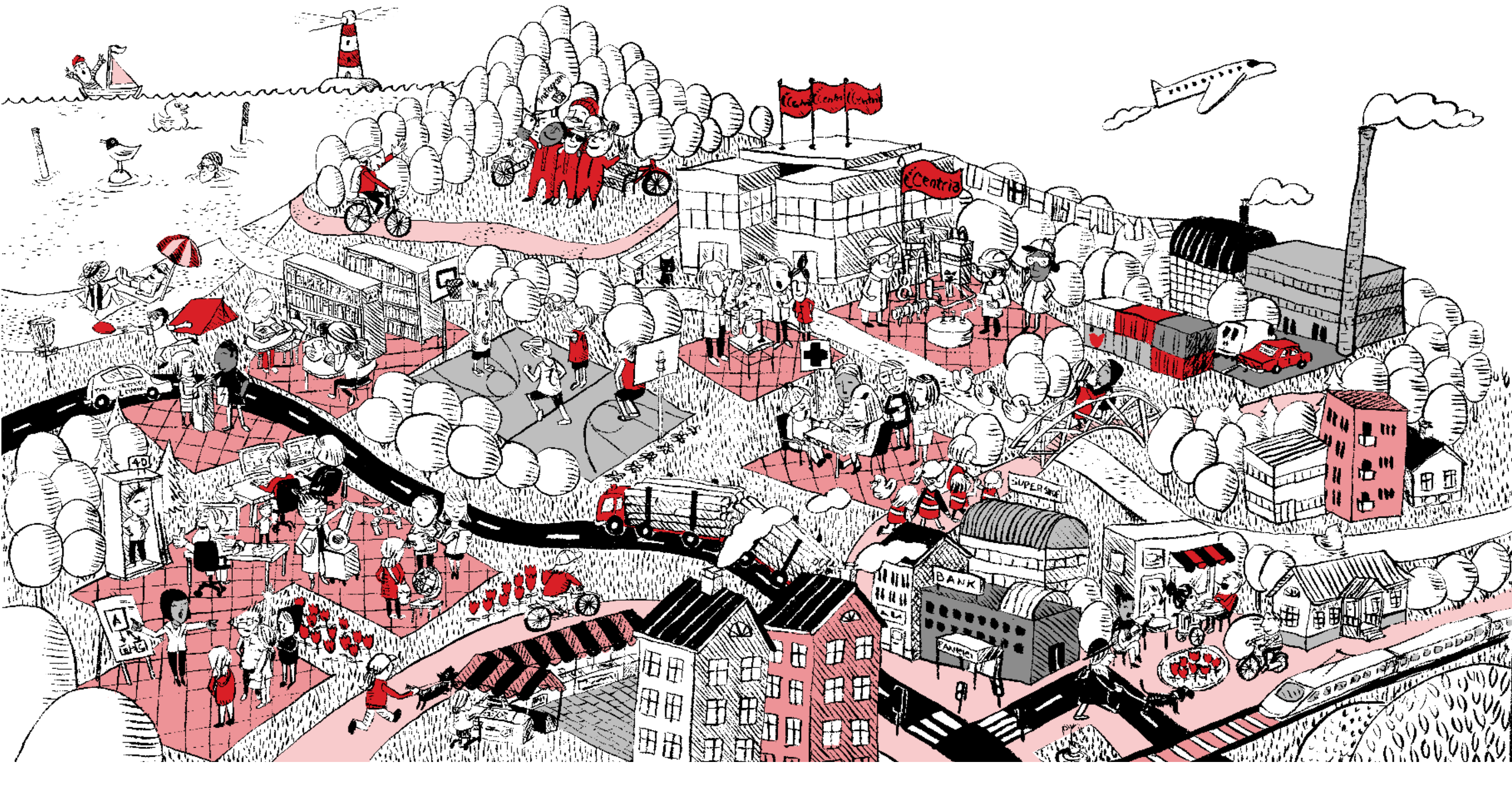

ABSTRACT

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All finished products available for consumer use is an assemble of different raw materials to yield the final commodity. Glass is an important product that is used in all parts of the world. Some finished glass products available for consumption are entirely composed of glass whereas others reflect a small percentage of glass in their final structure. Regardless of how much quantity of glass is present in the final products, silica has a very important role to play in all glass processes. Silica sand is a natural indispensable raw material in the glass industry for the processing of different variety of products.

This thesis report does not only illustrate the role and influence silica sand has on the quality of glass or expose its congenital features that makes it suitable for use in preference to other types of sand, but it will also examine techniques that are employed to enhance its purity for usage in producing high quality products. More emphasis will equally be laid on its importance in the production of different commodities and prospects its availability in the future since the demand for silica sand is high. The report elucidates that the continuous high use of silica sand to satisfy consumer needs will eventually lead to shortage and creates the awareness that different sand types should be tested and used to reduce the total dependence of silica sand in glass and other factories.

Key words

Silica sand, controlled pore gas (CPG), cullet, pulverized Fuel Ash (PFA)**,** batch.

FIGURES

TABLES

1 INTRODUCTION

The glass industry has emerged and developed to be one of the most important sectors in the society as far as producing different varieties of glass products and accessories are concerned. The high market demand for these products has been easily accomplished by the natural availability of important raw material used in the process. water and sand are the two most abundant natural resources that exist on Earth. Although they are not procurable in all parts of the world in the same proportions, each continent and country have access to this natural wealth. Silica sand otherwise known as white or industrial sand, is quartz that has been broken down into minute granules through the works of water and wind. Its natural characteristics and easy purification when aimed for use in producing high quality products has made it an indispensable raw material for the glass industry. Besides glass factories, other manufacturing plants such as foundry, ceramics and refractories also make use of silica sand for the process and development of their final products. Although silica sand has emerged to be a vital component in different manufacturing companies, it is important to monitor its rampant extraction to avoid jeopardizing the welfare of the environment and ecosystem.

This report will illustrate the innate characteristics that silica sand possess making it a preferred sand type for the glass industry but will equally expose the negative repercussions that over-dependence on silica sand has on the environment and the ecosystem. Proposed solutions and practical applications to avoid total reliance on silica sand will equally be mentioned in this report.

2 HISTORICAL BACKGROUND ON THE PRODUCTION OF GLASS

Glass is generally referred to as a transparent amorphous solid which has multiple uses. For example, optics, tableware, and windowpanes. The methods used in the production of glass and when glass was invented is still not known although it has been generally connected with ancient discoveries, only a few of these findings relatively seem possible. Yet, it is not well known how glass was invented. With regards to these findings on its origin, glass is known to be a naturally occurring material that later became a waste product of pottery. Another theory on the form of glass is seen during the formation of by-products in the melting of copper. Research has shown that glass is designed from the great effects of high temperature on sand and soda. Following this, the Phoenician merchants used the hearth of Africa soda that was established on the coastal sand for cooking. The version on the origin of glass was brought forth by the ancient historian Pliny the elder. Obsidian which is another word for glass was formed about 9000 years ago and has been widely utilized by prehistoric man. In 7000BC, the first appearance and development of glass was made in the Middle East. Studies show that the development of mirrors, coloured glass, and crystals were manufactured by the Renaissance in Venice. The production of glass began in 1870 in New Zealand and since then, there has been a tremendous increase in the use of glass worldwide regardless of the increase in the demand for plastics and metal products. The formation of new materials like the faience has been developed using various techniques to form a glaze layer over a silica core. The development of the faience which was realized in Egypt or Sumeria thus gave the name the Egyptian faience. Early 1500BCE, glass became the major industry in Egypt. This enabled various legends to describe the procedure of glassmaking. The most famous discovery of glass was recorded by the 1st -century historian Pliny the Elder in the North of modern Israel. (The Original Bristol Blue Glass 2021.)

In 1920, William L. Monro of the American Glass Co investigated the possibility on the discovery of glass. As such, he attempted to recreate the conditions which were described during a series of experiments. He built an open wood fire over a bed of glass sand which was mixed with an equal amount of soda and left to combust for over two hours. William L. Monro inserted a standard pyrometer into the bed of fire to frequently monitor the temperature generated in the bed. Throughout this experiment, he realized that a maximum temperature of 1210°C could be attained after the fire has been reduced into a mass of burning charcoal. A portion of the bed was fused into a vitreous mass after the fire had burned out and the ashes removed. The bed of glass sand which was mixed with an equal quantity of nitre was used to repeat the process of glassmaking. William used a bed of glass, sand, unmixed with other ingredients to carry out the production process the third time. The results of this experiment after the removal of the ashes show no evidence of any fusion. (Rasmussen 2009.)

The accounts discussed above on the origin and production of glass were not generally accepted as historically true and up to date. On these grounds, Scholars thought that glass was discovered either as a by-product of metallurgy or from an evolutionary sequence in the development of ceramic materials. Both theories on the origin of glass seem acceptable as the technologies used had procedures that could be seen as precursors of glass. It is well known that the evolutionary development of siliceous ceramics which is coated in alkali glaze originated from Egypt or Sumeria. The material referred to as Faience is seen as a predecessor of glass in the development process. Research has shown that faience primarily consists of silica which has little amounts of soda and other impurities. With this understanding, the initial discovery of glass would have occurred through few variations in the production of faience. These variations could easily happen because of the poor temperature control and the investigating effects of variable conditions on the production of faience. (Rasmussen 2009.)

3 OVERVIEW ON THE PRODUCTION PROCESS OF GLASS

Glass is made from a combination of various ingredients with different proportions and these ingredient are generally grouped into majors and minors. The majors entail (sand, soda, ash, cullet, and limestone) and minors (iron chromite, magnetite, salt cake, carbon, cobalt (II) oxide, selenium, alumina, and iron pyrites). These components are mixed in small quantities and melted at high temperatures to form a molten substance. This process is considered the main phase in the production process. The methods used in the melting process depend on the desired glass, scale of operation and its end use. Other parameters that influence the formulation of glass include the melting techniques used, fuel choice, the size of the furnace, and the raw materials. Water is equally an important component in the production process as it enables the ingredients to stick together. After these ingredients are combined, they are then mixed for about 3minutes in a rotatory mixer. The mixture is later transported into a batch hopper and eventually fed into a furnace. The desired type of glass is determined by the raw materials used while the colour of the glass produced is determined by the minors used. The colours of the final products are a result of the specific colorants used and the oxidation state of the glass. Carbon number is a scale used in measuring the degree of oxidation that is promoted by the addition of carbon. The carbon number for amber is -52, clear glass is zero, and dark green glass is -28. Coloured materials such as dyes are equally used to achieve the other colours for glass. For example, the green tinge which is seen in clear glass and marked with selenium is a result of the iron (II) ions that are naturally found in sand. Furthermore, the green and amber colours which is seen on glass bottles is not caused only by the degree of oxidization but also by the addition of iron sand cake mix and iron chromite which are mixed. The continuous feeding of glass into the furnace enables the production of glass using a particular recipe. The duration of glass production is about 12-48 hours and after the mixture is changed to produce a different type of glass with an acceptable standard. (Lynn,2007.)

There are several methods used in the production of glass. The main method used is the melting of raw materials at high temperatures. With this process, the raw materials are first selected, weighted, mixed and the impurities removed to get a uniform melt. Larger quantities of raw materials are melted in refractory tanks which are further connected to the glass forming machines. The components are melted in the furnace and the type of furnace used in this process depends on the amount and type of glass to be produced. Most of the incinerators used in the production of glass are composed of refractory blocks that work at a temperature of more than 1500ºC. Examples of different furnace commonly used are electric melter, recuperative melter, unit melter, and regenerative furnace. The materials used in the manufacturing of glass is divided into 5 categories and placed according to the role they play in the production process: colorant, modifier, fining agent, glass former, and flux. Glass former is known to be the major component present in all glass types. The most common types of glass former present in oxide glass is boric oxide (B_2O_3), Silica (SiO_2), and phosphoric oxide (P_2O_5). Reducing the processing temperature of silica requires the use of different types of fluxes like Na_2O and PbO. The overall cost of glass processing is reduced due to the addition of fluxes to silica, and this eventually leads to the degradation of properties. (Berenjian & Whittleston 2017.)

To resolve this problem of degradation, other property modifiers like sodium, magnesium, boron, calcium, and titanium are used to adjust the properties of glass. Colorants are also used to determine the colours of the final product. The change in the colour of glass is a result of the number of iron oxides present in the glass.Colorants like gold and silver change the colour of glass by forming colloids in the glasses. With the melting of raw materials inside the furnace, water and carbon dioxide emission takes place which is the root cause of the formation of bubbles. To remove the bubbles from the melt, fining agents like antimony oxides, arsenic, potassium, and sodium nitrates are included in the raw materials. High temperature and low viscosity are required to raise the gas bubbles to the top of the melt and carefully removed from the melt. Fining is vital in this melting process as it helps in controlling the homogeneity of glass as well as eliminate the bubbles. With the improvement in technology, glass industries involved in large scale production makes use of computers to effectively control the mixture of various materials and the feeding of these mixtures into the furnace. Over the years, oxygen has been used in the process of glass making to improve the quality of glass. Some of the benefits of using oxygen in this process is to reduce pollution, improve the quality of glass, and improve on the effectiveness of the furnace. (Berenjian & Whittleston 2017.)

The forming stage in the manufacturing and viscosity of molten glass gradually alternates due to the change in temperature. The formation process of glass is carried out by controlling the viscosity, which enables molten glass to be formed into flat sheets and filaments. For example, the viscosity of glass increases slowly as the temperature decreases. This different methods of forming glass depends on the applications. (Best Available Techniques (BAT) 2010/75/EU).

In the float process of glass making, a ribbon glass is formed by pouring the molten glass into a bed of molten metal and melted under a controlled temperature. This molten glass then floats on a thin bath of molten metal. The temperature is maintained in the production process at about 1000^{o}C to separate the irregularities to acquire the desired flat shape. Studies have shown that glasses produced using this method of production turns to have a smooth surface, a uniform thickness and does not require any polishing. In the wool process of glass making, the molten glass is removed from the rotating head using the centrifugal spraying method. This rotating head is made up of about 3000 holes. With regards to the diameter of the holes, only fine fiber is produced through the rotating head or spinner. Air is equally provided from above to direct the fiber downwards and eventually reduce the temperature. The binder is mixed as the fibers goes downwards to obtain the desired wool criteria. The quantity of binder to be used is determined by the mechanical properties of the wool. With this method, the thickness of the fiber is gotten from 20-30 µm. (Best Available Techniques (BAT) 2010/75/EU.)

3.1 Different types of sand

The composition of sand greatly depends on the rock source and underlying conditions. The bright white sand which is another type of sand can be found in the tropical and subtropical coastal settings. This white sand is known to be caused by eroded limestone which may comprise of coral and shell fragments. Also, the gypsum sand dunes of white sands national monument in New Mexico is also known for its bright and shiny colour. For example, arkose is a type of sandstone which contains feldspar that is gotten from the weathering and erosion of granitic rock outcrop. The various types of sand contain chlorite, magnetite, and glauconite in variable sizes. Desert sand which is derived from obsidian and volcanic basalts are black in colour and contains a lot of magnetite. Another form of sand is the chlorite-glauconite. This sand is green in colour. Majority of sand which are green in colour is made up of silica sands which are joined with bentonite water mixture. The characteristics of this type of sand is the same with sand gotten from lava which has a high olivine content. Olivine is a solid uniform solution made of fayalite (Fe_2SiO_4) and forsterite (Mg_2SiO_4). The physical characteristics and chemical composition vary as such, the chemical composition of olivine is specified to control the reproducibility of the sand mixture. Despite the uniqueness in its chemical composition, silica is more durable than olivine. (Sandatlas 2018.)

Also, other types of sand which originates from Southern Europe are embedded with iron impurities in the quartz crystals thus they have a profound yellow colour. An example of such sand is sea sand. In some areas, the sand deposits contain resistant minerals, chromite ($FeCr_2O_4$) and a little amount of gemstone. Angular sand that is very refractive and chemical inert has excellent thermal characteristics. Another form of sand which is frequently used in Aluminium silicate (Al_2SiO_5) and it occurs in three forms: audalusite, kynanite and sillimanite. They have a tendency of being disintegrated at high temperatures to form silica and mullite. As such, aluminium silicate is produced by calcining the minerals. Depending on the sintering cycle, silicate can be present as amorphous silica. With the grains highly angular, it enables the materials to have high thermal resistance, low thermal expansion, and high refractories. These materials are greatly used in precision investment foundries. (Toky, 2018.)

3.2 Pre-treatment of silica sand

Most naturally occurring substances serve as vital raw materials for processed commodities and contains impurities due to their exposure to different varieties of contaminants and alternation in climatic conditions. If these pollutants are not removed, they might have adverse and undesired effects on the outcome of the final products. The nature of the silica sand used in the manufacturing of glass has a direct effect on the quality of the final glass product. Silica is purified by acid leaching followed by thermal treatment. (Khalifa, Ezzaouia & Hajji 2014).

With this method, the silica sample is dipped in an acid mixture solution of HCl and HNO_3 with a volume proportion of 2:1 to remove metallic contaminants at the surface of the silica and then properly rinsed with deionized water. This cleaning step is aimed at removing impurities from the silica. After being annealed in an infrared furnace at a temperature of 1000 °C, silica is subjected to an acid leaching under power ultrasound using an acidic solution composed of 5% HF and 4% HCl.The obtained silica is then dissolved in a solution of HF and HCl for 4hrs to completely sock out the remaining contaminants present in the sand. HF is highly chemically compatible with Silica; it removes most of the impurities present while retaining the molecular structure of Silica. The silica is then dried under vacuum in an oven at a temperature of 120 °C. Depending on the type of glass that is being manufactured, the purity of the silica can be improved by repeating this procedure two or three times. (Khalifa, Ezzaouia & Hajji 2014.)

3.2.1 Glass ingredients

Silica is the main ingredient used in the production of glass. White fused quartz primarily composed of $Si0_2$ is used for unique application and is quite rare due to its high glass transition temperature of over 1200^{o}C. Normally, other substances such as addictive, colorants, stabilizers are added to simplify the process and give specific properties to the products; for instance, sodium carbonate is added to reduce the temperature of fusion of glass. However, soda makes glass water soluble, which is usually undesirable calcium oxide generally obtained from limestone, magnesium oxide and aluminium oxide. The resulting glass contains about 70-74% silica by weight and is called soda-lime-glass. Soda lime glass accounts for about 90% of manufactured glass. Most common glass have other ingredients added to change their properties. Lead glass or flint is more brilliant because the increased refractive index causes more reflection and enhances optical dispersion. Adding barium also increases the refractive index. In some industries, thorium oxide is also used to increase the refractive index and was formerly used to manufacture high quality lenses but since its radioactivity, it has been replaced by lanthanum oxide in modern eyeglasses. Another common glass ingredient is the “cullet” (recycled glass). The recycled glass saves on raw materials and energy. However, impurities in the cullet can lead to product and equipment failure. The table below shows a summary of the major ingredients used in the production of different glasses. (Willsey 2016, 34-57.)

TABLE 1. Main ingredients in glass production (Willsey 2016.)

S/N	INGREDIENTS
1	Quartz sand (Silica)
2	Sodium Carbonate (Na_2CO_3)
3	Magnesium Oxide (MgO)
4	Lime (CaO)
5	Sodium Oxide (Na_2O)
6	Cullet (recycled glass)
7	Soda Ash (Na_2O)
8	Feldspar

3.2.2 Material handling

The glass industry makes use of large-scale raw materials. Majority of these materials are either synthesized products or natural occurring. In the production chain, the materials which are mostly used range from coarse materials to finely grind powders, gases, and liquids. The type of gas mostly used include butane, sulphur dioxide, hydrogen, propane, nitrogen, natural gas, and oxygen. These gases are stored and conventionally handled through cylinders, pipelines, and dedicated bulk storage. The glass industry equally makes use of a wide range of liquid materials and those which are carefully handled like strong organic acids and phenol. (Best Available Techniques (BAT) 2010).

These materials are delivered by rail or road haulage and conveyed either directly to silos or stockpiled in bays. Storage bays can be open, partially enclosed, or fully enclosed. Where coarse material is stored in silos, they are usually open, filled and then transferred to the furnace through an enclosed conveyor system. For granular and powdered raw mate rials, they are rather delivered by rail or road tankers and are transferred either pneumatically or mechanically to bulk storage silos. In large continuous processes, the raw materials are transferred to smaller intermediate silos from where they are automatically weighted out to give a precise formulated batch composition. The batch is then mixed and conveyed to furnace area, where it is fed to the furnace through one or more hoppers. Glass industries use different feeder mechanisms; ranging from completely opens systems to fully enclosed screw fed systems. To reduce the quantity of dust when conveying fine particles out of the furnace, a constant percentage of water is maintained in the batch, usually 0-4%. The water content is sometimes introduced as steam at the end of the mixing operation, but the quantity of water added depends on the inherent water content of the raw materials. For instance, in soda-lime glass production, steam is used to maintain the temperature above 37^{o}C and inhibit the batch from drying by the hydration of soda ash. Due to its erosive nature and larger particle size, cullet is handled separately from the primary batch materials and may be fed to the furnace in measured quantities by a separate system. (Best Available Techniques (BAT) 2010.)

4 STRUCTURE OF THE GLASS INDUSTRY

Considering the existence of different varieties, characteristics and usage of glass products, the manufacturing process of glass in general is ambiguous in its interpretation. This is because unique glass products have distinct processes through which they can be produced. However, the manufacture of glass, regardless of the final product, requires four major processing steps that cannot be neglected: batch preparation, melting and refining, forming, and post forming. The production process begins with the selection of raw materials which is the basics for specific glass types. It is equally vital to mix the specific constituents in the right proportion to attain a correct composition of the desired products. The distinct processes in the production process of glass are illustrated in the schematic below. (Lynn, 2007.)

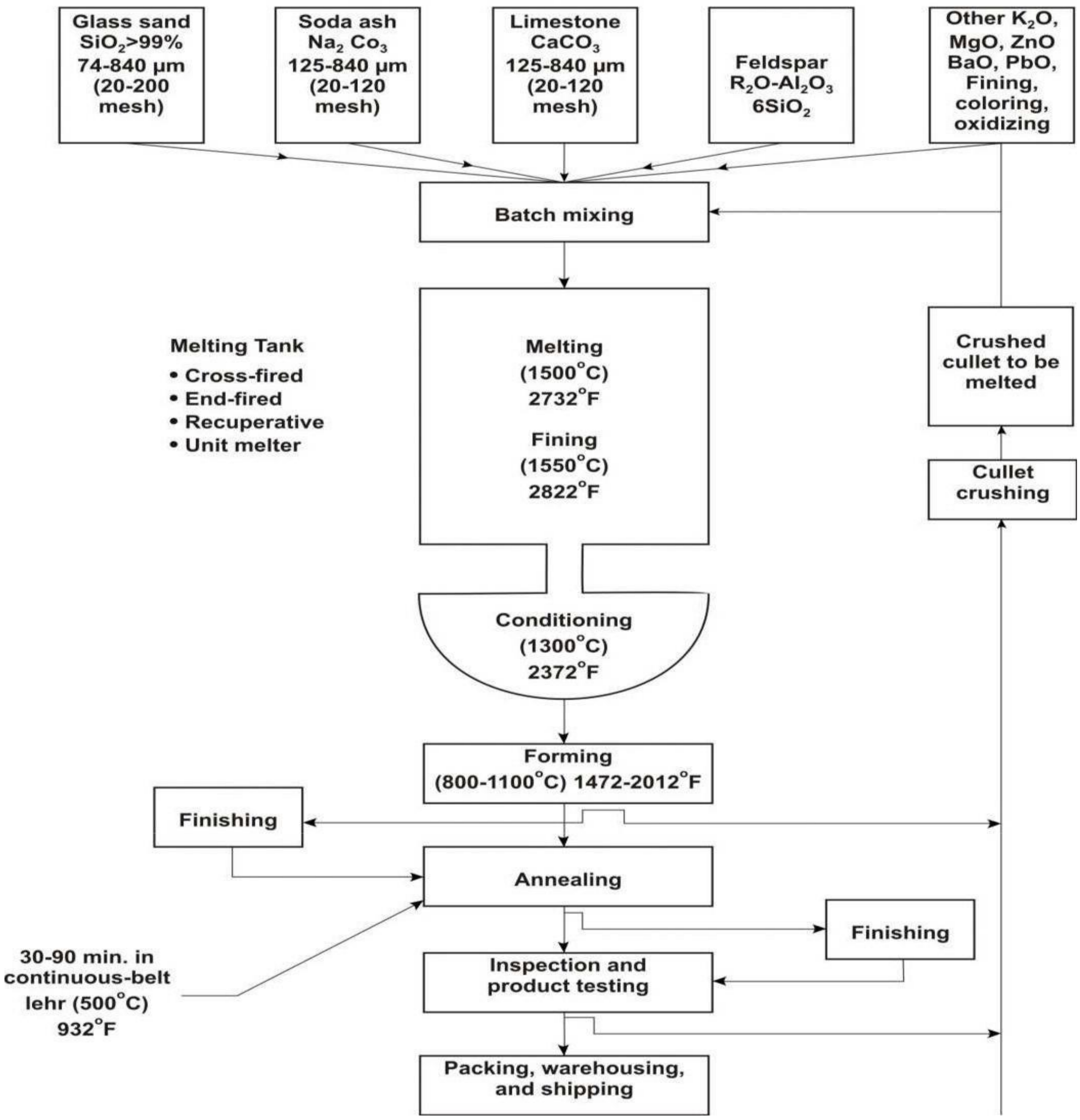

FIGURE 1. Scheme of glass manufacturing (Greenman et al 2013)

4.1 Batch preparation

Although there are many differences in glass products, all glass manufacturing processes begin with the weighing and mixing of dry ingredients to form a batch for the melting furnace. Glass batch, which is the starting material in glass processing can be formulated from various raw materials, some of them are directly mined from the earth crust whereas other are more refined such as the metal oxide powders used. Different chemical compositions can be used to create glass, and each formula applied in its production implicitly affects the mechanical, electrical, chemical, optical, and thermal properties of the final glass product. Generally, glass batch contains formers, fluxes, stabilizers, and sometimes even colorants that are used to form the batch. The main former in all types of glass is silica (SiO_2) in the form of high-quality sand. Other major formers utilized in the manufacturing of glass include feldspar, boric acid as well as ores such as colemanite, rasorite, ulexite. These category of chemicals are predominantly used as a source of boron f or the manufacture of high temperature glass, Pyrex, or fiberglass. Although silica alone can be used to make glass, it has a very high melting point of 1,713°c and is extremely arduous to work with in the liquid state due to its high viscosity. Consequently, fluxes such as sodium carbonate and potassium carbonate are added to lower the temperature enabling the batch to melt. (Lorraine 2016).

Alternatively, the use of lithium compounds like lithium carbonate and lithium alumino silicate as fluxes has been analysed and accepted as good substitute especially in the production of soda-lime glass. Stabilizers on their part are used to make glass more chemically stable, and to keep the finished glass produced from dissolving and crumbling. Most common stabilizers include limestone, alumina, magnesia, and barium carbonate. There are several additives used to colour and impart unique properties to glass such as iron, chromium, cerium, cobalt, and nickel. Another very important raw material also used in glass manufacture is “cullet.” Cullet is recycled glass usually obtained from within the production plants (rejects, trim, waste scrap) and from outside recycling operators. Cullets can constitute between 10-80% of the batch, based on the type of glass manufactured. Most glass manufacturers prefer using in-situ generated cullet because cullet from recyclers can be contaminated thus must be treated before it can be used to manufacture high quality glass like Flat glass. Glass manufacturers use cullet where possible becausoe it is cheaper than virgin materials and requires less energy for the melting process. In addition, as cullet melts, it forms a molten bath that ease the transfer of heat to the other materials in the batch. A typical batch plant showing the different parts and processes during glass production is shown in figure 2 below (Greenman, Ross, Shell, McCracken & Wishnick 2013.)

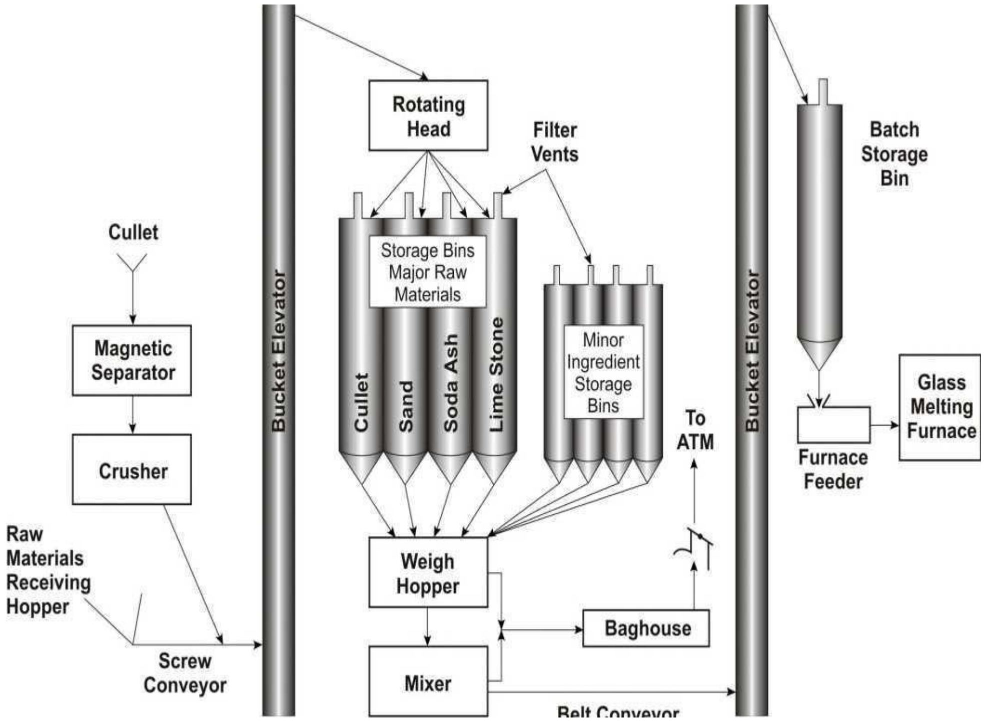

FIGURE 2. Batch plant (Greenman et al 2013)

4.2 Melting and refining

This process is considered as the most important in the glass manufacturing process because it predominantly determines and affects the outcome of the final product. The formation of glasses is principally achieved by melting crystalline materials at extreme temperatures. As the temperature of the molten glass reduces and cools, the atoms fuse into a disordered state rather than a perfect crystal formation. Glass materials remain in this plastic state after cooling, and subsequently do not have a sharp melting or freezing point. The actual melting of glass begins with the transformation of dry ingredients into a uniform molten liquid. First, the well-mixed batch is channelled to the melting furnace where it is heated to high temperatures ranging from 870 ºC-1700 ºC. During the heating process, the batch undergoes a series chemical reactions in specific order, melting, dissolution, volatilization, and redox reactions, respectively. At about 538°C, ingredients with a higher melting point in the batch dissolve. The dissolution process is accelerated by adding metal fluxes like sodium ash and sodium potash. At this point, molten sodium meta-silicate deposits on the silica grains. As heating continues to higher temperatures of 705 °C, more chemical reactions occur, and at about 760°C a liquid eutectic mixture is formed between the sodium silicate and silica. At this point, the alkaline earth carbonates present in limestone ($CaCO_3$) begins to break down and flux with the silica to yield molten eutectic glasses. At this point, the glass product begins to take shape. (Ross, Greenman, Gridley, Philip, & Derek 2002.)

Refining also known as fining, is a physical and chemical process that takes place in the melting chamber. This process standardizes the batch and smelted glass and equally eliminates bubbles from them. This section of the furnace is usually separated from the primary melting section by a bridge wall and the wall opening that the glass passes through is called a throat. Refining helps to remove gaseous seeds and bubbles and depending on the glass type, they may contain oxygen, water, nitrogen, or carbon dioxide. In general, the duration of the refining process depends on the type and class of the product. (Ross et al 2002.)

Homogenizing takes place in the melting chamber. During the melting process of glass, it might encounter numerous alterations such as instability in the refractive index and alterations of expansion coefficient density that impacts the optical and mechanical qualities of glass. Glass cannot be homogeneous if it contains so many grains and seeds. Its homogeneity depends on factors such as temperature, mixing characteristics, batch composition and time taken for the process. Usually, the extent of the uniformity achieved is based on the desired glass features and economical costs. Homogenizing takes place in the melting chamber and is completed when the glass quality meets the desired requirements. After homogenization, glass product is subjected to thermic checks. Normally, this process begins instantly after the top mean temperature of the glass melt is attained in the tank, but its starting point solely depends on the type of furnace used and its operating mode. Stable thermic condition is catalysed by using bubblers, stabilizing the gas, and blending the feeders. After this, cooling is performed to establish the operating temperature for forming. When glass has attained the required degree of thermal stability, it is channelled through forehearth, an insulated refractory channel with burners and air-cooling system. Thermal conditioning stabilizes glass and adjust its temperature thus it mandatory to maintain the stable temperature of glass for the forming process. The different categories of glass ingredients that are used in the primary stages of the process are shown in table 2 below. (Ross et al 2002.)

TABLE 2: Glass raw materials. (Best Available Techniques (BAT) 2010)

Formers	Silica (SiO_2). Boric acid (B_2O_3). Lead Oxide (PbO). Feldspar
Fluxes	Sodium Ash ($Na_2 CO_3$) Sodium Potash (K_2O) Lithium Carbonate (Li_2CO_3)
Stabilizers	Limestone ($CaCO_3$, CaO). Alumina (Al_2O_3) Magnesia (MgO) Zinc Oxide Barium Carbonate

4.3 Forming

Forming is phase were the molten glass formed at the furnace begins its transfiguration into a final shape. As it migrates from the melting tank into the forming machine, it appears like a thick red-orange syrup. This process proceeds quite fast because glass turns rigid when cool if the transformation process is not complete. There are numerous forming processes that can be applied in a glass industry; molten glass could be drawn, rolled, cast, molded, or pressed into different fibers. However, irrespective of the technique employed, glass forming begins with the flow of glass from the furnace where it has already been cooled to convenient temperatures for molding glass. At this stage, the forming process entirely depends on the desired finished product. The most common technique used in glass formation is the float process. Here, molten glass flows horizontally into a pool of molten tin about 58m long and 10m wide. As the hot glass passes over the molten tin it conforms to the perfect flatness of the tin surface and develops a uniform thickness without distortion. Alternatively, the molten glass is channelled through a wider aperture composed of non- reactive materials. This process is rather advantageous because it automatically generates a velocity that is more suitable for the final glass ribbon. (Greenman et al 2013.)

At the end of the chamber a continuous glass is drawn from the spreading glass. Glass that contains pollutants with refractory is pushed to the outside of the ribbon where it can be removed, scrapped, and thrown away. Through the float chamber, different temperature zones permit the heating, fire-polishing, stretching, and forming of the glass ribbon. The tin bath formed is maintained under a coat of inert nitrogen gas to prevent oxidation. In this chamber, the thickness of the glass is inversely proportional to the amount of heat required that is, the thicker the glass is, the less heating is required. Glass that emanates from the tin bath is at 604 ºC and then it is conveyed to finishing processes were the final product with its unique features are formed and shaped. The thickness of the glass leaving the bath usually ranges from about 0.078 to 0.78 inches. (Greenman et al 2013.)

4.4 Post forming and finishing operations.

After being formed into its final shape, glass products may be subjected to processes and alloying that gives it final features depending on its end use or as prescribed in the technical section of the manufacturers script. The processes include drying, tempering, annealing, and laminating. These distinct operations are introduced at different stages during the manufacturing processes, and all might not necessarily be executed on the same piece of glass product. Some glass products after being formed during the forming stage of the process are set but simply need to be laminated to shield them from potential damage whereas the durability and strength of other glass products needs to be amplified thus is subjected to tempering and annealing. (ACI New Zealand Glass Manufacturer, 2018.)

4.4.1 Annealing and tempering

The annealing process is aimed at cooling manufactured glass to its ambient temperature. To reduce the dangers of damaging the manufactured product, it is not advisable to put hot glass in low temperature places. This is especially very necessary for big and thick glass products to have a uniform and slow cooling. Annealing is used for all glass types especially flat and container glasses to provide a conducive strain rate and facilitate cutting. Since all products have their distinguish shapes and thickness, it is sometimes difficult to keep a uniform temperature. First, the glass is kept at a constant temperature with special annealing window and then gently cooled to ambient conditions. Tempering is another technique that is used to impart strength to glass and can be achieved by heating the annealed glass to the temperature of the softening and then cooling the product to the ambient air. This process enables a uniform temperature gradient over the surface and stress distribution of the glass and can have numerous conveyance systems; in-line system, gas/air float, tong-held and roller hearth. Other techniques employed during the tempering process include lamination and mechanical strength. (Ross et al 2002.)

4.4.2 Lamination and mechanical impact

Laminating entails placing thick microfilms between two or more glass sheets thereby shielding the glass product from destruction. This scheme of production is used in most glass manufactories especially automotive and architectural applications and the annealing process precedes lamination. The operation usually consists of three steps; First, a plasticized poly vinyl butyral resin is used as glue material. Then trapped air is excluded and the final step requires placing the glass product in an autoclave operating at 130Psi and a temperature of 150 ^{o}C. To obtain the final desired shape of the glass product, cutting and drilling operations are needed. A tube of meek steel and other soft metal is used to make gaps in the glass. Cutting can be done either mechanically or thermally. The mechanical technique is mostly utilized in most glass production factories and it is performed by using glass-cutting steel wheel; a sharp of flame and jet of water where the product is first subjected to extreme heat and then cooled with water. When the glass product is finally ready, it is thoroughly inspected before being packaged. After this procedure, the product is conveyed to the packaging department where they are well wrapped and tied. The undesired products and those that were stripped off at the inspection zone are rechannelled as Cullets to the batch preparation stage. (Greenman et al 2013.)

5 TYPES OF COMMERCIAL GLASSES

Glass is a product of variable composition that is mostly expressed in terms of the relative composition of oxides (SiO_2 , Na_2 , B_2O_5, CaO) present in it. There exist different types of products, equipment and materials that are composed of glass. On the same line, there are many different types of glass. Although these glasses have similar start up techniques applied in their manufacturing process, they mostly differ in terms of their chemical makeup and the method applied to manufacture them. Glasses are universally categorised based on their chemical composition. Since the composition of glass can differ indefinitely, the most widely utilized classification is based on their chemical composition, which gives rise to four major groups: Soda-lime glass, borosilicate glass, phosphate glass and special glass. Nevertheless, in commercial glass manufacturing they may be classified into three main groups: Soda-lime glass, Borosilicate glass and Phosphate glasses. This report will specifically focus on these 3 main categories of commercial glasses. The primary components, features, and applications of different types of commercial glasses is highlighted in table 3 below. (Martin 2006.)

TABLE 3. Primary components, characteristics, and applications of type of commercial glasses (Adapted from Kopglass, 2015)

Glass Type	Primary Components	Linear Thermal Expansion	Thermal Shock Resistance	Chemical Resistance	Applications
Borosilicate	SiO_2, B_2O_3	-30-60 x 10^{-7}/°C	Average - High	High	• Industrial equipment • Exterior lighting • Laboratory and kitchen glassware
Soda-lime silicate	SiO_2, Na_2O, CaO	-80-100 x 10^{-7}/°C	Low	Average	• Food and beverage containers • Windows • Lamp envelopes
Phosphates	P_2O_5	-90-110 x 10^{-7}/°C	Low	Low, except high resistance to hydrofluoric acid	• Bone scaffolds • Optical fibers • Heat absorbers

5.1 Soda lime glass

Soda lime glass otherwise known as soda lime silica glass is the most common glass manufactured worldwide. More than 90% of glasses produced round the world are represented by compositions of soda-lime silica glass. It is typically composed of 70% SiO_2 , 10% CaO and 15% Na_2O with small amounts of other compounds specifically oxides to make up its chemical composition. The calcium oxide is specifically used to lower the temperature as such facilitate the melting of silica while Sodium oxide acts as a stabilizer. In its chemical dissociation during the process, each Na ion is tetrahedrally attached to an Oxygen atom thereby decreasing the strength of the covalent bonds. This reduces the thickness and viscosity of the melt so that soda glass easily works at lower temperatures. The prevalence of this type of glass is linked with numerous factors; it is inexpensive, chemically stable, the melting process can be induced to take place at a lower temperature, and it is quite resilient i.e., it can conveniently be softened many times possible to suit the shape and design of a specific desired product. These unique characteristics explains why soda lime glass is used to manufacture a wide array of products such as light bulbs, windowpanes, bottles, vials. (Martin 2006.)

5.2 Borosilicate glass

Borosilicate glass typically contains 70-80% silica, 7-13% Boron oxide, 4-8% sodium oxide, and 2-8% aluminium oxide as glass network formers (Bauccio & Pfaender 1996). The percentage composition of Boron oxide in Borosilicate glass differs accordingly and its chemical constituent allows a very low coefficient of thermal expansion thus they are extremely resistant to high temperatures. Glass containing 7-13% B_2O_3 is known as low-borate borosilicate glass and is predominantly used to produce chemical equipment, lamps, and tube envelopes while glass containing 15-25% B_2O_3 is known as high-borate borosilicate glass otherwise also called leachable alkali-borosilicate glass. This glass can be further treated to manufacture-controlled pore glass (CPG) which is widely used as a stationary media in chromatography. The high boron oxide content and refined secondary phase segregation of its silica content enhances the chemical strength of these glasses thus high borate borosilicate glass are more chemically resistant than low borate borosilicate glass. (Hasanuzzaman 2016.)

5.2.2 Phosphate glass

Contrary to soda lime and borosilicate glass that utilized siO_2 and $B_2 O_5$ as primary glass former chemicals, Phosphate glass uses phosphorus pentaoxide (P_2O_5) as main ingredient. Their composition and chemical make-up is made more resistant to environmental attacks and corrosion for the specific applications. Generally, phosphate glasses are both scientifically and technological vital materials because they offer specific physical properties such as high thermal expansion coefficients, high electrical conductivity, low melting, and softening temperatures, good ultraviolet and transmission and optical features. These unique characteristics of phosphate glasses make them useful options for fast ion conducting materials and are more suited for doping with various colorants, transition metals ions and rare earth oxides. However, phosphate glasses have relatively poor chemical durability. Studies carried out have shown that the physical properties and chemical strength of phosphate glasses can be enhanced by adding different varieties of metal oxides of high valence cations such as $Al^{3+,}$ Bi^{3+}, Ti^{4+} as these oxides form stable cross-linked bonds. It has equally been reported that Bi_2O_3 occupies specific network forming and network modifying positions in oxide glasses thus the physical properties of glasses containing Bi_2O_3 exhibit discontinuous changes in their intrinsic structures. Due to their divert applications and usage in the field of glass ceramics, thermal and mechanical sensors, phosphate glasses have attracted a world-wide attention and publicity. (Sang, Young, Nam, Cha & Bong 2016, 54-81.) Although the physical appearance of most manufactured glasses look similar, their chemical compositions is different and usually depends on the general requirements of the final product. The chemical make-up of all types of glasses is distinct illustrated in table 4 below.

TABLE 4. Chemical composition of manufactured glass (Adapted from Best Available technique 2010)

OXIDE	BOROSILICATE GLASS	SODA-LIME GLASS	NEUTRAL GLASS
SiO_2	80.6% by weight	70% by weight	68% by weight
$Na_2O + K_2O$	4% by weight	14%by weight	17% by weight
Al_2O_3	2.4% by weight	4% by weight	0.6%By weight
B_2O_3	13% by weight	1% by weight	0.1% by weight
Cao + MgO	-	7% by weight	6% by weight
BaO	-	3% by weight	4% by weight

5.2.3 Importance of silica sand in glass production

Silica sand otherwise known as white or industrial sand is quartz that has been broken down into minute granules through the work of water and wind. They contain a very high proportion of Silica (SiO_2) and are used for numerous applications not essentially as construction aggregates. They are produced from loosely combined sand deposits and by squashing cemented sandstones. Unlike other types of sand, silica is highly rated for their natural, physical, and chemical features. They have a very high composition of Silica of more than 95%, have narrow grain size deposition ranging from 0.1-2mm, have an inherent colour composition of 0.025%-0.04% and most importantly, they have very low levels of deleterious contaminants (clay, Iron oxides, refractory minerals).For most applications, silica sand should meet up with very closely defined parameters and exhibit high quality. Though the production of glass requires different materials and ingredients such as limestone, felspar, calcium oxide, magnesium oxide its congenital characteristics enables silica to resist high temperatures and maintains a consistent appearance as a finished product. Silica represents more than 70% of the final product. As mentioned earlier, silica sand is not just vital for the glass industry to supply construction materials; it is also used in container glass for foods, beverages, and tableware. In its demolished form, ground silica is needed to produce fiberglass insulation and reinforcing glass fibers. Test tubes, televisions, computer CRT monitors, incandescent and fluorescent lamps are products manufactured by the glass industry using industrial sand. It can therefore be deduced that silica sand is a vital component not just for the glass industry but equally for the society because several products are equally dependent on the glass industry to supply them ingredients and start up materials for their product which is composed of Silica. (British Geological Survey 2020.)

FIGURE 3. Silica sand (Adapted from United Minechem Corporation, 2014)

5.2.4 Availability of silica sand for future glass production

Water and Sand are widely considered and classified as the most plentiful congenital resources on Earth. In fact, according to the recent classification made by the Norwegian University of Science and Technology, sand is the second most abundant natural resource that exist on earth. (Päivi ,2008). sand and gravel have surpassed fossil fuel and are presently the most extracted minerals on earth. They are widely used in many areas, in the construction of houses, buildings, roads, windshields, glasses, aircrafts, electronic gadgets, fertilizer filler, aquariums, cleaning oil spills, filtration of water. Other important uses of silica sand include the production of silica flour for use as fillers in paints, plastics, glass fiber manufacture and rubber sealant were colour is vital to retain the consistency of the product. Silica sand is also used as a vital component of autoclaved aerated concrete where it is included as a fine milled powder as an alternative to pulverized Fuel Ash (PFA) to give density and strength to the blocks. It seems logical to conclude that a substance that is abundant and used in most human activities is a vital component in human life and the ecosystem. Although not all species of this natural resource are of equal importance to man, it exists in all parts of the world. Sand can be found in beds, banks and flood plains of rivers, lakes, seashores and even deserts thus seems essentially limitless. (Päivi 2008.)

Due to the different applications and sectors in which sand is used, its demand is extremely high. Foundry factories that are established to produce metal casting equally make use of silica sand to process their products. In addition to the glass and foundry factories, Silica sand is also used as a main ingredient in numerous industries, namely oil and gas, paints and coatings, ceramics, and refractories, However, being the second most abundant natural mineral on earth it seems sand is infinite and will always be available. Scientists and researchers are concerned with the over utilization of this natural resource and now the world is facing a shortage of sand. People will wonder how we can possibly be running low on a substance basically found in every country on earth and that seem essentially limitless According to Pascal Peruzzi a researcher with the United Nations Research Programme, we cannot extract 50billion tonnes per year of any material without causing huge negative impacts on the planet and ecosystem. The main driver to the shortage of sand is urbanization, economic growth and over population. The world population is increasing at a very rapid rate. Increase in population obliquely suggests that more habitat, infrastructures, and space needs to be built and created to accommodate this new coming generations. The setting up of these structures makes use of huge quantities of sand. Rural Exodus also play a vital role in this crisis, more and more people especially in developing countries migrate to cities in search of jobs and better opportunities. This quest for an improved life creates an emergency for accommodation and space to host these people. Also, some countries with smaller territorial space and large population are constrained to engage in massive importation of sand. For instance, during the past 40year Singapore has added 50sq miles of land out of its territory solely from sand imported from neighboring countries. (Beiser 2019).

According to the report release in 2013 by Freedonia Group- a Cleveland-based industry market research firm, it shows that the global demand for industrial sand is forecast to advance by 4.8% to 291 million metric tons in 2018.With this alarming demand, the shortage of sand in the future is of logical concern. Table 5 below shows that this approximation was appropriate. (Beiser 2019)

TABLE 5. Global estimate on rise in demand for industrial sand (Adapted from Freedonia Group 2014)

WORLD INDUSTRIAL SILICA SAND DEMAND
(million metric tons)

Item	2008	2013	2018	% Annual Growth 2008-2013	2013-2018
Silica Sand Demand	169.7	222.5	291.0	5.6	5.5
North America	36.5	61.1	87.1	10.8	7.3
Western Europe	27.9	23.2	24.3	-3.6	0.9
Asia/Pacific	72.0	102.9	138.0	7.4	6.1
Central & South America	8.6	9.4	10.9	1.9	2.9
Eastern Europe	13.2	13.2	15.4	- -	3.1
Africa/Mideast	11.5	12.7	15.4	2.1	3.9

6 FACTORS AFFECTING THE STRENGTH OF GLASS

The widespread application of glass products in different sectors is possible due to its strength and hardness coupled with its transparency and chemical defiance. Modern residential and commercial buildings, sports complexes, transport facilities, home equipment and other devices requires glass with high durability thus fragile and weak glass product restricts its use. However, different conditions during its manufacturing, cutting, coating, storage, transportation, and environmental effects can drastically diminish the strength of glass. To minimize these factors that can reduce the toughness of glass and develop techniques that enhances it hardness is very important in glassmaking. The strength of glass is characterized by its ability to resist fracture when exposed to external loads and is highly determined by the strength of its chemical bonds (Nina & Vladimir 2015.).The following factors affect the strength of glass; elements on the mechanism of breakage, defectiveness on its surface, influence on technological factors and impacts on the environment.

6.1 Elements on the mechanism of breakage

The destruction of glass is quite a complex process, the development of which is based on the structure, the nature of the stress and loading rate, parameters of defects, and the temperature and composition of the environment. Distortion and fracture of glass are the results of the reactions that occur at the atomic and molecular levels of the structure. According to Cluster´s approach, glass can be regarded as a medium containing rigid and relatively weak bonds (See figure 1 below). If such a medium is subjected to heavy load, the burden is evenly distributed to all bonds in the lattice structure of the glass. As time elapses, the force and momentum of the load surpasses the strength of the bond in the glass structure resulting in cracking and brittle fracture. This is illustrated in figure 3 below (Nina & Vladimir 2015.)

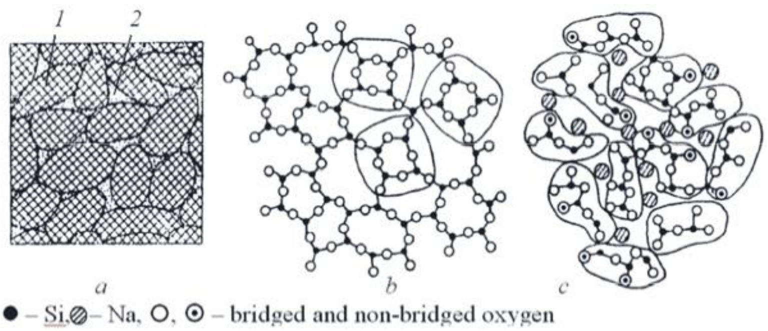

FIGURE 3. Glass structure showing the different bonds. (Adapted from Nina & Vladimir 2015)

6.2 Defectiveness on its surface

One very important factor that determines the strength of glass is the state of its surface. Minor scratches, cracks, inclusions act as stress concentrators under load and can lead to its destruction. In most cases, cracks are generated during the forming and annealing stages of production. Thus, when glass is formed, a thin surface layer of glass rapidly solidifies while the volume remain in the ductile state. Subjected to the weight of the forming machines and due to different thermal expansion of the glass in the volume and on its surface, the surface layer gets minor fractures. Also, the nature of the glass edges determined by the way it was cut has a significant consequence on the strength of the glass and is of paramount importance in upgrading the reliability of the products. Generally, cuts are known to averagely diminish the mechanical strength by about 60% due to the formation of minor cracks in different directions. The destructive layer on the surface is a network of microcracks; it depends on the speed of formation and has an abyss of 10-60 microns. (Nina & Vladimir 2015). The table 6 shows the impact of surface conditions on the strength of glass.

TABLE 6. Influence of surface conditions on the strength of glass (Adapted from Zhang & Mo 2017)

The Surface condition	**Strength, GPa**
Untouched, melted	0.9-1.0
After forming	0.22-0.28
Polished fine Abrasive	0.13-0.14
Polished largest Abrasive	0.035-0-041

6.3 The influence of technological factors

Deficiency on the surface of glass is determined by the parameters of the process; the speed of formation, performance of glass furnace, annealing process, mechanical strengthening, temperature conditions during forming. Other liquids and materials used in production such as liquefied tin and the protective layer in the float bath, the metals molds and lubricant in the designing of hollow products, the transit rolls affect the strength of the finished products. It is important to note that the strength of glass is unevenly distributed across the width thus increasing the productivity of the line decreases the strength and homogeneity of the product. When glass products are compressed, contacts with the cold form leads to the elevated surface deformities due to the prompt solidification of the thin layer. As temperature increases, the mold surface defect attenuates and the strength of the glass increases. Approximately 40% of glasses used in construction is lost while shipping, storage, and during installation. This is not just because of the mechanical damages but the corrosion processes as well. Generally, due to the innovative improvements, the strength of glass can be enhanced up to 70% (Zhang & Mo 2017.)

6.4 Influence on the environment

The impact the surrounding has on the strength of glass depends on the characteristics of the medium, temperature, the time of contact with the environment and the magnitude and duration of the stress. In terms of the natural contamination of the glass surface, there is a very substantial loss of strength. Wind bombardment of small particles of dirts, sand, salt creates diminutive craters that retain moisture. This moisture later condenses on the surface of the glass thereby weakening its internal strengths because of the dissociation of its bonds. A considerable loss in strength is witnessed at high humidity which is facilitated by the development of new microcracks. Thus, if the strength of glass in air is -0.053Gpa, the strength of this same glass in water is 0. 043GPa.From this, it can be noticed that the strength of glass is reduced under the influence of moisture due to the adsorption of water. (Zhang & Mo 2017).

7 ENVIRONMENTAL ISSUES ASSOCIATED WITH GLASS PRODUCTION

Over the last decade, glass industries have made significant efforts and advances to ensure that their processes and production patterns do not jeopardize the wellbeing of the environment. With the close attention that is given to the welfare of the environment and the ecosystem worldwide, protection acts, policies and laws have been put in place so that glass manufacturing factories can reduce and check the amount of pollution generated in production, operation and raw materials handling processes so that the production of their commodities do not release harmful and unwanted substances to the environment. Energy is mainly consumed for the control of particulates as well as volatile emissions of toxic contaminants during the different stages of production. Glass manufacturing factories are faced with three extensive issues related to the environment: emissions to the air, wastewater, and solid waste. (European Commission, 2001).

7.1 Emissions to the air

The glass manufacturing process is a high- temperature, energy-intensive activity that results from the release of waste products (such as sulphur dioxide, carbon dioxide and nitrogen oxides) during combustion and the high-temperature oxidation of atmospheric nitrogen. During glass manufacturing, the melting furnace accounts for more than 80% of the total contaminants emitted into the atmosphere in the entire glass production facility. Most of the pollutants generated and release originate from the container press and blow machines due to contact between the molten glass and the equipment lubricants. The manufacturing of specific glass types such as flat glass, container glass and artistic glass equally generate emissions related to burning in the annealing process where the glass product is maintained at 500-550°C in a controlled cooling process in the annealing oven. (European Commission, 2001).

Particulate matter are significant contaminants released by glass manufacturing industries. Irrespective of the final product obtained, all glass manufacturing factories makes use of dusty raw materials. The storage, mixing and coagulation of these raw materials are common activities carried out in glass industries thus dust emissions are expected results of raw material handling, storage, mixing and transportation. Particulates generated by these processes are more unrefined than those emitted from the hot processes with smaller particle sizes where the smaller ones readily amalgamate with the larger ones. The main sources of particulate matter emissions to the atmosphere originating from the melting process comes from the combination of volatile compounds from the batch and melt with Sulphur oxides to yield substances that condense in furnace waste gases, the transportation of the material to the batch and the burning of fossil fuels. (Greenman, 2013).

7.2 Solid waste

Generally, most activities in the glass industries produce relatively low levels of solid waste. Most of the activities within the factory do not have considerable inherent waste product streams and yield low levels of solid waste. The primary process deposits are unutilized raw materials, waste glass that has not been transformed into the product, and diminished product. The little waste generated predominantly comes from the shipping areas, defective products, and failed parts of the furnace. Waste refractories and dust are equally collected from the alleviation chimneys of the process plant. These solid wastes are easily identified, segregated, and channeled to waste deposits using clean-up and maintenance innovations at the receiving areas of the raw materials. larger factories have coordinated maintenance for identifying, cleaning, and recycling of potential cullet materials and they constantly replenish refractory surfaces. Presently, the scope of waste recycling is gradually upgrading as financial incentives are developed. (Integrated Pollution Prevention and Control, 2001.)

7.3 Wastewater

During the glass manufacturing process, the most considerable water use occurs during washing, cooling and during cullet separation and grinding. Majority of the aqueous emissions usually consist of contact cooling water system purges, cleaning waters and surface water runoffs. Specifically, the amount of liquid effluents released by glass manufacturers are quite negligible in comparison with other industrial sectors and are unique to specific processes. The quantity of liquid discharged can be affected by glass solids, soluble glass making materials and other organic compounds caused by the lubricating oil utilized in the cutting process and treatment of chemicals for the cooling water equipment. Irrespective of the minute quantity of wastewater generated in manufacturing factories, its negative impacts on the environment and ecosystem cannot be underestimated. (Integrated Pollution Prevention and Control, 2001.) The figure 4 shows the schematic of water distribution in glass manufacturing factories.

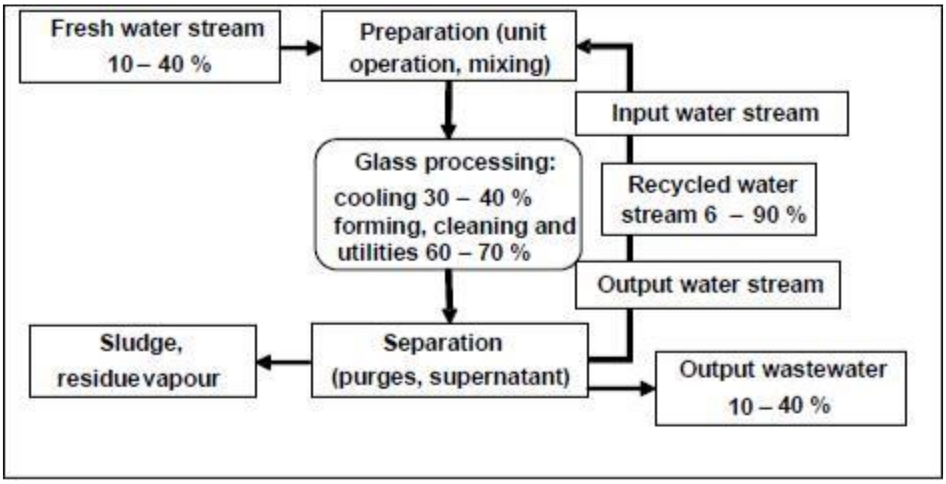

FIGURE 4. The scheme of water distribution at glassmaking plant (Greenman et al 2013)

8 DISCUSSION AND CONCLUSION

Although there are different sand types that exist and can be used for diverse purposes, silica sand has emerged to be the most demanded and widely used sand type in the construction of glasses and other incorporated products that constitute of glass. It is equally the preferred sand type used by other factories. Its natural state and artificial purification techniques employed specifically the acid leaching followed by thermal treatment explained in the pretreatment technique section to enhance it purity further demonstrates its importance in glass manufacturing factories. As demonstrated in this thesis report about the shortage and unavailability of sand in the future and looking at its diverse use in the production and alloying with other important wares, it is practical to ascertain as illustrated in the data that the demand for silica sand will continue to increase in the future and will be the most affected sand type to experience the crisis of shortage.

Especially in the context of glass production and other related accessories, the demand for silica sand is so intense that riverbeds and beaches are being stripped bare to extract this natural resource. This has negative consequences such as erosion in rivers, alteration in the PH level of water, and equally endangers marine fisheries and biodiversity. Although silica is used to manufacture numerous products that are important, its widespread exploitation without concern about the detrimental environmental impact is now a major worldwide sustainability challenge. With the problem of shortage and negative environmental impacts caused by the over exploitation of Silica sand, it is vital to think about how different sand types can be used to manufacture products. For instance, desert sand is plentiful but unfortunately cannot be used because it is eroded by wind rather than water so they are too smooth and rounded and cannot form stable concrete. A good alternative can be sea sand, but it must first be washed and treated.

To mitigate and avoid this problem, the usage of manufactured sand should be encouraged. Luckily, sand can be manufactured mechanically, and the raw material used for this purpose originate from bedrock and is produced in the same way sand is formed naturally. The rocks are squashed and grinded into smaller pieces using different types of crushers to meet the unique requirements of the sand needed. Manufactured sand is as uniform as natural silica and is more advantageous when it comes to concrete production because a lesser quantity of it is needed in the concrete mix to fill the void volumes between particles. Although the mechanical production of sand consumes more energy, production can be done in-situ which reduces transportation costs and prevents negative environmental impacts. By combining the different crushing and screening innovations that exist, these rocks can as well be reprocessed and transformed to high-quality and high-value products that meet the same requirement as natural silica. Also, in developed market like the EU and U.S, the use of recycled materials (Cullets) is highly utilized. If more mechanical sand is produced and other continents embrace the idea of using more of cullet in their processes, the over dependence on silica sand will be minimized.

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