Lecture 2.2: Glass Processing - I

Glass melting

Glass can be made by variety of methods, but in most cases, it is produced by melting raw materials at an elevated temperature. This process involves raw materials selection, weighing, mixing of components in appropriate proportion and removal of impurities to get a homogeneous melt. Large scale commercial melting takes place in refractory tanks which are further connected to series of glass forming machines. The melting of batch components takes place in furnaces. The selection of furnace depends upon the quantity and type of glass being produced. Most of the furnaces are made up of refractory blocks which can work at temperatures more than 1500ºC. The different types of furnaces commonly used are unit melter, recuperative melter, electric melter and regenerative furnace. The batch materials to manufacture glass can be divided into following five categories according to their role in the process: glass former, flux, modifier, colorant and fining agent. Glass formers are one of the most important components present in any glass. Silica (SiO₂), boric oxide (B₂O₃) and phosphoric oxide (P₂O₅) are the most common type of glass formers present in oxide glass. The use of silica glass is wide but melting temperature of silica is too high (1600-1725ºC). To reduce the processing temperature of silica, different types of flux such as Na₂O and PbO can be used. The addition of fluxes to silica reduces the overall cost of glass processing but results in degradation of properties. To overcome this problem, different property modifiers or intermediates such as boron, sodium, magnesium, titanium, and calcium can be used to modify the properties of glass. Colorants are used to control the color in the final glass. The amount of iron oxides (impurities) present in the glass results in unintentional change in color of glass. The other types of colorants used are gold and silver. These types of colorants change glass color by forming colloids in glasses. Finally, fining agents such as arsenic, antimony oxides, potassium and sodium nitrates are added to raw materials to remove bubbles from the melt. As the raw materials melt and react inside the furnace, carbon dioxide and water emission takes place which causes formation of bubbles. The high temperature and low viscosity is maintained to raise the gas bubbles at the upper surface of the melt and hence removed from the melt. Fining is important because it controls the homogeneity of glass by eliminating bubbles. Batch particles size and their mixing in proper proportion are other factors that provide homogeneity in glass structure.

Nowadays, large scale production of glass industries uses computers to control mixing of different constituents and feeding of mixture into the furnace. In recent years, oxygen is typically
used in glass making to enhance the combustion of glass. The benefits of using oxygen are improved furnace effectiveness, reduced pollution, good quality glass and longer furnace life.

**Glass forming**

Glass forming is an intermediate stage in glass manufacturing process. It comes in between glass melting and annealing. Manufacturing of almost all commercial glass comprises of different stages. The stages of glass manufacturing are illustrated in Figure 1.

![Figure 1. Schematic of typical glass manufacturing process.](image)

In forming stage of glass manufacturing, viscosity of molten glass changes gradually with temperature. Glass forming permits molten glass to be shaped into flat sheets and filaments by controlling the viscosity. For example, viscosity of the glass must increase slowly as the temperature drops to produce full lead crystal and the viscosity of the glass must increase rapidly as the temperature drops to manufacture glass fiber. Depending upon the applications, there are different processes of forming the glass. The most common type of glass forming process can be categorized as:

**Flat glass**

Flat glass, sheet glass, or plate glass is made by two processes. The processes are *float glass process* and *rolled glass process*. Both of these processes are continuous method. Thickness of the glass plate formed by these processes ranges from 0.8 to 10 mm.

In *float glass process* (Figure 2), a ribbon of glass is made by pouring molten glass from the furnace to a bed of molten metal such as tin, lead and low melting point alloys under controlled atmosphere. The molten glass floats on a thin bath of molten metal and then moves through the temperature-controlled kiln (also known as *Lehr*) and solidifies. The temperature of glass is maintained at 1000°C for a long period of time to separate irregularities and to get the desired flat
surface. Glass produced by this technique has uniform thickness, smooth surface and does not require any further grinding and polishing.

In the **drawing or rolling process** (Figure 3), the continuous stream of molten glass from a furnace passes through a pair of water cooled rollers. Generally, this process is used to make *patterned glass* and *wired glass*. The **patterned glass** is made by passing the glass through the rollers at a temperature of 1050ºC. This type of glass is made in a single pass process. Gap between the rollers are adjusted to get the desired thickness of flat-sheet glass. Similarly, *wired glass* is made by meshing steel wire into molten glass by rolling process. It is used for making low cost fire resistant glass which automatically breaks at high temperatures.

**Glass fibers**

Fiberglass is available in two types: *continuous glass fiber* and *short glass fiber (glass wool)*. The first one is used in fabrication of composite materials and latter one is used for thermal insulation.
Continuous glass fiber is produced by drawing molten glass through multiple orifices. The speed during drawing can be up to 500 m/s. Fibers of small diameter (2 µm) can be produced by this process. The process is schematically shown in Figure 4 (a).

In glass wool process (Figure 4 (b)), the molten glass is ejected from a rotating head by centrifugal spraying process. The rotating head or spinner cup contains more than 2000 holes. Since the holes diameter of spinner is very small, only fine fiber is formed. Air is supplied from the top to direct the fiber downward and to reduce the temperature. As the fibers descend, the binder is mixed to achieve the required wool criteria. The amount of binder decides the mechanical properties of wool. In this process, the diameter of the fiber can be achieved from 20-30 µm.

Figure 4. Glass fiber processing: (a) continuous glass filament process; (b) glass wool process.

Glass tubing

In this process, molten glass flows around a rotating hollow cone-shaped or cylindrical mandrel through which air is supplied continuously to avoid the collapsing of glass tube while the glass is drawn out by set of rollers. The temperature and flow rate of blown air determine the diameter and thickness of the glass tube. The process is shown in Figure 5.
**Figure 5. Continuous glass tubing process.**

**Toughened or tempered glass**

Glass can fracture due to stress concentration. To avoid the fracture of glass, local high compressive stresses are induced near the surfaces. This is done by thermal toughening of glass. Initially, the glass plate is heated to 650°C after which the outer surface is rapidly cooled by air blasts. Due to which thin compressive layer is created at the outer surface and the center of the glass becomes the region of tensile stresses. This causes the self-equilibrium. The glasses used in glazed door and making tabletops are made by this process and is termed as toughened or safety glass.

**Laminated glass**

It is made by bonding of two or more pieces of safety glass. The adhesive mostly used for bonding is polyvinyl butyral (PVB). Depending upon the number of safety glass layers, the strength of the glass may be increased or decreased. Nowadays, laminated glass is produced by bonding number of annealed glass layers with plastic interlayers. This type of glass is used in automobile windshields where strength is one of the key issues.