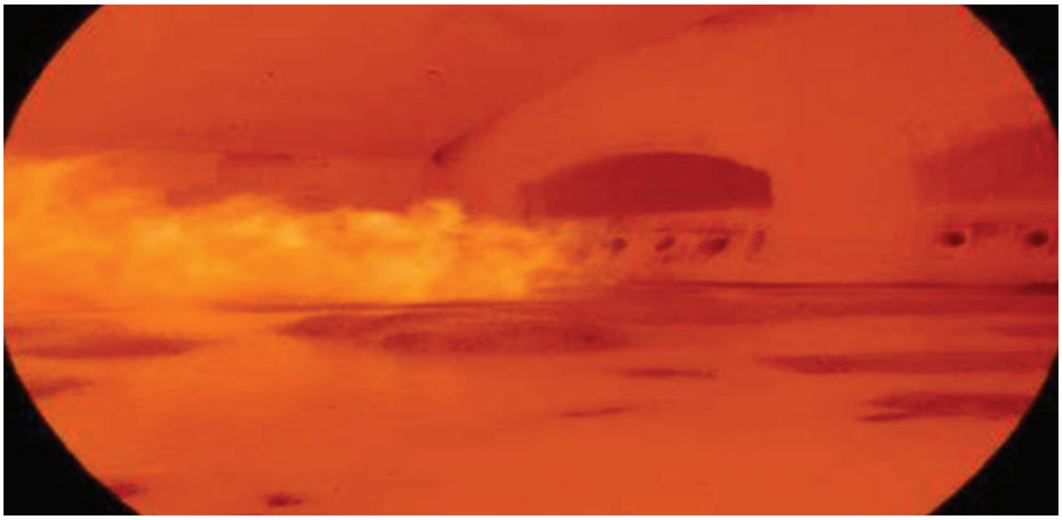
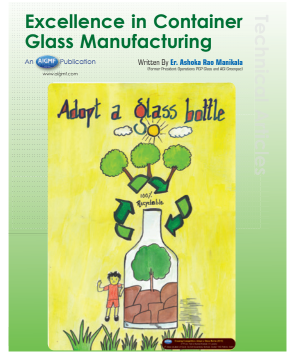
Furnace Design, Operations and Maintenance (chapter 3 of 15)





In this chapter from the book on "Excellence in Container Glass Manufacturing", we will learn in details about Furnace Design, Operations and Maintenance.

In container glass industry, glass melting furnace is considered as the heart of glass manufacturing process. It is a very important section of the glass plant which can directly make the investment either profitable or loss making. The glass quality, melting energy cost and the life of the furnace makes the business to get proper return on investment and hence utmost care should be given while deciding the furnace design, size and the refractory quality. There are many instances where due to poor design of the furnace, businesses collapsed. In the container glass industry, many components such as batching equipment, forehearths, forming machines, and other downstream machinery can be replaced, but the furnace must remain in operation for its entire lifespan, making mid-life design changes extremely difficult.

A glass melting furnace is designed to melt raw materials (batch) into glass. Depending on the intended use, various designs of glass melting furnaces are available. They use different energy sources, different heat recovery techniques and different furnace designs. The energy sources are mainly fossil fueled or by fully electric powered. A combination of both energy sources is also realized. Different heat recovery systems are regenerative, recuperative and non-heat recovery (all electric) furnaces. Different designs may be cross fired, end fired, deep refiner, furnace with electric boosting and oxy-fired furnaces. A glass melting furnace is made from special refractory material of high quality which can withstand severe working conditions.

In this chapter we are covering the following topics:

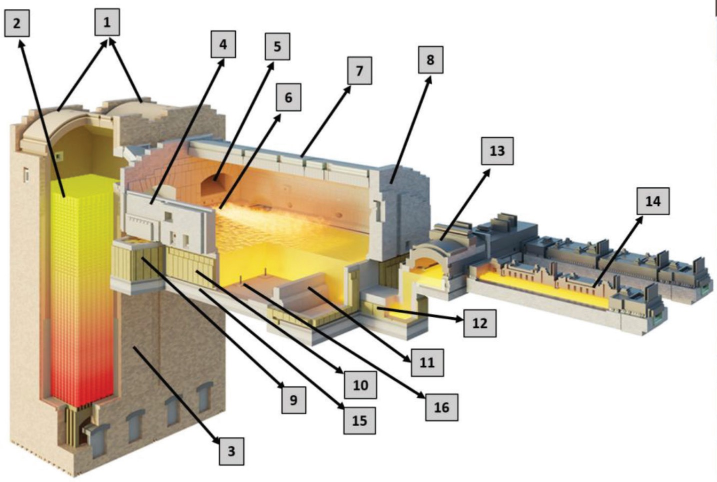
1. **Types of Furnaces**
2. **Furnace Design**
3. **Furnace Refractory Materials**
4. **Glass Melting Process**
5. **Furnace Heat-up, Operation and Maintenance**
6. **General Melting Problems and Remedies**

Container glass furnaces are generally very expensive and requires good operational skills. Design of furnaces are generally carried-out by leading companies like SORG, ASAHI, HORN, etc. The refractories required are of very high quality, which are supplied by reputed companies like SEPR, ASAHI, RHI. The furnace construction & start-up is also very critical and it is always desirable to construct & start the furnace under the supervision of experts from furnace designing companies.

The glass raw materials are fed to the glass melting tank in batches or continuously. The components in the batch are melted to form a liquid glass melt. In addition to the basic components, the batch also contains cullet from recycled glass to save energy. The cullet content can be up to approx. 85% to 90% (green glass), depending on the requirements of the desired glass colour. In the same furnace, different colours of glass can be produced based on requirements. For changing the glass colour, the entire process can take several days in large glass melting furnaces. For economical operation, the container glass melting furnaces are operated round the clock throughout the year for so-called mass glass (hollow glass, flat glass) production. The glass furnace can last up to 16 years & more, depending on the type of glass produced, draw, maintenance, hot & cold repairs, quality of refractory used, operation parameters etc. The furnace capacity or TPD (tons/day glass draw) can range from about one ton to over 1000 tons. The operating temperature inside the furnace, above the so- called glass bath is about 1550°C depending upon the composition of the batch, the required amount of molten glass and the design of the furnace.

Before going through the types of furnaces, let us understand common names used for the parts / sections of the furnace. In furnace there are basically two sections known as melter and regenerator / recuperator. Melter is the area where solid raw materials in the form of batch is melted by introduction of heat, and regenerator / recuperator is the area where energy is recovered for flue gas generated in the melter. We shall discuss more about regenerators and recuperators in later topics.

Container Glass Melting Furnace View- End Fired Regenerative Furnace



Parts Name of Furnace	
Part. No.	Part Name
1	Regenerator L&R Crown
2	Regenerator Checker
3	Regenerator Wall
4	Melter Super Structure
5	Flue Port
6	Melter Burner
7	Melter Crown
8	Melter Front Wall
9	Dog House
10	Melter Side Wall
11	Melter Dam Wall
12	Throat
13	Working End / Distributor
14	Forehearth
15	Melter Bottom
16	Melter Booster Electrode

Figure 3.1

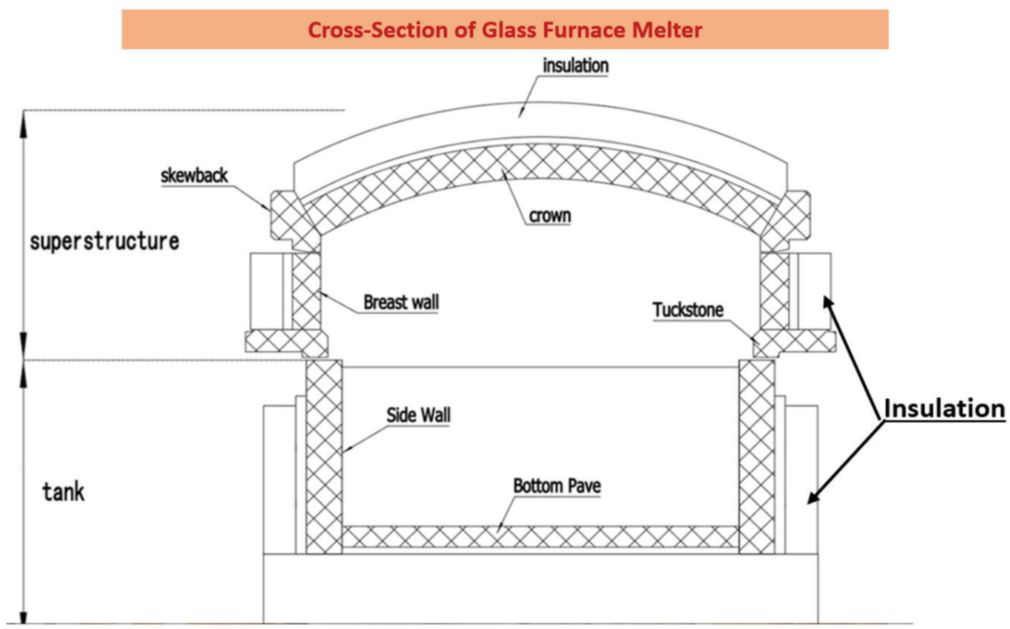


Figure 3.2

Cross sectional view of a Glass melting furnace

1. TYPES OF FURNACES

Furnaces are used for many applications. Few of them are: -

1. **Metal Production & Treatment**: Used for melting and alloying metals like iron, steel, and aluminium, as well as heat treatment for enhanced strength and durability.
2. **Chemical Processing:** Employed in catalytic reactions that require specific heat ranges.
3. **Glass Manufacturing:** Essential for producing glass through carefully controlled heating processes.
4. **Cement & Lime Production:** Used to heat raw materials to create cement and lime for construction.
5. **Power Generation:** Furnaces help produce steam to generate electricity.

These applications highlight the versatility of furnaces across different sectors. Furnaces are generally classified on various categories as per Table 3.1.

Now there are new type of furnaces under the "type of fuel used" category, namely All Electric Furnaces and Hybrid Fired Furnaces.

1.1 Glass Furnaces

Almost all glass is produced in a furnace, where a precise mixture of raw materials is combined and

Table 3.1

Classification method	Types and examples
Type of fuel used	Oil-fired
	Gas-fired
	Coal-fired
Mode of charging materials	Intermittent / Batch
	Periodical • Forging • Re-rolling (batch/pusher) • Pot
	Continuous • Pusher • Walking beam • Walking hearth • Continuous recirculating bogie furnaces • Rotary hearth furnaces
Mode of heat transfer	Radiation (open fire place)
	Convection (heated through medium)
Mode of waste heat recovery	Recuperative
	Regenerative

melted into a homogeneous mixture. Like many industrial manufacturing processes, glass melting can be broadly categorized as either a continuous or discontinuous (batch) process.

1.1.1 Continuous glass production furnace

Continuous glass melting processes work like a production line: a mixture of raw ingredients is added continuously at one end of the furnace, and glass is extracted continuously at the other. Continuous melting processes are high-throughput and preferred wherever a high volume (say 30 - 1000 tons per day) of the same type of glass is required. Continuous processing is typically used for production of architectural glass, fiberglass, screens for consumer electronics, and food and beverage containers.

1.1.2 Discontinuous or batch production

In discontinuous or batch processing, a batch of raw materials is added to a single melting vessel and melted into glass. Once the glass is formed, it can be removed from the vessel and formed into products. Batch-processing glass in this manner trades throughput for flexibility, enabling manufacturers to produce multiple formulations of glass depending on customer demand, without cross-contamination. Discontinuous glass melting is typically used for smaller production runs and is often required for uncommon glass types with relatively niche applications such as optics, electronics or signal applications.

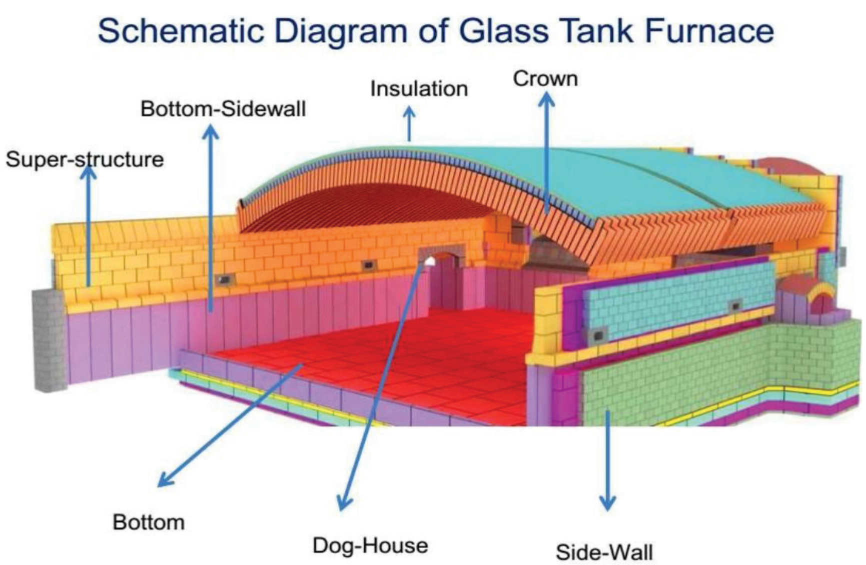


Figure 3.3

1.2 Types of glass furnaces

The melting point of most glasses lies around 1400-1600°C, depending on its composition. As a result, glass production requires a great deal of heat energy, usually provided in the form of natural gas, liquid fuels etc., injected into a combustion chamber. Because of this high energy demand, glass furnaces are constructed to minimize heat loss, and often features some form of waste-heat reclamation system. Different furnace types and designs exist, depending on the quantity of glass to be produced, the type of glass production, as well as economic (and logistic) factors.

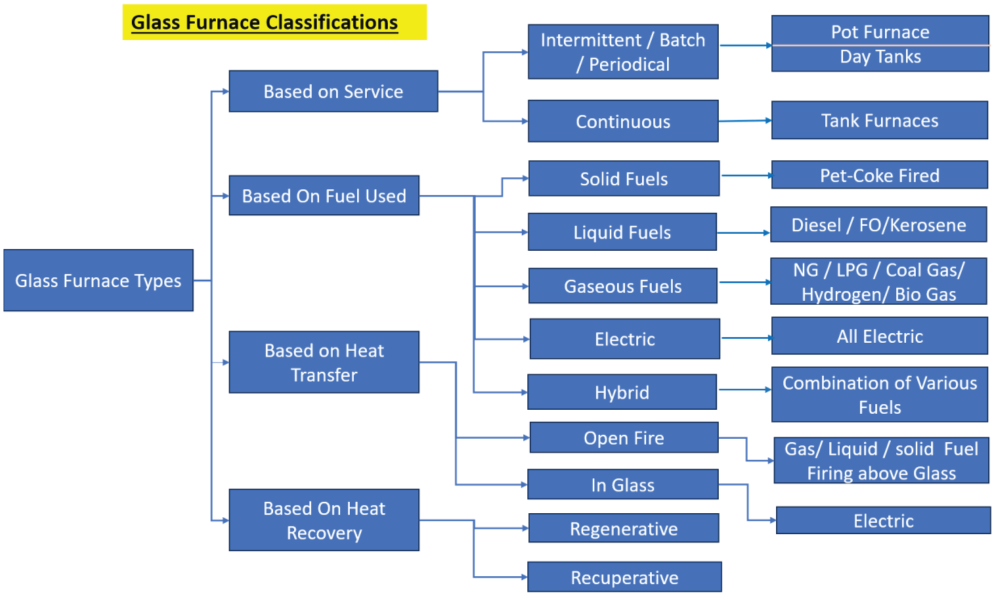
The main types of glass furnaces include:

1. Pot furnaces (discontinuous)
2. Day tanks (semi-continuous)
3. Recuperative / unit type melters
4. Cross-fired regenerative furnaces
5. End-port fired regenerative furnaces
6. Oxygen-fired unit melters
7. Special (segmented) melter
8. All-electric furnaces
9. Hybrid Furnaces

1.3 Table 3.2 shows various types of glass furnaces

Based on the service, the furnaces are intermittent (discontinuous) batch

Table 3.2



type or continuous type.

1.4 Discontinuous furnace (day tanks and pot furnaces): The following actions take place (generally in a one-day cycle) within discontinuous melting furnaces.

a) Melting tank or pot is charged with mixed raw material batch.

b) This batch is heated to the desired temperature.

c) The glass is melted, fined, homogenized and subsequently cooled down to the working temperature to allow forming by the craftsman or semi-automatic machines taking portions (gobs) of glass from the glass melt pot.

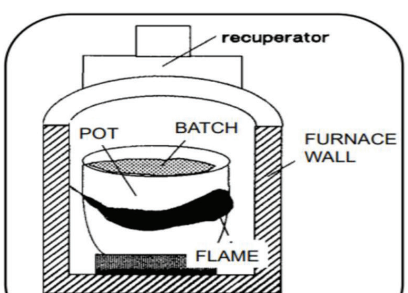
Pot furnaces are structures built of refractory materials in which there is no contact between the furnace and the glass. Glass is melted in several pots made of refractory materials which are resistant to glass attack at high temperatures. The pots are charged with a batch, which is melted over a number of hours and worked on a 24 or 18-hour cycle. An average pot can hold 600-700 kg of glass. Pot furnaces are used where the glass is formed by hand and mouth blowing. One of the main advantages of this system is that several types of glasses can be melted at the same time. A pot can be used for about 30 melting cycles and can therefore produce between 18 and 21 tons of glass.

1.5 Regenerative glass furnaces

Regenerative furnaces are mostly used for container glass melting. They have two large regenerator chambers (normally called south & north side or left & right side) to recover heat from hot exhaust gases.

Regenerative furnaces run in cycles: the direction of gas flow & required cold air flow and flue gases is periodically reversed so that during one cycle, hot exhaust combustion flue is passed through one part of regenerator to absorb heat and combustion air is passed through other part of regenerator to recover the heat. During the next cycle, the flow is interchanged in regenerators. The process of the cycle changes in glass furnace is known as reversal system.

Regenerative furnaces always have an even number of regeneration chambers, so that heat regeneration can occur in both directions. Regenerative glass furnaces can be either cross-fired or end-fired depending on application: cross-firing, the use of multiple combustion gas inlets down opposing sides of the furnace, allows more precise control over the location and temperature of hot spots within the furnace; while end-firing (a single inlet of combustion gas at the end of the chamber) generally reduces structural heat losses due to the increased residence time of the combustion gases. As the furnace requires very large regenerative chambers with special checkers, the cost of such type of furnaces



Example of a pot furnace

Newly Built Pot furnace in a factory

Pot furnaces were the earliest type of glass melting furnaces, dating back to ancient Egypt. They are still used today, mainly for the artisanal production of small quantities of glass. They consist of a clay pot or crucible, which is placed in a furnace and heated to high temperatures using a fuel source such as wood or gas. The glass ingredients are added to the pot, and as the temperature rises, they fuse into glass. Pot furnaces are usually not suitable for industrial production, as they have limited temperature control and require high labor input.

Figure 3.4

The Day-Tank Furnace is a gas fired glass melting furnace to produce soda- Lime transparent and colored glass. The range dimension is up to 4000 kg. Its main feature is the flexibility use because you can introduce raw materials subsequently melted and finally gathered.
The working cycle is 24 hours, divided as follows: 12 hours for filling and melting, 3 hours for the rest (the glass cooling down) and about 8-9 hours for gathering and preparing of glass items. The tank is in circular shape to help the homogeneity of the glass mass temperature. The heating system has gas burners which works on the surface of the glass bath. The working temperatures goes from 1450°C (to melt soda-lime transparent glass) up to 1490°C (to melt dark colour like blue or green).

Figure 3.5

are substantially higher compared to other types of furnaces.

Regenerative furnaces are available for glass production up to 750 tons/day, at present. The energy consumption per kg of glass can be as low as 780 Kcal at 50% cullet but it depends on raw materials used, furnace size, capacity, design, fuel used, furnace conditions etc. For specialty glass the energy consumption can be in the range of 1100 – 1300 Kcal/Kg of Glass.

1.6 Recuperative glass furnaces

Recuperative furnaces employ a slightly different approach to reclaim waste heat. In this type of furnace, the chimney and gas inlets are coupled with a radiative heat exchanger. This enables the continuous transfer of heat from exhaust gas to combustion gas, without the requirement for gas flow reversal as in regenerative furnaces. This enables recuperative furnaces to be employed for continuous glass melting applications, while also offering a relatively low investment cost. The absence of regeneration chambers also simplifies construction of the furnace and results in a smaller footprint; however, the heat transfer efficiency of recuperative furnaces is generally lower than that of regenerative furnaces.

1.7 Oxygen-fueled (“oxy-fuel”) glass furnaces

Oxygen-fueled (“oxy-fuel”) glass furnaces are a relatively new way of tackling the problem of high heat energy demand: by replacing the air entering the furnace with oxygen (typically at over 90% purity), the total amount of gas entering the chamber can be reduced while maintaining the same combustion energy input. This means the energy required to heat the input gas is reduced, while also reducing waste heat in exhaust gas. Other furnaces waste a large amount of energy simply heating the nitrogen in the air. In general, oxy-fuel furnaces have the same basic design as recuperative furnaces, with multiple lateral burners and a limited number of exhaust ports. Most oxygen-fired glass furnaces don’t use heat recovery systems to pre-heat the oxygen supply to the burners, although there are some developments in oxygen and natural gas preheating. The benefits of oxy-fuel furnaces include cheaper furnace designs, lower NOx emissions per ton of molten glass, smaller flue gas volumes, smaller footprints for furnace systems, and reductions in fuel consumption. While oxygen costs may potentially exceed the reduction in fuel costs, research indicates that switching to an oxy-fuel furnace substantially reduces energy costs for both large and small glass manufacturing operations.

1.8 All-electric glass furnaces

Electrically heated furnace technology is nearly as old as regenerative furnace technology. These work in a radically different way to conventional furnaces, avoiding combustion altogether and instead imparting heat energy to the glass mixture using high- voltage electrodes. These are typically used for fiberglass production but are also used for specialty glasses. Typically used for small- batch production, all-electric furnaces offer high thermal efficiency, a high degree of control over temperature, and can yield highly homogeneous glass while minimizing atmospheric pollution and economizing raw materials that volatilize readily.

1.9 Figure 3.6 shows the cross-sectional view of various types of furnaces used in glass manufacturing.

Although the theoretical minimum energy use is 669 Kcal/kg for soda-lime glass and 561 Kcal/kg for borosilicate glass, in practice average energy use varies between 700 to 3500 Kcal/kg (Ref. table 3.3).

2. FURNACE DESIGN

As furnace is a very critical equipment in glass manufacturing and is generally

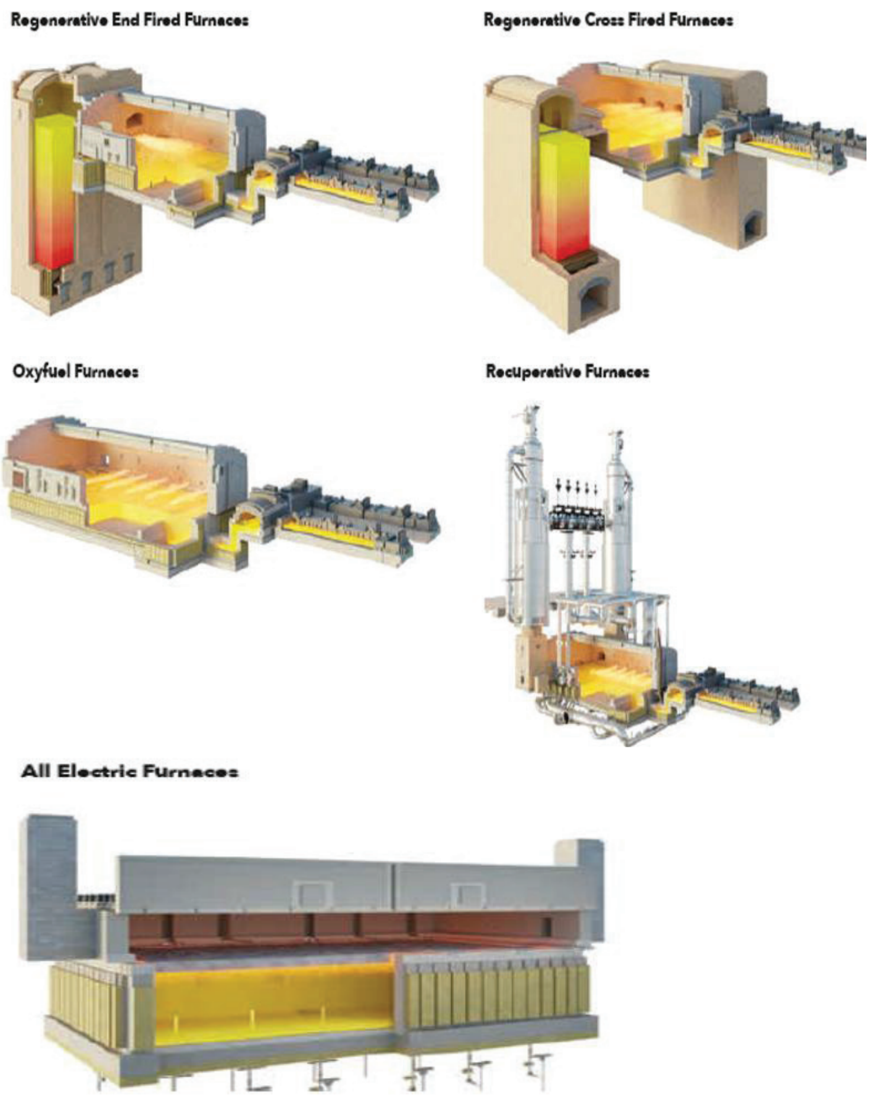


Figure 3.6

considered as "heart" of glass plant, proper design is very important. For design and supply, factory should prepare a proper project charter.

2.1 Project Charter

For designing the furnace, it is always essential to provide proper input to designer / project team. Following details are to be provided to make good furnace design.

1. **Get a detailed project charter prepared by the factory for furnace.**

   Project charter provides detailed requirement for furnace design.

   A sample project charter for 600 TPD furnace is shown in Table 3.4.

2. **Provide factory layout and building layout of the existing facility (if furnace is to be installed in the existing plant) or proposed layout for new facility.**

   It is essential for the designers to design the furnace with building limitations or propose new requirement for new facility. The furnace size, regenerator size can be suitably designed with this information.

3. **Provide no. of forehearths required, details of minimum & maximum draws, temperatures & gob weight for each forehearths.**

   With these inputs, the designer will be able to design the throat, working end and forehearths. Designer will be able to check the requirements through CFD simulation of furnace after design and verify that the requirements can be met with the design he proposes.

4. **Provide the RM specification, batch composition, cullet usage details:**

Table 3.3

Estimated Energy Consumption of Manufacturing Processes of various types of Glass furnaces			
Process	**Specific Energy use Range Kcal/Kg of Glass**	**Average Specific Energy use Kcal/Kg of Glass**	**Average Total Sp. Energy use Kcal/Kg of Finished Glass**
Batch Preparation	60-300	120	133
Melting & Refining			
- Flat Glass	1150-1550	1300	1700
- Container Glass : <100 t/d	1200-1750	1350	1850
- Container Glass : >100 t/d	780-1099	860	1300
- Container Glass : All Electric	700-860	780	1220
- Flacconage : <100 t/d	1450-2150	1700	2250
- Flacconage : >100 t/d	1150-1550	1300	1800
- Fibre Glass	1670-3500	2050	3500
- Borosilicate Glass	2300-3500	2800	3350

Note: Above specific energy use can be depending upon many factors like type of fuel used, combination of Fuel & Power usage, draw and packing efficiency. Total Sp. Energy use Kcal/Kg of finished Glass is the total energy used in BH, Furnace, WE, FH, Forming, Annealing, utility and others/ Kg of Finished Glass. Example- a container glass furnace, for 600T/D draw, use 56000 SCM / Day of NG in Furnace, 4500 SCM/Day of NG for WE+FH, 1300 SCM/Day of NG for Lehr and 90000 KWH power for all utility. Finished Glass is 545 Tons/day. For this case, Average Sp. Energy use-Kcal/Kg of glass=(56000*8450)/(600*1000) = 788. Average Total Sp. Energy use Kcal/Kg of Finished Glass = ((56000*8450 + 90000*860)/(545*1000))=1100 Kcal/kg. (CV of NG = 8450 Kcal/SCM, CV of power = 860/KWH)

Table 3.4

Project Charter- Furnace

600 TPD Container Glass Furnace

Project Description:

600 TPD Clear Flint, Container Glass Furnace for commercial Glass, having 8 production lines. The furnace should be able to convert to amber and green, as and when required.

1. Furnace Capacity: 500 TPD without electric boosting and 100 TPD electric boosting, total 600 TPD, with 30% cullet. The Furnace is to be designed accordingly.
2. Batch charger: Fully closed, energy efficient Batch charger- 2 sides charging with one space charger
3. Type of Furnace: Regenerative end fired continuous Glass Tank furnace, NG, FO & PG (Procedure Gas) Fuel Firing System
4. Glass Quality: a) Speed / 100 gm < 30 nos. (Gaseous inclusion size up to 0.5 mm) b) Glass homogeneity B+
5. Cullet % : Avg. 30% (Internal + External)
6. Glass Colours: Oxidizing flint and amber / Flint after conversion
7. Type of Glass: Soda lime Type-III Flint
8. Furnace Life: 12 years Min.
9. Burner: 8 Energy efficient low NOx Burners (4 on each side)
10. Products: Container Glass for all segments
11. No. of Prod lines: Eight, with equal draw distribution from throat on both sides
12. Fuel Furnace: Natural gas, LPG, furnace oil & producer gas working end & forehearth: Natural Gas
13. NCV of Fuel: Natural Gas: 8200-10500 Kcal / SCM (NCV) furnace oil: 9100 kcal / litre producer gas: 1400 Kcal / SCM
14. Dog house: Sealed dog house with closed batch charger to increase energy efficiency of the furnace
15. Regenerator: Design should incorporate chimney base temp not to exceed 430 deg C.
16. Throat: New Throat design for low corrosion & more hot glass in distributor.
17. Furnace Energy: Furnace Design should be most energy efficient. Online Oxygen Analyzer with Lambda control is required. CCTV camera for meeting monitoring to be incorporated in the Furnace with SCADA display. (Based on the techno commercial feasibility the requirement can be decided).
18. Boosting: Complete system with energy efficient transformer, electrodes & holders, water cooling system.
19. Furnace Instrumentation:
    1. Operator console + Engineering consol operation for furnace / SCADA System- 2 Monitors
    2. Auto fuel control along with Lambda control
    3. Auto Glass level control system
    4. Auto furnace pressure control system
    5. Measurement system for furnace temperature control
    6. Batch charger control system
    7. Dog Silo Level control system with batching
20. Spares:
    1. Batch charger 1 No.
    2. Boosting Electrode with holder 3 nos.
    3. Essential spares for reversal system and other critical equipments
    4. Low NOx Burner spares- 3

21 Documentation:
   1. Furnace operation manuals
   2. Batch charger manual
   3. 2 sets of furnace design drawings
   4. 2 sets of refractory drawings
   5. Furnace Heat up chart

22. Guarantee:
    1. SFC to be guaranteed for 30% cullet and for NG firing
    2. 600 TPD Draw to be achieved at 30% cullet
    3. Seed count should be below 30 seeds / 100 gm

With this input, designer will be able to work out furnace size, SFC required, regenerator load & design and boosting requirements.

5. **Provide details on fuel to be used with NCV values:**

   With this detail, designer will be able to design the furnace with suitable burners, refractories and boosting requirements.

We are not going into detailed design aspects of furnaces as it is not important & also not easy for glass manufacturers to involve & understand the total design of the furnace. However, the operations requirements in terms of glass draw, quality, performance, scope etc., are to be understood well. For this, accurate inputs to be provided to the designers for optimum design of the furnace. For the following critical & important factors, clear specifications should be given in furnace design and can be part of the project charter. These requirements are to be mutually agreed by both the parties and documented while finalizing the order.

1. **Furnace Draw:** It should be clearly discussed with designer. As draw can vary with percentage of cullet usage, boosting, fuel to be used, maximum furnace operating temperature and raw materials specification, very clear specification should be mutually agreed and recorded with designer.
2. **Seed Count and Glass Quality:** Seed count, bubbles & blisters impact glass quality. The required specification is to be clearly mentioned.
3. **Glass Temperature:** All the minimum & maximum temperatures of riser glass (throat), working end and forehearth entry temperatures to be discussed and clearly specified in order.
4. **Design validation by Furnace Modeling:** It is better to witness the furnace modeling test at reputed companies like M/s Glass Service in Czech Republic.
5. **Specific Fuel Consumption:** This is one of the critical factors. The guaranteed SFC for minimum and maximum draw with percentage of cullet, fuel, fuel combinations, raw material specifications, glass quality (seeds, bubbles and temperature) to be discussed and made as part of guaranteed terms to achieve the desired results. Many times, due to lack of understanding between manufacturer & designer, the guaranteed specifications are not achieved resulting in blaming each other. It is mutually beneficial for both parties to draw a clear specification of operating parameters, input parameters like fuel, cullet, RM and boosting to get the desired guaranteed figures.
6. **Furnace Life:** Furnace design, material used, material specifications, equipments used, operating parameters like temperature, pressure, cullet percentage, RM specification, cooling and various controls, interruptions in furnace operations like power failure & equipment failures, furnace heat up and furnace maintenance are the major factors that can affect the furnace life. All the above should be considered in detail while designing and selecting equipments / refractories. Few of the actions that impacted the furnace performance and life are following :

A) In one furnace, fine water mist cooling for metal line was introduced within 2 years of operation of new furnace, thinking that life will improve. Contrary to the assumption, due to presence of mist, the side blocks developed cracks and furnace was damaged totally in a span of 4 years. Also, the specific fuel consumption was very high due to too much cooling.

B) In one furnace, during the heat- up, there were a lot of interruptions (power, compressed air & fuel supply), which resulted in many cracks & damages to refractories. This seriously impacted furnace life.

C) Before glass draining after furnace heat-up using cullet, direct batch was started and this created choking of throat during heat-up.

D) Very fine cullet was charged during heat-up and it formed dusty atmosphere inside the furnace and operators were not able to monitor the optical temperatures properly. Thinking that temperatures are low, gas was increased, which resulted in overheating of crown and it damaged the silica crown.

E) Improper sized cullet was fed at high pressure into furnace during heat- up which resulted in sandblasting like effect on refractory surfaces and stone like material appeared in glass for a few weeks after draining, resulting in huge loss.

F) Due to high contamination in cullet, lot of foreign materials entered the furnace which resulted in damage to boosting electrodes due to sparking and also the bottom refractory damaged because was downward drilling effect of contaminants (un- melted metallic contaminants). The glass quality was poor due to high seeds and frequent yellow lines in glass. Furnace bottom leaked within very short span.

G) In one case, there were many power outages and equipment breakdowns. This resulted in abnormal changes in furnace operating parameters resulting in damage to furnace & regenerator crowns. Furnace life was impacted due to this.

H) Due to usage of very high dusty raw materials (fine materials in silica sand, quarts, lime stone & others), the regenerator clogged quickly resulting in very high SFC and lower furnace life.

There are many cases in industries where above type of errors in operations occur and it impacts the life & overall performance of the furnace. If furnaces do not perform well, the glass quality and company's profitability can be severely impacted.

7. **Heat-up and after Commissioning Services:** Heat-up procedure and supervision are very important factors. Procedure should be clearly specified. After commissioning services like performance test, system up-gradation (Software updating), monitoring performance regularly online and giving feedback, boosting performance monitoring (pushing electrodes, electrode current and temperatures) etc., should be specified clearly in order. Regular furnace audits can also be a part of order.

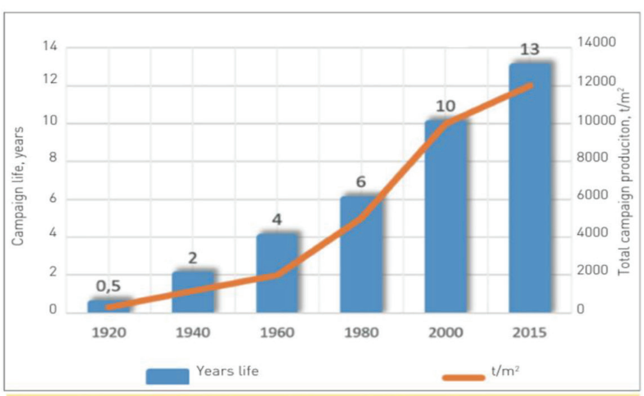
2.2 Furnace Type Selection: Considering the present energy situations, environmental impacts and customer requirements, type of furnace are to be decided. As there are many options available, considering the local conditions, statutory requirements and future requirements, a good brainstorming is to be done to select suitable type of furnace. You can opt for flexibility in furnace design considering the cost of design and future operational costs. Sometimes, it is better to keep additional boosting provisions, multi fuel provisions, heat recovery provisions, sustainable energy usage provisions, furnace conversion provisions and additional glass draw provisions etc., after evaluating the additional cost of design vs. benefits.

3. FURNACE REFRACTORIES

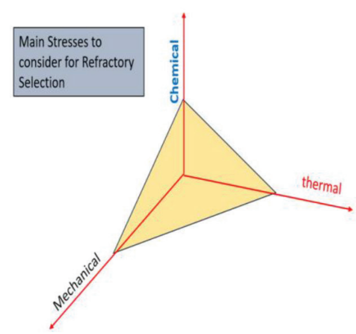
The furnace personnel should have good knowledge of refractory materials as the selection of correct refractory material will decide the furnace cost, furnace life and quality of glass. Even though furnace designer will design the furnace and suggest refractory materials required, the plant glass team should discuss and finalize the refractory material specifications for various parts of furnace. For furnace side walls itself, AZS blocks of different specifications are required for different locations. Dog house corners, melter corners, throat side walls, throat blocks, booster blocks etc., require special AZS quality blocks, depending upon temperature and service factors. Where the high abrasion of blocks is expected, special blocks of high abrasion resistant are used and similarly where high temperature is expected, special high temperature resistant quality blocks are used. The selection, operation and maintenance of refractory materials in Figure 3.7 shows the campaign life of the furnace.

The Figure 3.7 shows the campaign life of furnace over last 100 years and main consideration to select suitable refractory material.

From the chart (Figure 3.7), it can be observed that the furnace life has been increasing substantially over the years. Glass furnaces have evolved in size and longevity while, at the same time, production temperatures, throughput and product requirements have become more challenging. Over time, the refractories have



General Furnace Life in Yrs. and Campaign Draw in t / sq.mtr



Based on stresses generated on furnace Refractory, suitable refractory material to be selected / used.

Figure 3.7

undergone many changes to improve their consistency and quality, address environmental concerns, while at the same time, minimise glass defects. Among the challenges for improved furnace life are refractory wear and its effect on glass quality, repair methods that can be carried out while the furnace is in service, techniques for monitoring refractory wear during operation, energy use and its source, etc., Appropriate refractory selection should consider that the temperatures for melting and refining glass fall in the range of 1300°C to 1580°C, and are composition dependent. In addition, the bath's oxidation state (redox) influences the type and severity of the bath's reaction with these refractories. Because the bath is mainly heated by flames through radiation (top down), the temperatures under the crown can reach 1650°C or higher and the gases in this area are often loaded with alkalis which are detrimental to refractory life.

The refractory materials used for the construction of glass melting furnaces should meet the following basic requirements:

1. The glass contact refractories should withstand continuous operating temperature of +1560°C.
2. Should have sufficient mechanical strength to resist impact, friction, high-temperature and high-speed flame, smoke, and dust, and other mechanical effects.
3. Should retain excellent high-temperature structure and can withstand mechanical load for a long time at operating temperature.
4. Should have strong resistance to the corrosion effect of the molten compound, molten glass, and gaseous substances.
5. Strong resistance for any reaction with batch or glass and should not pollute liquid glass.
6. Should have excellent thermal shock resistance.
7. Should have high-temperature volume stability and small residual shrinkage or expansion.
8. Should meet the specification with respect to thermal properties such as heat capacity, thermal expansion and heat conduction.

Refractory selection for glass furnace is to be made for regenerator checker, regenerator wall, crown & bottom, melter doghouse side wall, burner area side wall, melter sidewall, melter corners, melter crown & super structure, melter bottom, gable and suspended arch. For different part of glass furnace, different refractory brick should be used. The detailed application is given below:

1. Regenerator checker, wall, crown & bottom usually use magnesia refractory brick, magnesia-chromite refractory brick, magnesia-zirconia refractory brick, magnesia-alumina refractory brick, magnesia-silica refractory brick, light weight magnesia-silica brick, chamotte refractory brick, silica refractory brick and sillimanite refractory brick.
2. Melting tank sidewall, corner, crown & bottom usually use fused cast AZS refractory brick, fused cast AZS bottom block, fused cast b-alumina brick, zirconia-mullite (zirmul) brick, silica refractory brick, corundum- zirconia-mullite ramming mix and zirconia mullite ramming mix.
3. Working end crown, sidewall, bottom & tuyere usually use fused cast AZS refractory brick, fused cast AZS bottom block, fused cast a-b alumina brick, fused cast b-alumina brick, zirconia refractory brick, silica refractory brick, corundum-zirconia-mullite ramming mix and zirconia-mullite ramming mix.
4. Burner usually use fused cast AZS refractory brick, fused cast a-b jargal block and sintered zirconia refractory brick. Dog house wall usually use silica refractory brick, gable usually use zirconia refractory brick and silica refractory brick.
5. Suspended arch usually use fused cast AZS refractory brick, zirconia-mullite (zirmul) brick and silica refractory brick.

Different types of refractories can be used in particular area of the furnace. However, their life, cost, reaction to glass or flame (or flue), behaviour to thermal, chemical & mechanical impacts will be different. Hence a cost effective but most suitable refractory solution for the service condition should be considered for getting good furnace life and consistent glass quality.

3.1 Refractories and their properties

Refractories are inorganic, non-metallic, porous and heterogeneous materials composed of thermally stable mineral aggregates, a binder phase and additives. The principal raw materials used in the production of refractories are normally the oxides of silicon, aluminium, magnesium, calcium and zirconium. There are some non-oxide refractories like carbides, nitrides, borides, silicates and graphite.

Refractories are chosen according to the conditions they face during their use. Some applications require special refractory materials. Zirconia is used when the material is required to withstand extremely high temperatures. Silicon carbide and carbon are two other refractory materials used in some very severe temperature conditions, but they cannot be used in contact with oxygen, since they oxidize and burn in atmospheres containing oxygen.

Refractories are the materials which are resistant to heat and exposure to different degrees of mechanical stress and strain, thermal stress and strain, corrosion/erosion from solids, liquids and gases, gas diffusion, and mechanical abrasion at various temperatures. In simplified language, they are considered to be materials of construction which are able to withstand high temperatures.

Refractory products are a specific sort of ceramics that differs from any 'normal' ceramics mainly with their coarse-grained structure being formed by larger grog particles joined by finer intermediate materials (bonding). ASTM C71 defines refractories as 'non-metallic materials having those chemical and physical properties that make them applicable for structures or as components of systems that are exposed to environments above 538°C.

Refractories are to be chemically and physically stable at high temperatures. Depending on the operating environment, they need to be resistant to thermal shock, be chemically inert, and/or have specific ranges of thermal conductivity and of the coefficient of thermal expansion. Refractories are used in high temperature processes because of their heat-resistant properties and stability at high temperatures. They are normally used as linings for high-temperature furnaces and other processing units such as kilns, incinerators and reactors since they are able to withstand physical wear, high temperatures, and corrosion by chemical agents. They are also used to make crucibles. They find extensive uses in iron, glass and steel industry.

The qualities of refractories are dependent on their chemical, physical, mineralogical and thermal properties. Refractory materials have a range of properties to meet the requirements imposed by different processes. The general requirements from the refractories are (i) ability to withstand high temperatures and trap heat within a limited area like a furnace, (ii) ability to withstand sudden changes of temperature, (iii) ability to withstand load at service conditions, (iv) ability to withstand chemical and abrasive action of the materials such as liquid metal, liquid slag, and hot gases etc., coming in contact with the refractories, (v) ability to resist contamination of the material with which it comes into contact, (vi) ability to maintain sufficient dimensional stability at high temperatures and after/during repeated thermal cycling, (vii) ability to conserve heat, (viii) ability to withstand load and abrasive forces, and (ix) low coefficient of thermal expansion.

Refractories are normally tailor-made on the basis of (i) process parameters such as temperature profile, mode of operation, and operating atmosphere etc., (ii) expected quality characteristics, and (iii) best techniques for engineering and application, so that the final physical, chemical, and thermal properties are compatible to the application.

Refractories perform four basic functions namely (i) acting as a thermal barrier between a hot medium (e.g., flue gases, liquid metal, liquid slags, and molten salts) and the wall of the containing vessel, (ii) insuring a strong physical protection, preventing the erosion of walls by the circulating hot medium, (iii) representing a chemical protective barrier against corrosion, and (iv) acting as thermal insulation, insuring heat retention.

Refractories are expensive, and any failure in the refractories results in a great loss of production time, equipment, and sometimes the product itself. The type of refractories also influences energy consumption and product quality. Hence, the issue of getting refractories best suited to each application is of highest importance. Economics greatly influence these issues, and the refractory best suited for an application is not necessarily the one that lasts the longest, but rather the one which provides the best balance between initial installed cost and service performance. This balance is never fixed, but is constantly shifting as a result of the introduction of new processes or new types of refractories.

3.2 Classification of refractories

Refractories are classified into a number of ways on the basis of (i) chemical composition, (ii) chemical properties of their constituent substances, (iii) by the place of use, (iv) the refractoriness, (v) method of manufacture, (vi) physical form, (vii) according to the applications, (viii) based on thermal conductivity, (ix) according to the principal base features, or (x) based on compactness.

3.2.1 Classification based on chemical composition

Based on the chemical composition the refractories can be classified as follows:

- **Silica refractories** – Silica refractories comprise of silicon oxide (SiO_2) also known as silica. These refractories are produced either from quartz or fused silica. Silica refractories contain at least 93% SiO_2. The raw material is quality rocks. Various grades of silica brick have found extensive use in the iron and steel industry furnaces. In addition to high fusion point multi-type refractories, the other important properties of silica refractories are their high resistance to thermal shock (spalling) and their high refractoriness. The outstanding property of silica brick is that it does not begin to soften under high loads until its fusion point is approached. Other advantages are flux and slag resistance, volume stability and high spalling resistance.

- **Fireclay refractories –** Fireclay refractories comprise around 75% of the production of refractories on a volume basis and are essentially hydrated aluminium silicates with minor proportions of other minerals. Typical composition consists of SiO_2 less than 78% and Al_2O_3 less than 44%. As a type, they are extremely versatile and least costly of all refractory bricks and are extensively used in the iron and steel industry. Fireclay refractories are produced by firing of certain types of clays. The principal mineral for these refractories is kaolinite. Fireclay bricks are divided into five different classes namely (i) super-duty, (ii) high-duty, (iii) semi-silica, (iv) medium- duty, and (v) low-duty. The super- duty and high-duty classes are divided further into three types under each class.
- **Alumina refractories –** Alumina refractories are also having basic constituents of Al_2O_3 and SiO_2 but these refractories have a minimum of 50% Al_2O_3. Alumina refractories are divided into seven different classes by percent alumina. These classes are (i) 50% Al_2O_3, (ii) 60% Al_2O_3, (iii) 70% Al_2O_3, (iv) 80% Al_2O_3, (v) 85% Al_2O_3, (vi) 90% Al_2O_3, and (vii) 99% Al_2O_3.
- **Magnesia refractories –** The main constituent of these refractories is magnesia (MgO). The main sources of magnesia are brines (often deep well type) and seawater as well as sintered and fused magnesia. Magnesia-carbon refractories are important refractories of this type.
- **Dolomite refractories –** The main constituents of these refractories are MgO and calcium oxide (CaO). These refractories are produced from sintered dolomite.
- **Magnesia-chrome or chrome-magnesite refractories –** The main constituents of these refractories are MgO and chromium oxide (Cr_2O_3). Depending upon the percentage of MgO and Cr_2O_3 in the refractories these refractories are called either magnesia-chrome refractories or chrome-magnesite refractories. Here, a distinction is required to be made between chrome-magnesite refractories and magnesite-chrome-refractories. Chrome-magnesite material usually contains 15% to 35% Cr_2O_3 and 42% to 50% MgO whereas magnesite-chromite refractories contain at least 60% MgO and 8% to 18% Cr_2O_3. Chrome-magnesite refractories are used for building the critical parts of high temperature furnaces. These materials can withstand corrosive slags and gases and have high refractoriness. The magnesite-chrome refractories are suitable for service at the highest temperatures and in contact with the most basic slags used in steelmaking. Magnesite-chrome refractories usually have a better spalling resistance than chrome-magnesite refractories.
- **Silicon carbide refractories –** Silicon carbide refractories are produced from silicon carbide (SiC), a raw material synthesized in a resistance-type electric furnace at temperature greater than 2500°C, through the reaction of silica with carbon.
- **Zirconia refractories-** In zirconia refractories, main constituent of the refractory is zirconium oxide (ZrO_2). Zirconia refractories are useful as high temperature construction materials. They tend to be used in applications where temperatures are above 1900°C, such as casting nozzles and gates, crucibles, furnace liners and kilns. The thermal conductivity of zirconium dioxide is found to be much lower than that of most other refractories and the material is therefore used as a high temperature insulating refractory. Since zirconia shows very low thermal losses and does not react readily with liquid metals, it is mainly useful for making refractory crucibles and other vessels for metallurgical purposes.
- **Carbon refractories –** The main constituent for these refractories is carbon. Carbon, formed carbon, manufactured carbon, amorphous carbon and baked carbon are the terms which are used for these refractories. Carbon can also be in graphitized or semi-graphitized form. The carbon refractories are primarily used in highly reducing environments. Carbon refractories have a high refractoriness and high temperature of softening under load. They resist well the action of slags and have high thermal stability.

3.2.2 Classification based on chemical properties of their constituent substances

Refractories are typically classified on the chemical behaviour of their constituent substances, i.e. their reaction to the type of slags. Accordingly, to this classification, refractories are of three types namely (i) acid refractories, (ii) basic refractories, and (iii) neutral refractories. Also, there are some special types of refractories.

- **Acid refractories** – These refractories are attacked by alkalis (basic slags). These are used in areas where both slag and atmosphere are acidic. Examples of acid refractories are silica refractories, zirconia refractories and alumino-silicate refractories.
- **Basic refractories** – Basic refractories are those which are attacked by acid slags but stable to alkaline slags, dusts and fumes at high temperatures. Since they do not react with alkaline slags, these refractories are of considerable importance for furnace linings where the environment is alkaline such as steelmaking operations. The most important basic refractories are magnesite refractories, dolomite refractories, and magnesia-chrome refractories.
- **Neutral refractories** – Neutral refractories are chemically stable to both acids and bases and are used in areas where slag and atmosphere are either acidic or basic. The common examples of these refractories, materials are carbon graphite (most inert), chromite refractories, and alumina refractories. Out of these graphite is the least reactive and is extensively used in metallurgical furnaces where the process of oxidation can be controlled.

Figure 3.8 shows classification of refractories based on chemical behaviour of constituents.

Special refractories are expensive refractory materials which have been manufactured using synthetic (fused / sintered) grains free from impurities, under highly controlled production parameters. They are used for special purposes like – construction of crucible, some parts of furnaces and, research and development purposes etc., where the cost of the refractory is of no consideration. They include materials like pure alumina, sialons (Si – Al – O – N), thoria (ThO_2), beryllia (BeO), zirconia, boron nitride, and spinel etc.

3.2.3 Classification based on the place of use

Iron & steel, and glass industries are the major consumer of refractories with around 80% of refractories being consumed by them. The different areas of the manufacturing processes in glass industry are exposed to different temperatures and flue gases. The diversity in the operating conditions of different equipment's demands different grades for different areas of application. Glass industries use good quantity of refractories for furnace melter, regenerator and forehearths. Here too, the refractories are classified into areas of use. They are (i) furnace side wall, (ii) furnace super structure, (iii) furnace crown, (iv) furnace bottom, (v) regenerator walls & checkers, (vi) forehearth & working end and (vii) feeder expendables.

3.2.4 Classification based on refractoriness

Based on the property of refractoriness, the refractories are usually classified into four classes. These are namely (i) super-duty, (ii) high-duty, (iii) intermediate duty, and (v) low duty. Super duty refractories have PCE (pyrometric cone equivalent) value ranging from 33-38. High duty refractories have PCE (pyrometric cone equivalent) value ranging from 30-33. Intermediate duty refractories have PCE (pyrometric cone equivalent) value ranging from 28-30, while low duty refractories have PCE (pyrometric cone equivalent) value ranging from 19-28.

3.2.5 Classification based on method of manufacture

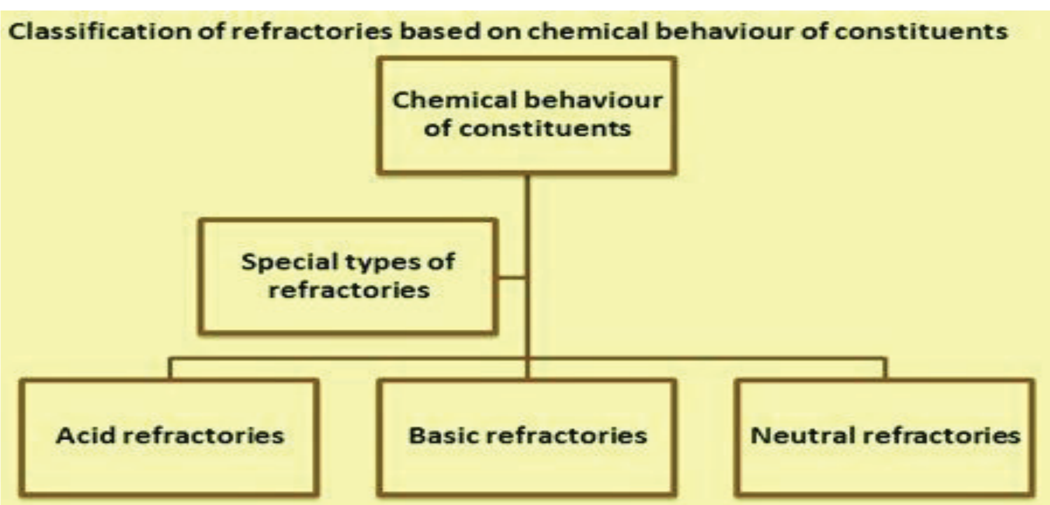


Figure 3.8

The refractories can be manufactured by several methods consisting mainly of (i) dry press process, (ii) fused cast process, (iii) hand moulding process, (iv) forming process consisting of normal, fired or chemical bonded, and (v) unformed refractories such as monolithic, plastics, ramming masses, gunning materials, and castable etc., and are classified accordingly.

3.2.6 Classification based on physical form

Refractories are classified according to their physical form. These are the shaped and unshaped refractories. The shaped is commonly known as refractory bricks and the unshaped as monolithic refractories.

Shaped refractories are those which have fixed shapes when delivered to the user. The shaped refractories are normally known as refractory bricks. Brick shapes are usually divided into two types (i) standard shapes and (ii) special shapes. Standard shapes have dimensions which are conformed to by most refractory manufacturers and are generally applicable to all kinds of furnaces of the same type.

Special shapes are specifically made for particular furnaces. This may not be applicable to other furnaces of the same type. Shaped refractories are almost always machine- pressed, thus, high uniformity in properties are expected. Special shapes are most often hand-moulded and are expected to exhibit slight variations in properties.

Unshaped refractories are without definite form and are only given shape during their application. They form joint less lining and are better known as monolithic refractories. These are categorized as plastic refractories, ramming mixes, castable, gunning mixes, fettling mixes and mortars.

Ramming refractory materials are in loose dry form with graded particle size. They are mixed with water for use. Wet ramming masses are used immediately on opening. Ramming masses are used mostly in cold condition so that desired shapes can be obtained with accuracy.

Castable refractory materials contain binder such as aluminate cement which imparts hydraulic setting properties when mixed with water. These materials are installed by casting and are also known as refractory concretes.

Mortars are finely ground refractory materials, which become plastic when mixed with water. These are used to fill the gap created by a deformed shell, and to make wall gas tight to prevent slag penetration. Bricks are joined with mortars to provide a structure.

3.2.7 Classification according to applications

Chemical characteristics of the furnace process usually determine the type of refractory required. Theoretically, acid refractories should not be used in contact with basic slags, gases and fumes whereas basic refractories can be best used in alkaline environment. Actually, for various reasons, these rules are often violated.

3.2.8 Classification based on thermal conductivity

Based on thermal conductivity, refractories can be **(i) conducting such as SiC, ZrC, (ii) non conducting such as silica, alumina, or (iii) insulating refractories.**

The function of insulating refractory is to reduce the rate of heat flow (heat loss) through the walls of furnaces. The desirable feature of insulating refractories is the low thermal conductivity, which usually results from a high degree of porosity.

Structure of air insulating material consists of minute pores filled with air which have in them very low thermal conductivity. The air spaces inside the brick prevent the heat from being conducted but the solid particles of which the brick is made conduct the heat. So, in order to have required insulation property in a brick, a balance has to be struck between the proportion of its solid particles and air spaces. The thermal conductivity is lower if the volume of air space is larger. Importantly, the thermal conductivity of a brick does not so much depend on the size of pores as on the uniformity of size and even distribution of these pores. Hence, uniformly small sized pores distributed evenly in the whole body of the insulating brick are preferred.

The high porosity of the brick is created during manufacturing by adding a fine organic material to the mix, such as sawdust. During firing, the organic addition burns out, creating internal pores. Other ways to accomplish high porosity involves (i) by using materials which expand and open up on heating, (ii) by using volatile compounds like naphthalene, (iii) by using aluminium (Al) powder in combination with NaOH solution (called chemical bloating), (iv) by using substances which by themselves have open texture e.g. insulating brick grog, vermiculite, ex-foliated mica, raw diatomite etc. (v) by using foaming agents to slip, and (vi) by aeration etc.

Because of their high porosity, insulating bricks inherently have lower thermal conductivity and lower heat capacity than other refractory materials.

Insulating materials can be classified into four types with respect to application temperature. These four types are **(i) heat resistant insulating materials for**

application temperatures up to 1100°C (examples are calcium silicate materials, products from siliceous earth, perlite or vermiculite, silica based micro porous heat insulators, and alumino-silicate fibres), **(ii) refractory insulating materials for application temperatures up to 1400°C** (examples are lightweight chamotte and kaolin bricks, lightweight castable, and mixed and aluminium oxide fibres), **(iii) high refractory insulating materials for application temperatures up to 1700°C** (examples are lightweight mullite and alumina bricks, lightweight hollow sphere corundum castable and bricks, and special high refractory fibres) and **(iv) ultra- high refractory insulating materials for application temperatures up to 2000°C** (examples are zirconia lightweight bricks and fibres, and non-oxide compounds). Several other types of insulating refractories include castable, granular insulation, and ceramic fibre insulation, which is light weight. Extremely lightweight materials have a porosity of 75% to 85% and ultra- lightweight, high-temperature insulating materials have a total porosity greater than 85%.

3.2.9 Classification according to the principal base features

Based on principal base features refractories are of two types. The first type is oxide- containing refractories. They are namely based on oxides and their compounds, the most important oxides are Al_2O_3, CaO, MgO, SiO_2, Cr_2O_3, and ZrO_2. The second type is non-oxide refractories. Example of non-oxide refractories are carbon-based refractory materials, and carbides, nitrides, borides, and silicides. This group included also sialons which are the silicon nitride sinterable derivatives.

3.2.10 Classification based on compactness

Based on this classification refractories are of two types. The first type consists of dense refractories with their true porosity less than 45%. The second type consists of insulating refractories with their true porosity more than 45%.

3.3 Melter refractories: Melter use refractories are suitable for high temperature, abrasion and corrosion. Different quality of refractory materials is used based on experience, service requirements, maintenance requirements, life expectation, glass quality requirements and cost.

Figure 3.9 shows the type of refractory being used in melter of container glass furnace.

3.4 Regenerator refractories: Regenerator is the important part of furnace which is subjected to severe operating conditions like thermal shock due to reversal system (cold & hot), chemical attack from hot flue gases, abrasion & corrosion due to high velocity flue gas flow, material deposit from batch & flue, mechanical load due to weight of top layer checkers

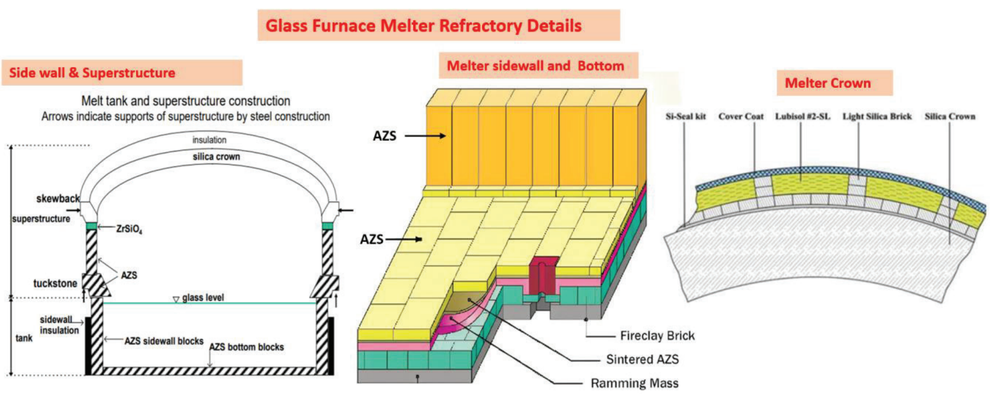


Figure 3.9

Container Glass Regenerator Refractory Scheme

For Regenerators, different kinds of refractory materials are used based on fuel used, Raw Materials used, type of Glass Produced and cost. Regenerator Checkers and arches are subjected to severe Chemical, thermal and Mechanical attacks. Hence based on the severity of service and ease of maintenance, Alkaline refractory solution or Zirconia Brick solution is used. Checkers of different design, shape and materials may also be used based on Energy Efficiency, maintenance requirements and Life.

1. Alkaline brick Scheme:

In this scheme, Bonded high purity magnesium brick /Checkers, to the top layer of the regenerator is selected. Normal magnesia chrome brick or magnesia Olaf brick resistant to sulfate attack is selected for the middle layer, low porosity clay brick is selected for the lower layer. High alumina brick resistant to spillage is used as the transition brick between magnesia brick and clay brick.

2. Electrocast zirconia AZS Refractory Scheme:

The cruciform made from fused zirconium corundum lattice brick (ER-1681) is used in regenerator. The top arch and crown of the regenerator is usually made of fused AZS brick or directly bonded magnesia brick or silica brick. The upper & middle layers of the side wall and the dividing wall may be made of magnesia brick. The lower layer and Bottom Arch may be made of low porosity clay brick.

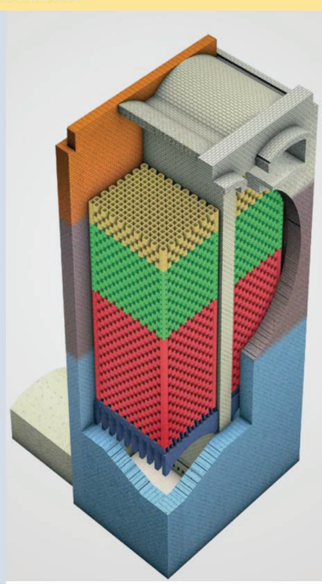


Figure 3.10

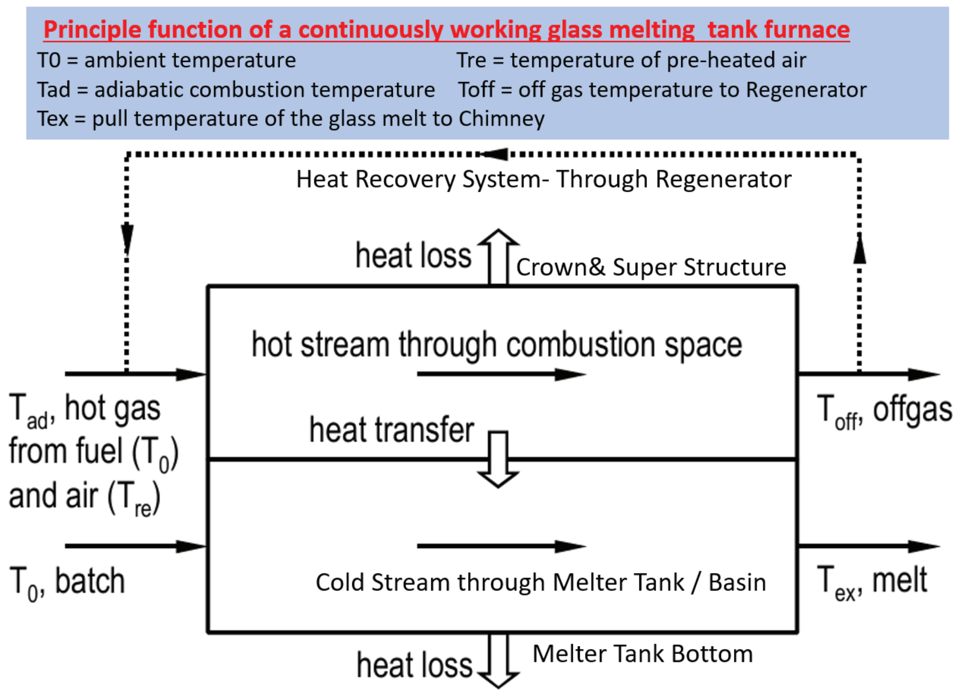


Figure 3.11

on bottom layer checkers & arches. Hence based on above parameters, energy recovery efficiency, service life, ease of maintenance and cost, suitable refractories are selected.

Figure 3.10 shows general refractory solution for regenerators.

4. GLASS MELTING PROCESS

Glass is melted in furnace by applying heat to the batch inside the melter. The glass melting process starts from a granular mixture of natural and synthetic raw materials (the so-called batch) and yields a thermally and chemically homogeneous melt made available at a well-defined temperature level. Figure 3.11 illustrates how a continuously working glass melting furnace functions in principle.

4.1 Melting reaction: During the operation of the Furnace, batch melting reaction is taking place. The composition of a glass batch is dependent on the glass type to be produced. A glass batch producing container glass typically contains silica sand (SiO_2), soda ash (Na_2CO_3), dolomite ($MgCO_3 \cdot CaCO_3$) and/or limestone ($CaCO_3$), sodium sulphate (Na_2SO_4) as fining agent and a reducing agent such as carbon or the steel slag calamite. Melting of glass batches is a complex process involving different reaction types such as dehydration reactions, crystalline inversions, solid-state reactions between the different raw material grains, decomposition reactions, melt forming reactions and dissolution processes. Below, a short description of the characteristics of these different reaction types is given.

4.1.1 Dehydration reactions: In the glass batch, water may be present as either molecular water and chemically bonded water (e.g. $Na_2CO_3.H_2O$ or water bonded in clays). Molecular water is added to the glass batch to lower the dusting of fine batch particles during transport towards the glass furnace and to prevent extensive carry-over of loose batch particles in the glass furnace. Molecular water, with a fraction of about 1.5-4 wt.% in the glass batch, is released at temperatures below 100°C. The temperature at which chemically bonded water is released, is dependent on the bonding strength of the water molecule(s) to the batch constituents and may last up to temperatures of 600°C. The impact of dehydration reactions on the melting process of the glass batches is mainly the consumption of extra energy during water evaporation.

4.1.2 Crystalline inversions: During melting of glass batches, structural modifications of some crystalline batch constituents occur. An example of a crystalline inversion in sand containing glass batches is the transformation of the α-modification of quartz into the β-modification of quartz at 573°C. Crystalline inversions have no significant impact on the melting process of the glass batch.

4.1.3 Decomposition reactions: The main decomposition reactions during melting are the calcination reactions. The typical weight loss for a float batch, without the presence of cullet, due to these calcination reactions equals about 15-20 wt.%. Alkaline (Na_2CO_3, K_2CO_3) and earth-alkaline carbonates ($MgCO_3$, $CaCO_3$, $SrCO_3$ and $BaCO_3$) either decompose due to temperature increase, i.e. thermal calcination above a certain temperature level, or via a reaction with other batch constituents, i.e. reactive calcination. As an example, the thermal calcination of limestone is given by

$$CaCO_3(s) \xrightarrow{T\uparrow} CaO(s) + CO_2(g)$$

The calcination temperature for the earth-alkaline carbonates, is dependent on the bonding strength of CO_2 with the earth-alkaline oxide and equals 414°C, 900°C, 1240°C and 1373°C for $MgCO_3$, $CaCO_3$, $SrCO_3$ and $BaCO_3$, respectively.

An example of reactive calcination of a carbonate is the calcination of soda ash via a solid-state reaction with silica sand resulting in the formation of a crystalline sodium silicate phase. The formation of sodium metasilicate ($Na_2O.SiO_2$) due to reactive calcination of soda ash with silica sand is given by:

$$Na_2CO_3(s) + SiO_2(s) \longrightarrow Na_2O \cdot SiO_2(s) + CO_2(g)$$

Although the formation of $Na_2O.SiO_2$ is already thermodynamically favourable at temperatures below 347°C, the kinetics of these solid-state reactions are low even at temperatures of 723°C. These low reaction kinetics are caused by slow solid-state diffusion of reacting species through the formed crystalline binary silicates towards the interface of the reacting grains. Enhanced reactive calcination is observed at the presence of a melt phase by which the transport of reactants and reactions products is acceleration due to the higher diffusion coefficient of the formed oxides in the liquid state compared with the solid-state.

4.1.4 Melt forming reactions: Melt phases are either formed by the melting of pure substances (e.g. the melting of soda ash at 856°C) or by eutectic melting of two solid species. An example of eutectic melting is the melting of a mixture of $Na_2O.SiO_2$ and $Na_2O.SiO_2$ at 837°C. The formation of these so-called primary melt phases is regarded as the measurable onset for both reactive calcination of carbonates and the dissolution of solid oxides in the glass batch such as e.g. silica (SiO_2), zircon ($ZrO_2.SiO_2$) and alumina (Al_2O_3).

4.1.5 Dissolution reactions: The dissolution rate of the oxides such as silica is dependent on primary melt phase properties such as viscosity, surface tension and composition. Next to these properties, the particle size of the oxide grains has a large impact on the dissolution rate of the oxides in the glass melt. Because the main fraction of commercial glass batches is occupied by silica, the dissolution process of silica is regarded as the most significant criterion for the degree to which the melting of a glass batch based on silica sand has advanced.

Concerning the melting of glass batches, two reaction paths are distinguished for soda- lime-silicate glass batches, i.e. the carbonate route and the silicate route.

The carbonate route is characterized by reactive dissolution of silica sand with a binary melt phase of soda ash and limestone at temperatures below 897°C. Soda ash and limestone may form a double carbonate by a solid-state reaction according to

$$Na_2CO_3(s) + CaCO_3(s) \longrightarrow Na_2Ca(CO_3)_2(s)$$

At 817°C the double carbonate forms a low viscous melt phase, with which silica grains may form a sodium calcium silica melt (silica reaction with $Na_2Ca\ (CO_3)_2$ forms a viscous $Na_2O.CaO.SiO_2$ melt plus CO_2 gas).

$$Na_2Ca(CO_3)_2(l) + \nu\ SiO_2(s) \longrightarrow NCS(m)^8$$

For the silicate route, the (eutectic) melting of crystalline sodium silicates is regarded as the onset for batch melting. The eutectic melting of soda disilicate with silica at 799°C is given by

$$Na_2O \cdot 2SiO_2(s) + SiO_2(s) \longrightarrow NS(m)$$

The carbonate route is assumed to be predominant at rapid heating rates in the order of 200/min whereas the silicate route is predominant at heating rates in the order of 10 K/min. The presence of different reaction mechanisms as function of heating rate was clearly demonstrated by experts, who studied the reactivity of mixtures of glass batch components with hot-stage microscopy. In general, the carbonate and silicate route reactions are as following Figure 3.12.

4.1.6 Melting points of silicate and eutectics are: The melting points of the meta-silicate Na_2SiO_3 and of the di-silicate $Na_2Si_2O_5$ are:

Ts (Na_2SiO_3) = @1089°C ; Ts ($Na_2Si_2O_5$) = @874°C

The melting points of Eutectics:

Teut ($Na_2O.\ 2SiO_2 + SiO_2$) = @793°C.; Teut ($Na_2O.\ 2SiO_2 + Na_2O.\ SiO_2$) = @846°C; Teut ($2Na_2O.\ SiO_2 + Na_2O.\ SiO_2$) = @1020°C.

In combination with calcium oxide, an even lower (ternary) eutectic temperature may occur.

Teut ($Na_2O.\ 3CaO.\ 6SiO_2 + SiO_2 + Na_2O.\ 2SiO_2$) = @725°C.

Carbonate route	$Na_2CO_3 + CaCO_3$	→ $Na_2Ca(CO_3)_2$	(melts at ±820°C)	(550-850°C)
	$Na_2Ca(CO_3)_2 + 2SiO_2$	→ $Na_2SiO_3/CaSiO_3 + 2CO_2$	reaction enhances > 820°C	
Silicate route	$Na_2CO_3 + 2SiO_2$	→ $Na_2Si_2O_5 + CO_2$ forms eutectic melt with SiO_2	(silica route)	(700-860°C)
	$Na_2CO_3 + SiO_2$	→ $Na_2SiO_3 + CO_2$	(silica route)	

Figure 3.12

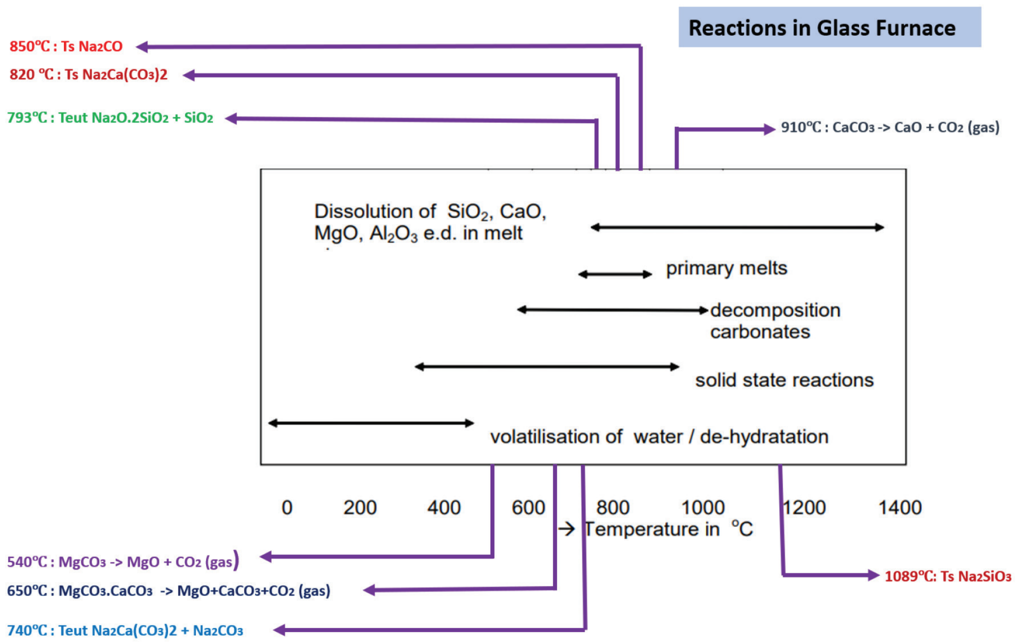


Figure 3.13

4.1.7 Summary of glass furnace reactions: Figure 3.13 shows the summary of various reactions taking place in glass furnace at different temperatures during batch melting.

4.1.8 Gas release during initial batch melting stage: During these initial batch melting reactions, much CO_2 gas is released. About 14 - 20% of the mass of normal soda-lime-silica batches is transferred into volatile CO_2. Besides CO_2 gas, the melting loss consists of water vapor (several mass percents, depending on: batch humidity, water content in cullet and presence of hydrated raw materials) and any possible evaporation products (SO_2, HBO_2, HCl, NaCl, HCl, KOH, PbO, Pb, NaOH, Se-components). For one ton of batch, approximately 100 SCM of CO_2 is released from furnace at room temperature and normal atmospheric pressure. This is almost equals to 500 SCM of CO_2 at furnace operating temperature and pressure.

4.1.9 Glass furnace emission in operation: Pollutants released during the manufacture of glass are sulphur oxides (SOx), nitrogen oxides (NOx), in very rare cases carbon monoxide (CO), carbon dioxide (CO_2) or nitrous oxide (N_2O). Also, emissions of heavy metals are produced by the melting process. Emissions of particulate matter can also result from handling raw materials. Heavy metals can sometimes be present in the particulate matter. The main relevant pollutants are SO_2, NOx, and CO_2. The waste gases released from melting furnaces consist mainly of combustion gases generated by fuels and of gases arising from the melting of the batch or vapour released from the melt, which in turn depends on chemical reactions taking place in the furnace. The proportion of batch gases from exclusively flame heated furnaces represents 3–5% of the total gas volume.

Sulphur oxides: The amount of SO_2 released during glass manufacturing is mainly determined by the sulphur content of the fuel, the sulphur content in the batch and the sulphur absorption ability of the glass produced. The sulphur added to the batch is partly bound in the glass as SO_3 or sulphide in the reduced molten glasses. Glass contains up to 0.4 wt.% SO_3. The SO_3 content in the flue gases is 5–10 % of the SO_2 content. The amount of SO_3 depends on the excess air. The SO_2 content in the off-gas is also determined by the operating conditions of the glass melting tank. With tank furnaces operated by alternating flame heating, based on the regenerative principle, an increase of the SO_2 content in the off-gas during the firing interval is observed. This is most likely due to enhanced sulphate decomposition at temporarily reduced combustion conditions, a decrease in the sulphur absorption ability of the molten glass with an increasing temperature in the upper zone of the furnace, and evaporation of already condensed sulphur species in the air preheater. The oxygen content in the combustion space of the furnace also has an impact on the SO_2 content of the off-gas. If the amount of excess air is decreased, in order to minimise fuel input and to suppress NOx formation, an increase in the SO_2 content of the off-gas may be observed. This is due to the fact that the sulphur absorption ability of the molten glass falls with decreasing oxygen content in the upper furnace zone and due to sulphate decomposition in the gas atmospheres containing reduced species such as hydrocarbons and CO. Since natural gas and city gas contain only trace amounts of sulphur, a much lower SO_2 content in the off-gas of glass melting tanks fired with gaseous fuels is observed compared to oil fired glass melting tanks.

Nitrogen oxides: The relevant NOx emission process step within the production of glass is the melting stage. NOx emissions released by glass furnaces are nitric oxides [NO to about 90% due to the near stoichiometric operation of the furnaces, the remainder of the NOx in the flue gases being nitrogen dioxide (NO_2)]. The concentrations of nitrous oxide in glass furnace waste gases are in general below the detection limit.

Four main NOx formation mechanisms exist. Three of them are combustion related and include thermal, fuel and prompt NOx formation. The fourth mechanism (the 'batch' NOx formation) results from the use of nitrates in the raw materials for certain glasses. In the glass melting furnace, the glass melting temperature ranges from typically 1350°C to 1600°C, leading to flame temperatures above 2000°C. This explains the presence of high NOx concentrations, almost exclusively due to thermal NOx formation. Several parameters influence the mechanism of thermal NOx formation: flame temperature, type of fuel (gas firing gives higher maximum flame temperatures than oil firing), oxygen content in the flame reaction zone, and retention time of the combustion gas in high temperature zones of the flame. These parameters are in direct relation with operating parameters as for example type of burner, burner positions, burner settings and melting furnace design, amount of excess air, mixing of fuel and combustion air, air velocity, etc. Prompt NOx formation is relatively small and when firing natural gas, fuel NOx is sensibly zero. The release of nitrogen compounds during heating of the nitrate containing raw materials and, in the refining, agents also contribute to NOx emissions. The quantity of nitrogen oxides arising from the feed material will be affected by the concentration and composition of the nitrates in the feed. For example, certain tinted glasses in the flat glass sector require the use of nitrates, which produce additional NOx emissions almost as great as uncontrolled emissions from a clear flat glass operation: typical emissions might be 2500 mg/Nm^3 for clear glass and 4000 mg/ Nm^3 for glasses that use nitrates. It must be acknowledged that such tints may be only occasionally manufactured. In the special glass industry, melting of much oxidized glasses or using fining agents such as antimony oxide or cerium oxide, requires addition of nitrates to the batch. This increases the NOx emissions for these furnaces.

When using gas-fired glass melting tanks, the flame temperature achieved is higher compared to oil. As a consequence, oil- fired tanks emit less NOx than gas fired tanks. Moreover, as end-fired furnaces have different flame characteristic from cross-fired glass melting furnaces, the former often show lower NOx emissions. Recuperative furnaces induce lower NOx emissions (if expressed in mg/Nm^3, not in kg/ton) than regenerative furnaces, due to their lower preheating temperature, but because of the increased energy consumption of recuperative furnaces (they are less energy efficient) the specific NOx emissions (per ton molten glass) may be almost the same as for regenerative furnaces.

Carbon dioxide: It is the major emission pollutant released from furnace. If natural gas is used as fuel in furnace, it generates CO_2 of 0.2296 T/T of glass. For various fuels, the CO_2 generation from combustion and from batch is given in Table 3.5.

This chart will help to identify opportunities to reduce CO_2 in glass manufacturing. By changing fuel or by changing batch composition, reduction in CO_2 is possible. Example: By replacing virgin batch with more cullet, CO_2 reduction is possible. Also changing fuel which generates lower CO_2 also can be used to reduce emission.

4.1.10 Process-related emissions: The most important source of atmospheric emissions is the hot furnace. The heavy metals from the raw materials or the fuel partly vaporize in the hot furnace. The heavy metals, depending on type of glass and raw materials, which are emitted to air, may be arsenic (in very few cases), lead and selenium.

If fuel oil or petroleum coke is used in the combustion process nickel and vanadium may also be found. In some areas of the world, fluorspar is often used as a flux in the melting process. If recycled glass originating from these countries is used in the batch some extra fluorine (HF) may be emitted.

4.1.11 Emission controls: Emission reduction measures in the glass industry include primary and secondary reduction measures,

Table 3.5

CO_2 Generation for a particular Glass Batch in Glass Furnaces for various fuels

Type of Fuel	CO_2 from Combustion (T/T)	CO_2 from Batch (T/T)	Total CO_2 (T/T)
Coal	0.4048	0.1465	0.5513
Fuel Oil	1.0596	0.1465	1.2061
Natural Gas	0.2296	0.1465	0.3761
All Electric Furnace	0.0000	0.1465	0.1465

mostly aiming at reducing emissions of NOx and SOx. Also measures for CO_2 reduction to reduce environmental impact are also important. Some measures include:

a) Lowering the amount of excess air;

b) Reduced air preheating;

c) Staged combustion;

d) Flue gas recirculation;

e) Reburning / 3R process;

f) Low NOx glass melting furnaces;

g) Oxy-fuel firing;

h) Electric melting;

i) Selective Non-Catalytic Reduction (SNCR);

j) Selective Catalytic Reduction (SCR)

Measures for decreasing emissions to air from the combustion process may also result in a reduction of the heavy metal and dust emissions. Dust emissions from handling raw materials can be reduced using fabric filters or using different improved handling techniques like ESPs. The emissions of carbon dioxide from the carbonisation process can be reduced by adding more recycled glass or using non-carbonate basic materials and by fossil fuel energy saving measures.

5. FURNACE HEAT UP, OPERATION AND MAINTENANCE

5.1 Pre-conditions for smooth operation of furnace

For smooth operation and high glass quality, the input quality of raw materials (batch), fuels and utility must be consistent. As the word saying GIGO (Garbage in Garbage Out), the input quality into furnace has direct bearing on output quality. Following are the major requirements:

1. Batch homogeneity should be consistent.
2. Batch raw materials quality (physical, chemical) should be according to specifications.
3. Batch moisture should be maintained within the specification.
4. Fuel CVs should be consistent as close as possible without much variation in pressure and temperature.
5. Combustion air and atomising air pressure should be maintained constant as far as possible.
6. Batch supply and feeding should be smooth without interruption such that glass level is maintained constant inside the furnace.
7. The atmosphere around the furnace should be well maintained with good ventilation system. The building with good roof should be constructed for furnace to avoid rain water entry on the furnace area. Rain water contact would lead to thermal shock and damage to refractories and also can spoil the furnace equipments leading to breakdowns. Furnace life and melting quality would depend on smooth operation of furnace with minimum interruptions.

5.2 Furnace Heat-up

Furnace Heat-up after Construction / Cold repair

a) Once the furnace is fully constructed and ready to heat-up, ensure that the entire furnace inside is totally vacuumed and no contaminants are present. It is essential to avoid glass quality problems at later stage.

b) Heat-up procedure to be properly followed. A recommended heat-up chart is shown below in Figure 3.14. The cullet charging slowly and steadily to be done by experts, till glass is drained. It would take another 72 hours for cullet charging.

c) During heat-up, proper furnace pressure is to be maintained. A thumb- rule for pressure is shown in Figure 3.15. If pressures below this guideline are attained, it should be noted that most of the heat source for the furnace bottom and throat will be via radiation from the crown. In certain instances, this may not be acceptable. If tamped

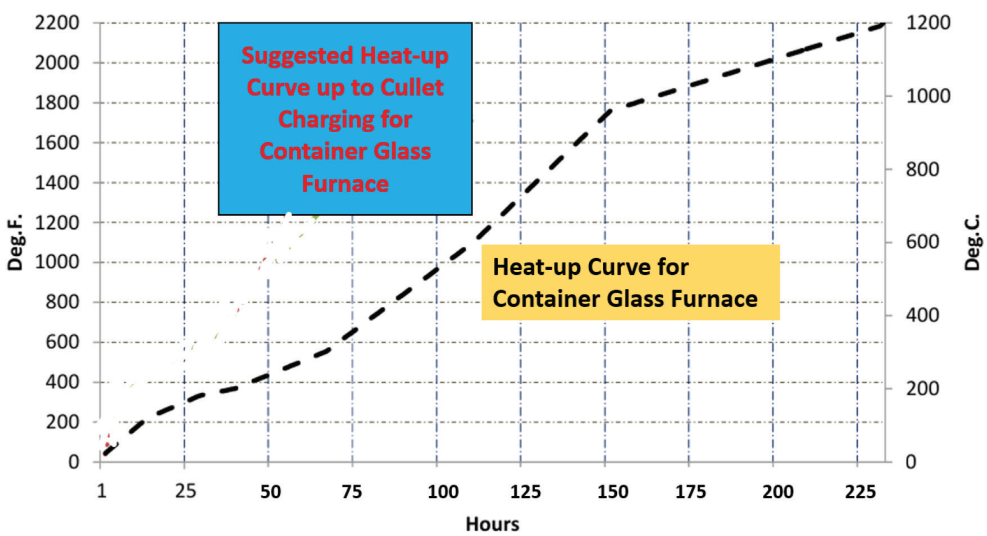
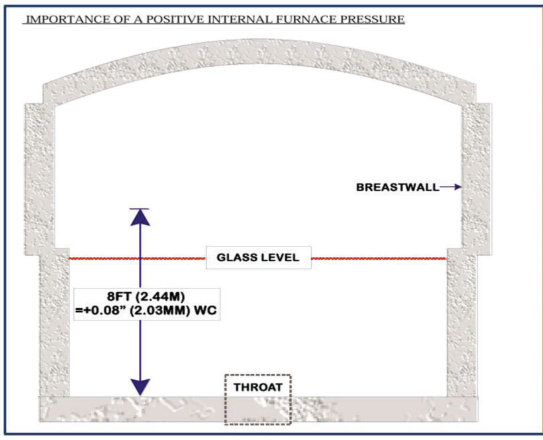


Figure 3.14



Furnace Pressure: During Heat-up Internal furnace pressure is one of the most crucial items in obtaining a thorough heat-up of the refractories. The furnace pressure must be high enough to drive the heat to the bottom, through the throat and out the forehearths. The pressure must also be constant. General rule of thumb is to have +0.01 inch of water column for every foot of height from the throat to the furnace pressure tap. If the tap is 8 feet above the throat, then the furnace pressure should be at +0.08 inch W.C or higher to ensure that the heat is driven to the bottom. GLASS LEVEL THROAT BREASTWALL 8FT (2.44M) =+0.08" (2.03MM) WC

Figure 3.15

or rammed refractories are present then steam explosions can occur when the heat source is via radiation vs. convective heat. Convection provides more uniform temperatures across the entire refractory surface and starts the drying process much earlier than radiant heat. It is also very important to note that excess pressure during heat-up will cause refractory joints opening-up from sealed areas wherever mortar is applied.

d) After 1250°C, cullet charging (flint) should be done under controlled conditions, as per recommendations of experts. Throat electric boosting should be switched on as per the specialist's suggestion so that the throat is not cooled to prevent glass getting frozen. Control the gas flow, temperature of furnace & working end and furnace pressure such that the cullet is melted as per the recommended rate of charging.

e) Cullet size should be uniform with size of 6 to 15mm. It is always recommended to use flint cullet while heat-up of furnace till glass is drained to avoid throat jamming.

f) Expansion control is a critical activity during heat-up. Experienced team should be engaged to control expansion.

g) Silica expansion is critical up to 650°C and later it remains constant, Figure 3.16 shows furnace refractory material expansion.

h) During heat-up, the furnace sealing and cooling is to be provided as per the furnace expert's advice.

5.3 Furnace operation after Heat-up

It's important that furnace is operated as per SOPs with minimum draw changes, to get better glass conditioning in forehearth. Some of the important points to be followed are following:

1. Furnace pressure should be maintained such that slight positive pressure is always maintained in dog house to prevent heat loss. Operating at high pressure should be avoided as this can lead to high energy loss, lower the furnace life and high maintenance. Operating at negative pressure will lead to cold air entry into furnace through various openings like dog house, peep holes etc.
2. Metal line cooling, throat cooling and all other cooling requirements should be provided as per furnace supplier's recommendation. Ensure correct flow and pressure for cooling.
3. Furnace pressure monitoring should be done accordance to design. Establish the correct

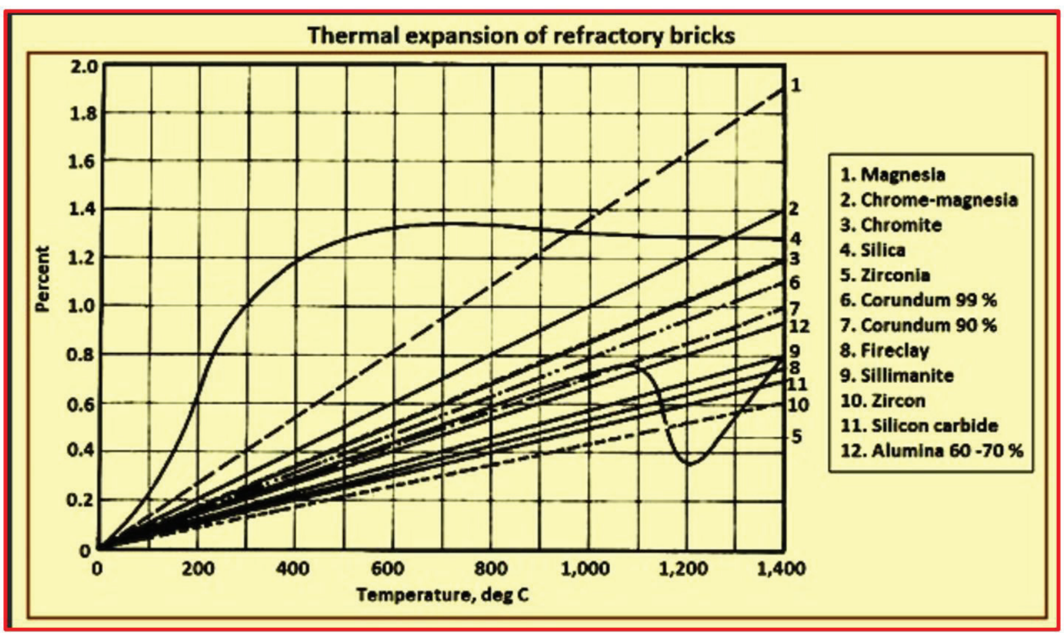


Figure 3.16

pressure by experience (by maintaining positive pressure) or by data analytics (analyse pressure vs. SFC or pressure vs. temperature etc.,).

4. Daily draw variation should be controlled and generally it should be within +/- 3%. For this proper production planning is essential. This will help to get consistent quality of glass with good furnace SFC. It is advisable to gradually increase or decrease draw to suit the production plan.
5. For proper melting, good glass flow currents are to be maintained. This is explained separately in this chapter.
6. Regularly monitor optical temperature immediately after the end of the reversal cycle. The optical measurement should be monitored on walls at same location to get the correct data.
7. Batch charging should work on auto. Good charging system with uniform batch piles are required.
8. Reversal timing can be fine-tuned by using data analytics. However, it is recommended to have the reversal timing within 20 to 30 minutes range. This can be discussed with designer of furnace. Reversal time can be optimized by data analytics for better SFC.
9. Many manufacturers in glass furnaces are losing significant amounts of energy because of too much air entering the furnace, resulting in heat loss through flue gases. The excess air results in oxygen that isn't consumed during combustion, and this oxygen absorbs otherwise usable heat and carries it out of the stack. The chemically ideal amount of air entering a furnace is just enough for all the oxygen in the air to be consumed. However, this ideal (known as the stoichiometric air-to- fuel ratio) is difficult to reach because fuel and air do not completely mix, meaning that a certain amount of excess air will always be necessary for complete combustion. In fact, too little excess air results in inefficient burning of fuel, soot buildup, and unnecessary greenhouse gas emissions. Excess air is to be measured at furnace to regenerator port during stable condition, preferably after 15 minutes of reversal timing. Oxygen in flue gas has to be measured to get excess air %. Following chart shows the relationship between O_2% in dry basis and excess Air.

To figure potential savings, you need to know: a) The temperature of the products of combustion as they leave the furnace. b) The percentage of excess air or oxygen in flue gases, at which the furnace now operates. c) The percentage of excess air or oxygen in flue gases, at which the furnace could operate. On the chart, determine the available heat under present and desired conditions by reading up from the flue gas temperature to the curve representing the excess air or O_2 level; then, read left to the percentage available heat (AH). Calculate the potential fuel savings:

% Fuel Savings = 100 X [(%AH desired- %AH actual) /(%AH Desired)]

10. For container glass furnace, recommended O_2% to be maintained in flue gas (in port), as following.

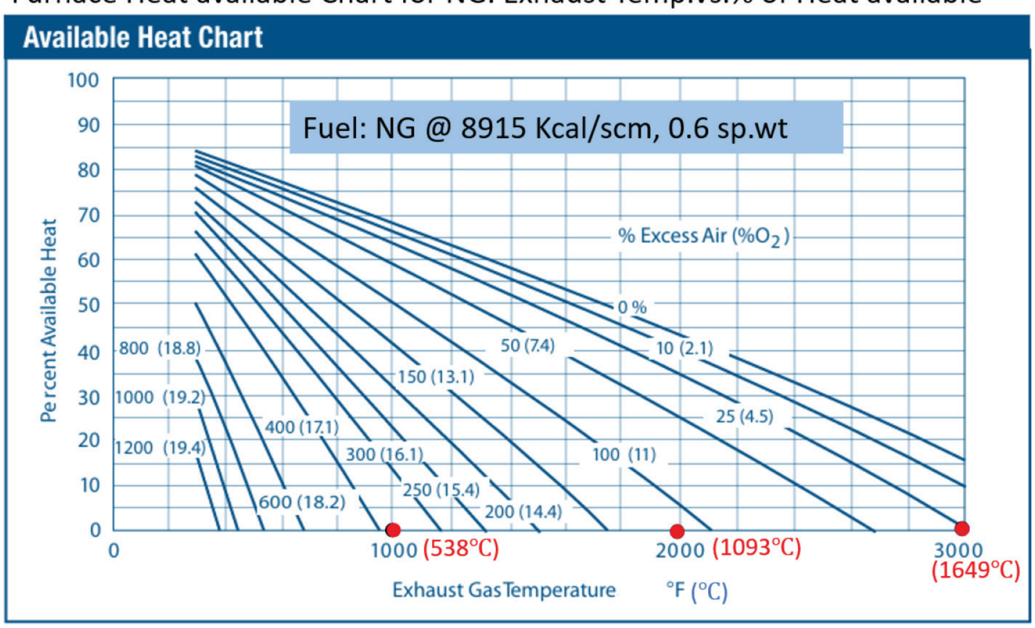
(i) NG firing – 1.8 to 2.2%

(ii) Fuel oil firing – 1.5 to 1.8%

(iii) Pet coke firing – 2.2 to 3%

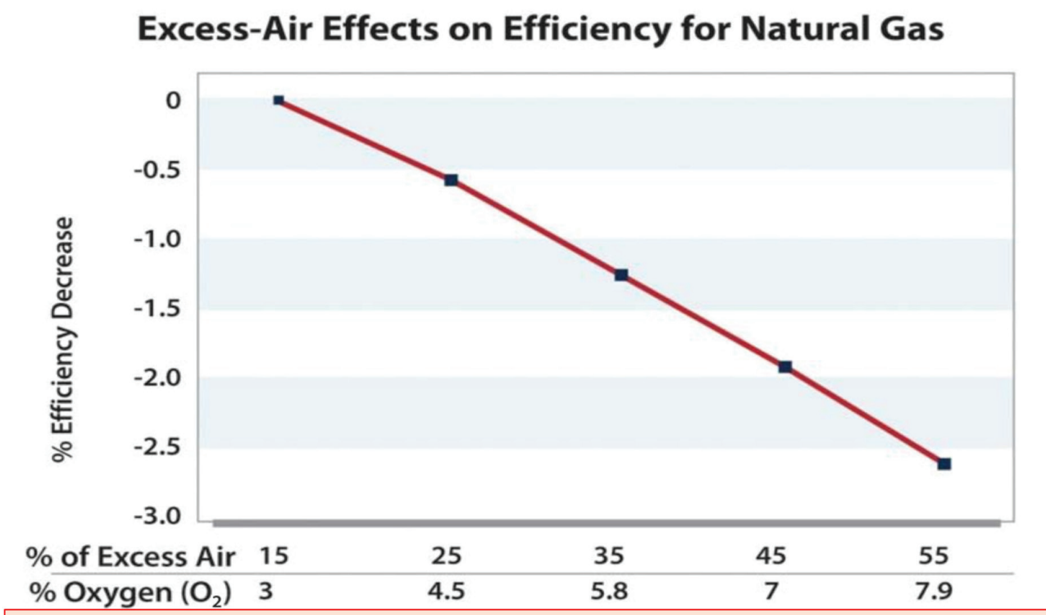
(iv) Producer gas firing- 1.5 to 2%

Furnace Heat available Chart for NG. Exhaust Temp.Vs.% of Heat available



Use the available Heat Chart above to estimate the savings obtainable by tuning burner air-gas ratios. The excess air curves are labeled with corresponding oxygen percentages in flue gases.

Figure 3.17



Example: When O_2 in Exhaust increased to 7% from 3% (Excess Air to 45% from 15%), Thermal Efficiency drop is close to 1.9%

Figure 3.18

(v) LPG Firing – 1.8 to 2%

The following chart (Figure 3.18) shows thermal efficiency drop for NG at various excess air levels.

11. The amount of excess air within the system can be determined by analyzing the amount of oxygen in the flue gas. Use natural gas combustion as an example. Assuming the CO level in flue gas is very low and incomplete combustion can be neglected, oxygen content in flue gas can be measured in two numbers: dry reading A% or wet reading B%. With those measurements, the following formulas can be used to calculate excess air:

Excess air% = 0.895xA%/(21-A%) where A% is dry O_2 reading

Excess air% = 1.105xB%/(21-B%) where B% is wet O_2 reading

Figure 3.19 shows the difference in dry and wet O_2 measurement.

12. The chart (Figure 3.20) shows the relationship between furnace flue gas temp. vs. % heat utilised for various % of excess air and combustion air temperature. The example shows how to use the chart.

Example 1: A glass furnace is having exhaust flue temperature of 600°C @ 2.09% O_2. If the exhaust temperature can be brought down to 400°C, find the energy saving for same excess air (conditions are marked in red, in chart).

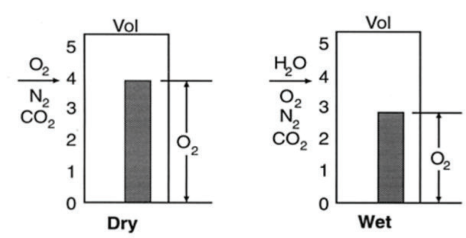
Solution: From chart, @ 600°C, the heat utilised is 66% and @ 400°C, it is 75%. By reducing flue gas temperature by 200°C, 9% of energy can be saved.

Example 2: In glass furnace, the combustion air temperature is increased from 316°C to 538°C by waste heat use. The excess air is 10% and flue gas temperature is 600°C, for both cases. Find the energy saved for this situation.

Solution: The conditions for the above situations are marked (yellow) in above chart @316°C & 538°C. The heat utilised @ 316°C of combustion air is 77% and at 538°C, it is 85%. Hence saving is 8%.

13. Automatic glass level with good consistency is essential for good glass quality, good production and energy saving. Highly advanced measurement

Wet & Dry O2 Measurement Comparison



The definition of oxygen measurement on a "dry" basis is based on the assumption that the moisture content in a flue stream is removed before the oxygen content is measured. Portable oxygen analyzers provide a "dry" oxygen measurement.

There will be a difference in the two methods of measuring oxygen. The assumption is that this difference is due solely to moisture (H_2O). The following relationship holds:

$$O_2 \text{ dry} = O_2 \text{ wet} (1/1\text{-}H_2O)$$

As H_2O appears in the flue stream, O_2 dry measures higher than O_2 wet.

In situ oxygen analyzers measure oxygen content on a "net" and "wet" basis. Portable oxygen analyzers provide oxygen measurements on a "gross" and "dry" basis. Consequently, the two may provide different readings. Generally, if the measurements from the portable analyzer are slightly higher than the measurements from the in situ analyzer, the in situ analyzer is considered to be properly calibrated. However, if the oxygen measurements from the in situ analyzer are higher than the readings from the portable analyzer, then it is likely that a problem exists. A known test gas can be used to verify the accuracy of both the portable and in situ analyzers.

In order to verify that the in situ analyzer is properly calibrated, a known oxygen balance nitrogen test gas can be injected into both the in situ analyzer calibration port and the portable analyzer's input port. In this case, because no combustibles or moisture are present in the known test gas, the readings should be identical. This verification can be completed using a Rosemount Analytical Portable O_2 Test Gas Kit.

Figure 3.19

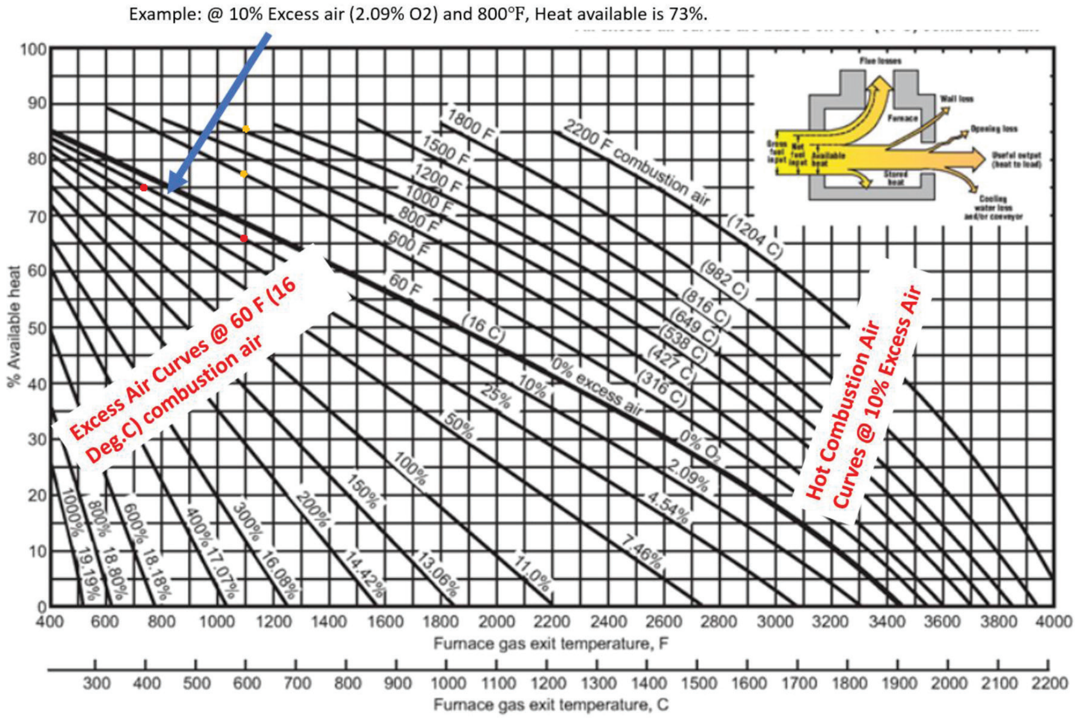


Figure 3.20

and control systems ensure exact and reliable determination of the glass level in the furnace during the melting operation. If the glass level sinks below a specified level, a signal is automatically relayed to the batch charger that then feeds new molten material into the furnace. There are several methods of measuring glass level such as glass contact probes, probes that detect the ionized air layer just above the glass bath, probes using isotopes and vision systems. All face the same problems; they need to be very precise and they will have to operate, over a very long time, in very harsh environments.

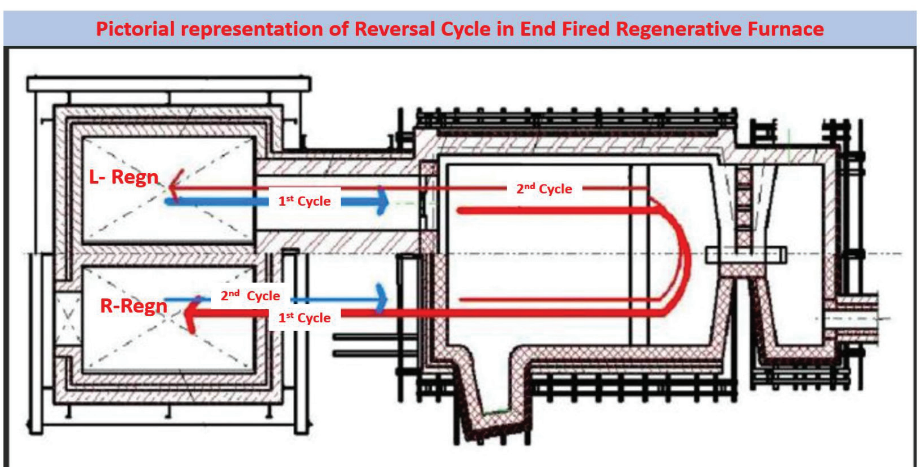
There are few types of glass level controllers and they are:

a) Contact Probes: Many systems utilize glass contact probes, often with platinum tips, to measure the glass level directly. These probes can operate in high-temperature and harsh environments, providing reliable measurements.

b) Radar Sensors: Some advanced systems employ radar technology to measure glass levels without direct contact. These sensors send radar waves to the glass surface and calculate the level based on the time it takes for the waves to reflect back, offering high accuracy and minimal maintenance.

c) Electrode Systems: There are water- cooled and ceramic electrodes, respectively, to measure glass levels through the furnace walls or feeders. These systems can automatically relay signals to batch chargers to maintain optimal glass levels.

Glass level controllers are vital components in the glass manufacturing process, ensuring that furnaces operate efficiently and produce high-quality glass. With various technologies available, including contact probes, radar sensors, and integrated systems, manufacturers can choose solutions that best fit their operational needs. For more detailed



Reversal system: During the 1st reversal cycle, combustion air flows through L-Regn and during this time, burners installed in Melter below the Left side Port are getting fired. The combustion waste gas (after heat partly utilised for Melting in melter), at high temperature then flowing to Right side regenerator and flowing down through Chequers. During this period, chequers absorb heat and Flue gas temperature drops to around 450°C and then flue goes out to Chimney. Flow of combustion air and Flue is shown in bold Blue & Red arrows. After the reversal, the cycle changes and Combustion air flows from Right regenerator and absorbs heat from Checkers and Cools the chequers, thus recovering the heat. Then this is used for combustion in Right side burners and the flue is passing to chimney through Left Regenerator. While passing through chequers of R-Regn, heat is absorbed by Chequers (which was cold after 1st Cycle) and Flue gas temperature is dropping to around 450°C. The Chequers release heat to Combustion air during the next cycle (3rd Cycle). This is achieved by Reversal system installed in the furnace and the cycles repeats continuously.

Figure 3.21

information, you can explore specific products from manufacturers like SORG, ZIPPE, and HORN. Accuracy up to +/- 0.1 mm is achievable.

5.4 Reversal system in Container Glass Furnace: In regenerative furnaces heat recovery is possible by installing regenerators. There are two types of regenerative furnaces namely end fired and cross fired regenerators, as explained earlier. Heat recovery through regenerators is achieved by reversal system where combustion air is used for burning fuel is getting heated by Flue gases, as explained in below image. Figure 3.21 show reversal system in an end fired regenerative furnace and the system is for cross fired.

5.5 Glass flow Currents & Heat transfer: With good experience, one can achieve lower SFC, high glass quality and increase draw at lower temperatures, if good glass current is maintained. The following image shows the heat transfer process in glass furnace. In the furnace, heat source is by pet coke, hydrogen, gas, oil or electrical. The heat source is the flame for pet coke, gas or oil which is above batch and below the crown. The Figure 3.22 shows the heat transfer in a cross fired furnace.

The temperature of the flame is higher than the furnace crown, super structure, the batch piles and the molten glass. Heat is therefore, transferred from the flame to those areas by radiation and convection. The main heat transfer from flame and waste gas is by radiation. Transfer by convection happens only when flame touches the batch. Below glass level, heat is transferred to the underside of the batch by conduction, radiation and convection. From the molten glass. Heat is transferred to the molten glass mainly by radiation from flame and crown. However, some heat is transferred by convection and conduction too. The heat within the glass is travelled by internal radiation, conduction and convection. Figure 3.23 shows the heat transfer and glass flow currents in a glass furnace.

Maximum heat is utilised (80 to 90%) for batch melting as it involves raising the temperature till the batch melting stage and then the heat required

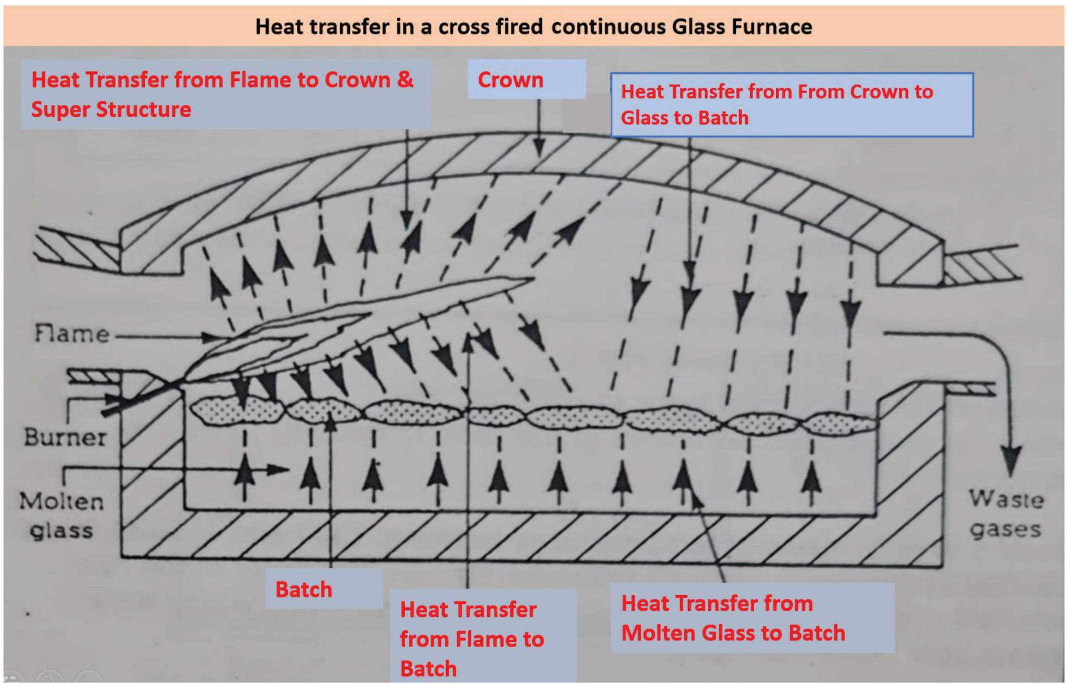


Figure 3.22

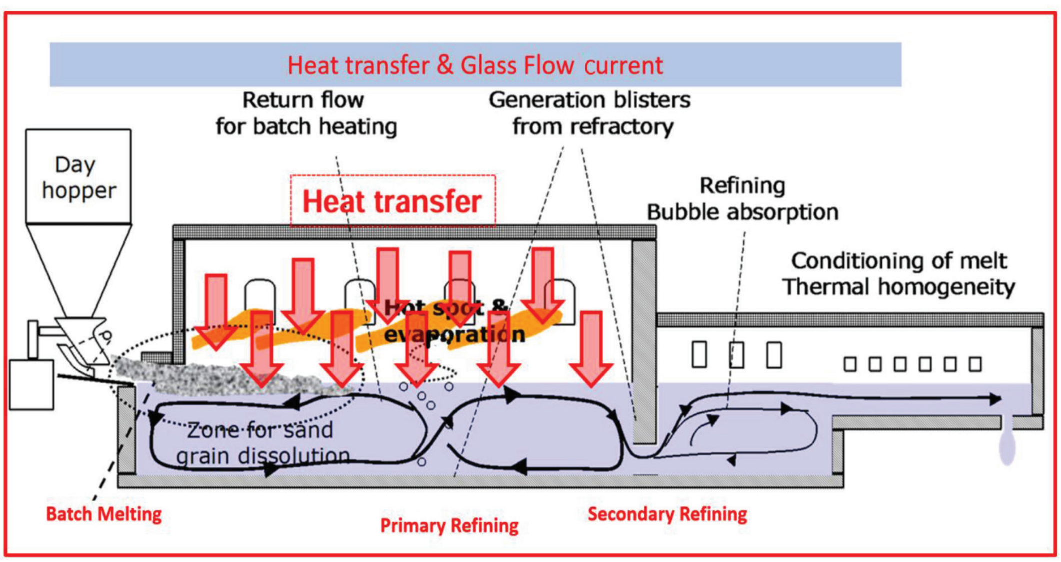


Figure 3.23

to convert glass into liquid state from solid state (latent heat). Very less heat is required for primary and secondary refining.

5.5.1 Glass flow current

The batch is heated by fuel firing in the furnace or by electric heating. Batch is slowly turning into molten glass and it starts flowing, following certain patterns due to pull and free convection. As the temperature in different areas of furnace are different, the viscosity & density of glass varies in every area of furnace, the free convection flow is generated. The entire batch & glass is trying to move towards the hot spot where the viscosity & density of the glass is lowest. This avoids shortcut of glass flow directly and helps in good melting of glass.

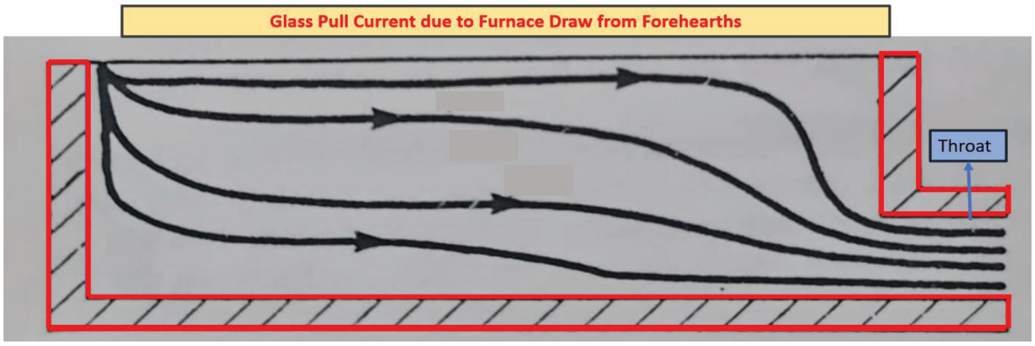


Figure 3.24

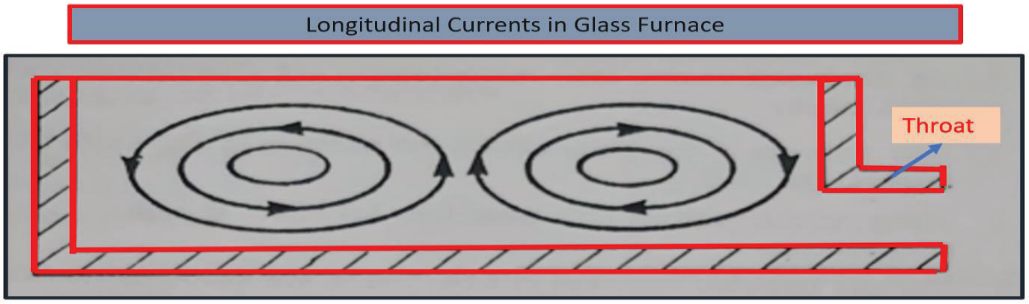


Figure 3.25

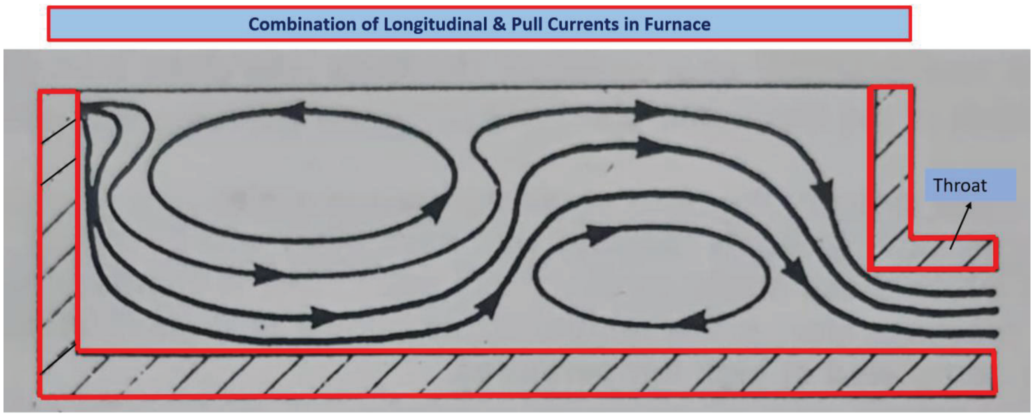


Figure 3.26

There are two types of glass flow currents in furnace. They are generated naturally due to glass pull (draw) from forehearths and different temperatures in furnace in different areas of furnace.

5.5.2 Pull durrent: Pull is the term used in glass industry for the amount of glass that is being drawn from the furnace for production. This pull is sum of all machine's draw and draining from conti-drains. Glass pull is generated due to flow of glass from the forehearths. The glass is flowing to the forming machines from forehearths through throat. This draw is generating the pull current in the furnace.

Figure 3.24 shows the pull current generated due to draw.

5.5.3 Longitudinal current: In the furnace, the batch is charged from doghouse area of the furnace at normal temperature. The flame in the furnace heats the different furnace areas differently creating many temperature distribution zones. As explained above, due to different zones, the glass density viscosity vary in each position of furnace. This creates longitudinal currents in glass as shown in Figure 3.25.

The pattern assumed by the two above currents can be quite complex because they are all influenced by the pull current, furnace design and temperature distribution along the furnace length.

5.5.4 The actual currents in furnace may vary due to following various reasons:

a) Design

b) Draw / Pull

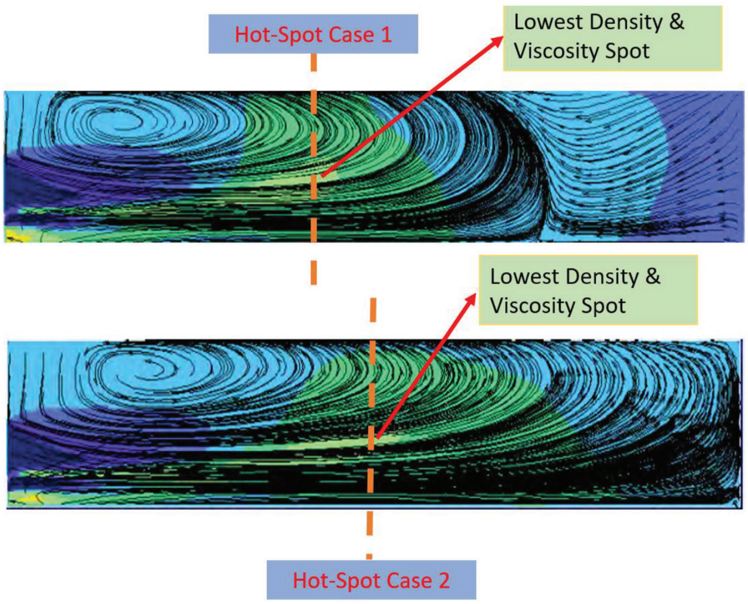
c) Temperature distribution, Hot Spot

d) Boosting

e) Barrier, melter boosting (side, bottom)

f) Bubbler

g) Weirs & Dams



When Hot-spot in furnace is changed, the Glass flow current is changing as shown here. In Case 1, the Glass currents are of shorter dia. circle where as in case 2, when Hot-spot is moved forward, the Glass current are of larger dia. circles . This is due to change in Glass density & Viscosity of glass in Hot-spot area in case 1, when hot spot changed.

Figure 3.27

Let us discuss how the above factors can impact the glass currents.

Design: Design of furnace like type, size, fuel, design provisions like electrical boosting, bubblers and weirs & dams will have impact on glass flow currents in furnace. These flow currents will impact glass quality, furnace sfc, temperatures and furnace melting capacity.

Draw / Pull: Increase or decrease in furnace draw will create glass pull current towards the throat. This will impact the temperature, melting quality and glass quality.

Temperature Distribution / Hot spot: The hot spot in furnace can be adjusted by burner angle, pressure and fuel characteristic. Here also, due to the hot spot location in the furnace, the glass movement will change, as shown in Figure 3.27.

Boosting: Due to boosting, the batch heating improves and glass temperature pattern in furnace at top, middle and bottom changes compared to non- boosting (base case), resulting in change in glass flow current. Figure 3.28 shows temperature changes for base case and boosting case.

Bubblers: The linear row of bubblers is usually installed between melting and refining zones of the tank. The influence of bubbles on glass is very strong as the carry-over effect helps the gas refining process to be completed more rapidly and effectively. Bubbling improves the heat transfer by bringing the relatively colder glass melt from the bottom to the surface of the melt. During the ascent and growth of the bubbles, they enhance the flow of molten glass around them, absorbing

Temperature gradients (Over top glass Surface) and Glass Currents for Furnace without Boosting (Base Case) and Boosting Case. This pattern depends on Boosting capacity, draw, Furnace temperature, batch composition etc.

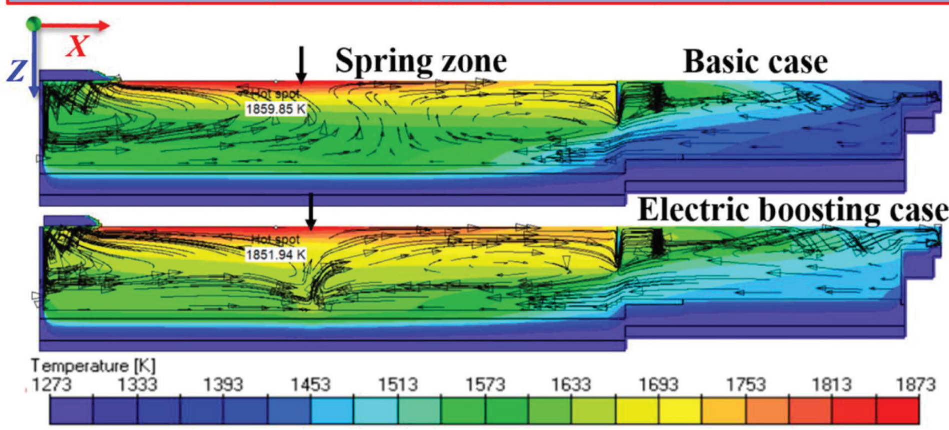


Figure 3.28

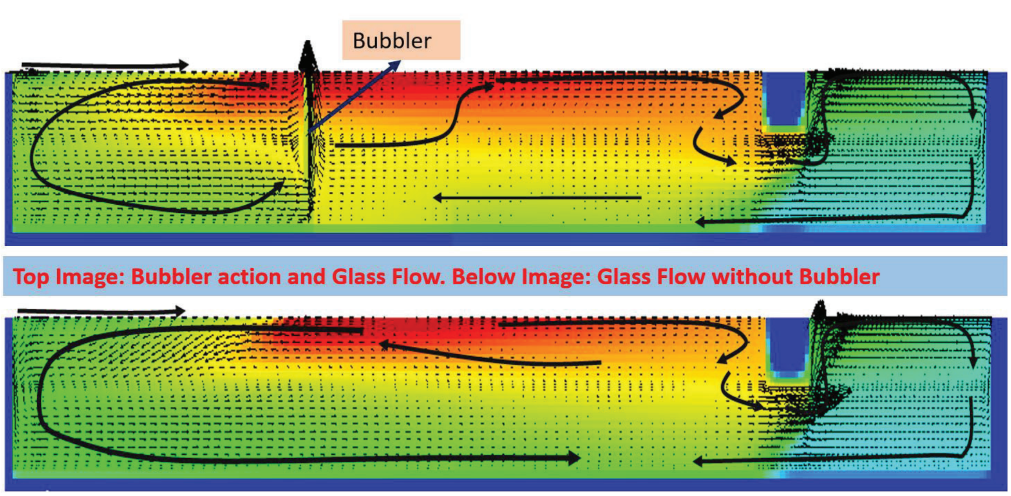


Figure 3.29

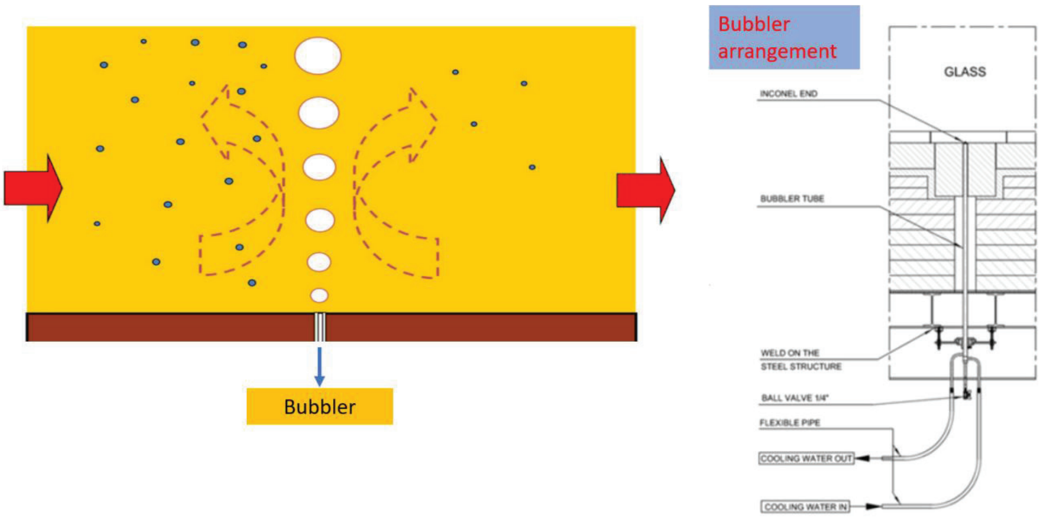


Figure 3.30

some small bubbles in the process. Thus, the bubbling process improves glass melting efficiency, enhances glass clarification, and promotes uniformity. However, the working environment of bubblers involves high temperatures, especially at points in contact with glass, requiring materials that can withstand temperatures above 1100°C. This involves using either special high- temperature-resistant materials or employing dedicated cooling systems.

Figure 3.29 shows the bubbler action on glass flow current.

Bubbler is a good option for improving glass quality; however, maintenance & operation should be done properly. The bubbler arrangement is as shown in Figure 3.30

Weirs & Dams: Similar to bubbler, dam-wall improve the temperature profile and glass flow currents, resulting in remarkable influence to the glass quality and saving energy. The application of a weir (cross wall, flow barrier, dam) will influence the glass melt flow (mostly applied in the area of the hot- spot).

5.5.5 Hot Spot in Furnace: Figure 3.32 shows an example of the Temperature pattern in a large Furnace.

5.5.6 Computer based – CFD (Computational Fluid Dynamics) simulation of an end fired furnace: CFD is becoming popular and very useful tool to see the performance of furnace before furnace is installed. This will give the overall characteristics of glass with respect to various input & output conditions. Figure 3.33 shows an example of CFD where temperature gradient of glass & furnace can be seen in the simulation.

After the design of the furnace, one can go through CFD simulation to check the design parameters and see whether any changes are required in design.

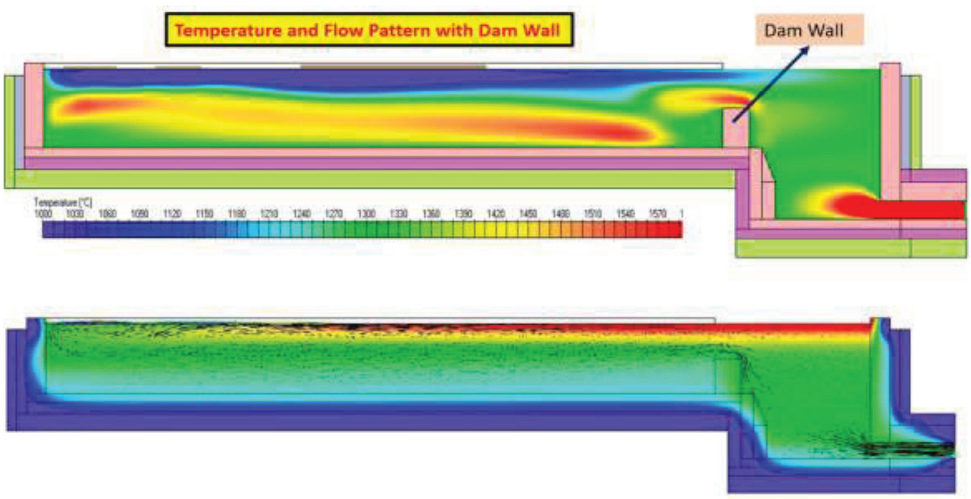


Figure 3.31

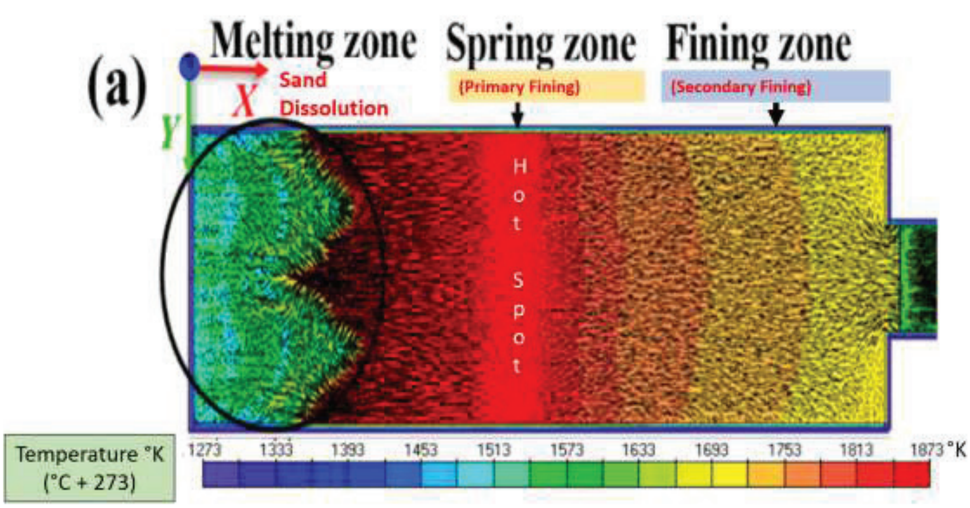


Figure 3.32

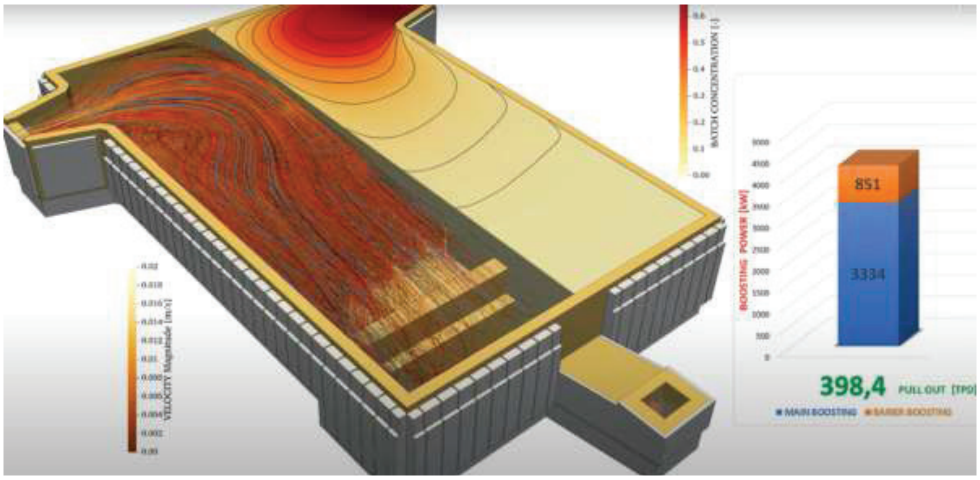


Figure 3.34

Glass Service can conduct CFD simulation independently. The glass melting process is too hot to make easy measurements & analysis or look inside into the process. Therefore, physical modelling and more recent Computational Fluid Dynamics (CFD) have become a vital and necessary tool to optimize the combustion, glass melting, conditioning and forming process. With the simulation tools you can find significant benefits and improvements, without any risks to disturb the actual process or destroy the expensive investment.

Figure 3.34 shows an example of CFD Simulation.

One can check the energy consumption, temperatures, pull and other important parameters during the simulation and make corrections in design suitably to optimise the parameters. This can be a good tool to save investment cost also.

5.5.7 Importance of Hot Spot: In the glass melting furnace, hot spot is very important to create proper glass flow current and avoid the short-circuiting of glass for proper melting and refining. Normally the hot spot is created at 50% to 70% of the furnace length. Hot spot very close to dog house will create loss of heat as the exhaust is close to dog house and flame can short-circuit. This also can make the furnace capacity to drop as the batch melting time is very short. Similarly, if hot spot is very far (close to throat), the refining may not complete as the batch melting itself would take long time. When hot spot is close to throat, the riser temperature of glass from throat also will increase which may impact glass conditioning issue. Hence a balanced approach to maintain proper hotspot considering the furnace design, draw and glass quality to be decided. This requires good practical glass furnace operation knowledge and proper monitoring of temperatures, observation of glass melting & currents (batch movement, scum area and refining area) and burner settings.

Also, the utilisation of electric boosting in melter area and barrier area in terms of loads to be decided on various factors like draw, design, hot spot, glass quality etc.

5.6 Glass residence time in Furnace: Independently of the type of glass we are going to produce, or which kind of furnace we are going to install, the final quality of our glassware product might be rejected due to dimensional instability or cosmetical defects, which are both linked to the quality of the glass melt in terms of physical and chemical homogeneity, thermal stability, aging of contact glass refractories and turnover time of the melt inside the refractory tank (furnace). The glass melt requires a MRT (minimum residence time) within the melting tank in order to be adequately processed. To avoid defects, it is important to ensure that all particles remain in the furnace long enough to allow good dissolution and homogenization. Minimum residence

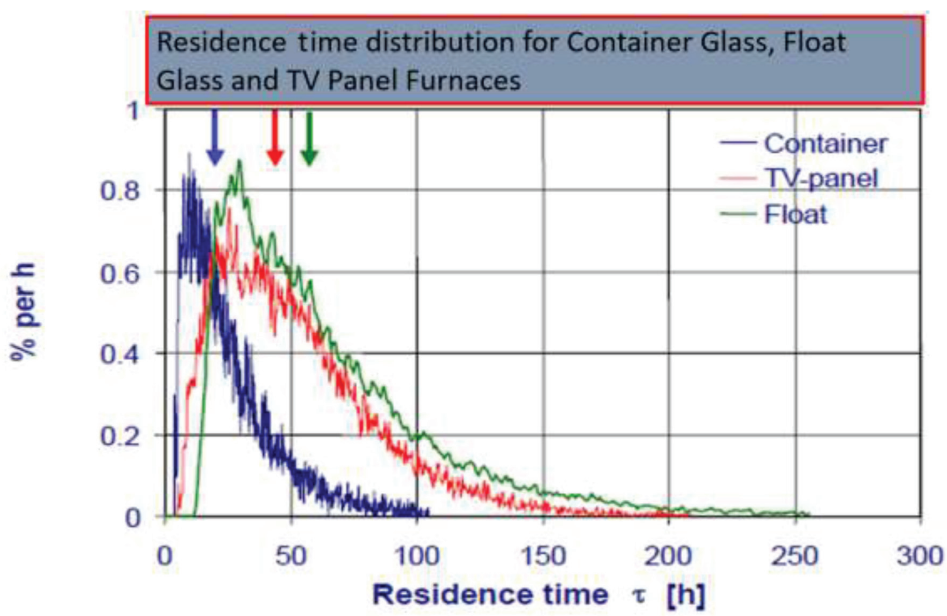


Figure 3.35

time is thus a very important factor for a good glass quality and homogeneity. The Processing includes completely dissolving the raw materials, removing the bubbles, and homogenizing the melt. Therefore, the glass melt must be circulated and mixed sufficiently within the tank to yield a product that meets the quality specifications. Convection flow has the greatest influence on the residence time as well as the circulating and mixing behaviour of melt. Figure 3.35 shows the minimum residence time for few types of glasses.

Ratio of the minimum residence time / Average residence time for container Glass is between 0.14 to 0.19.

5.7 Furnace Maintenance: Lesser the breakdowns in the furnace, the furnace life can be better and with smooth furnace operation, higher glass quality can be achieved. Any interruption in furnace operation will lead to abnormal changes in furnace behaviour, which will impact melting and change furnace parameters (pressure, temperature, expansion, cooling). This will ultimately impact glass quality and furnace life. A good furnace repair expert in company earns the respect of everyone concerned with furnace life, production, good furnace operation and fuel economy.

The maintenance activity can be split into following:

1. Refractory maintenance
2. Mechanical equipment maintenance
3. Instruments & controls maintenance
4. Electrical equipment maintenance
5. General maintenance

Furnace is always at very high temperature in normal operation and most of the furnace maintenance activities are carried-out in hot condition. Many times, the engineers and operating personnel make superficial inspection due to hot conditions in the furnace area and they neglect the inspection leading to poor maintenance. As the furnace is the heart of glass manufacturing, it should be given top most importance as any disturbance in furnace will make the entire glass production to suffer. For encouraging the operation & maintenance team to do proper inspection of furnace, working environment and safety to be given top priority. There should be good approach to all critical areas like throat, furnace crown, regenerator crown, peep holes etc., so that the maintenance team can easily approach those areas safely for inspection. Regular inspection around the furnace should be carried-out by safety & furnace heads to check the safety and working environment conditions. Any abnormalities or improvement possibilities observed should be attended quickly to make the areas safe for doing maintenance.

As furnace maintenance activity is itself a large subject and difficult to cover it fully in this book, only few important guidelines are provided. It is recommended that the factory prepare their own maintenance & repair manual covering all the equipments/ refractories in the furnace. For this activity, following are the recommendations:

a) Depute few personnel for training on operation & maintenance of furnaces by experts like AGR, Glass Service etc. The trained personnel may be asked to prepare the manual.

b) Get complete repair and maintenance procedure / manuals from refractory and equipment suppliers. This can be part of the maintenance manual.

c) Engage specialists for critical major maintenance or inspection works. Critical jobs like furnace drilling, replacement of bottom boosting electrode holders, repair of throat, cleaning regenerators, etc., may be carried-out by experts. Note down the procedure adopted by experts or get the procedure from them for future works. However, avoid any adventurous kind of maintenance in Furnace, if there is not enough skill and knowledge. There are many instances in Industry where during the repairs glass leak, crown damage and fatal accidents occurred, resulting in abrupt stoppage of furnace.

d) Engage specialists for preparing operation & maintenance manuals and training the team. Also utilise their services as and when required for supervision of critical maintenance activities.

5.7.1 Refractory maintenance: 90% of furnace construction involves refractory. Glass is contained by special refractories in furnace. Firing and heat is contained by special refractories in furnace superstructure and crown. Flue transfer and heat transfer taking place in furnace ports & regenerators, where special refractories are used. Similarly for molten glass flow from throat is to machines, special refractories are used in throat, working end and forehearths. Different refractories for different applications are used in glass furnaces and hence good knowledge of type of refractories & their maintenance is necessary.

Refractory maintenance involves following steps:

1. Proper heating, cooling procedures
2. Refractory inspection

3. Refractory repairs – hot & cold repairs

Systematic heat-up and cooling procedure to be adopted for new refractories used in furnace construction as per standard guidelines. After heat-up, cooling adjustments, especially for furnace sidewalls in furnace glass level area (metal-line), joints etc., to be made properly. Cooling Pressure and quantity to be monitored and ensure that it is meeting the requirements.

Regular refractory inspection may be carried- out by factory team and outside agencies. Following are the recommended activities:

a) Periodic visual inspection by operators & engineers.

b) Regular refractory surface temperature monitoring by non-contact thermometers.

c) Endoscopic inspection of furnace to gauge the refractory corrosions, blockages etc.

d) SmartMelter® radar inspection by Paneratech or other experts to gauge the furnace refractory thickness (especially bottom and side wall).

5.7.2 Periodic visual inspection by operators & engineers: A periodic inspection will help in identifying the maintenance requirement of the furnace. A checklist may be prepared and provided to engineers & operators for noting the observations. Checklist can be a part of SOP of furnace.

5.7.3 Regular refractory surface temperature monitoring by non- contact thermometers: The furnace refractories are subject to continuous corrosion due to glass flow currents in glass contact blocks, chemical & thermal actions on super structure & crown refractories, chemical & mechanical actions on regenerator checkers etc. The main reasons for corrosion are shown in Figure 3.36.

It is recommended to regularly monitor the refractory surface temperatures in critical areas like side blocks, bottom blocks, and throat blocks. As the thickness of refractory reduces due to corrosion, the surface temperature will keep on increasing for same operation parameters. It is always better to measure the temperatures on same surface points regularly to get the proper gauging the refractory corrosion and taking preventive action.

When it becomes necessary to make more extensive repairs to sidewall, throat or bottom, it may be necessary to keep the glass from draining out of the area that is being patched. This may require partial draining of glass. The area where patching is required, the surface to be cleaned by chipping of any cold glass present on the surface and then repair block or overcoat block should fit as tight as possible to the outside of the block.

To achieve longest possible furnace life, overcoat blocks shouldn't be installed sooner than necessary. When an area of the sidewall glass line (metal line) can no longer be darkened with wind and or when there is clearly visible number of small cracks on the surface, then overcoat is necessary. But it must be noted that once overcoating is done, the cooling wind will not be effective on the original block and this accelerates the erosion of the original block. Therefore, it is necessary to seal the worn metal line area of original block with high alumina mortar and keep the cracked side wall blocks intact using steel gratings with jacks as long as possible. Then the cooling wind can still be effective until the blocks are worn thin and overcoating block is fixed.

It is recommended to use solid AZS blocks to overcoat the side walls, throat or bottom. Regular cast AZS blocks are not recommended for overcoat instead use solid cast AZS blocks which are denser and have no scar. They are available in standard sizes. It may be necessary to go for second overcoat some times and it is good practice to overcoat larger area than the area covered during first overcoat. In most cases installing second course of overcoat over the first overcoat is not recommended. It is better

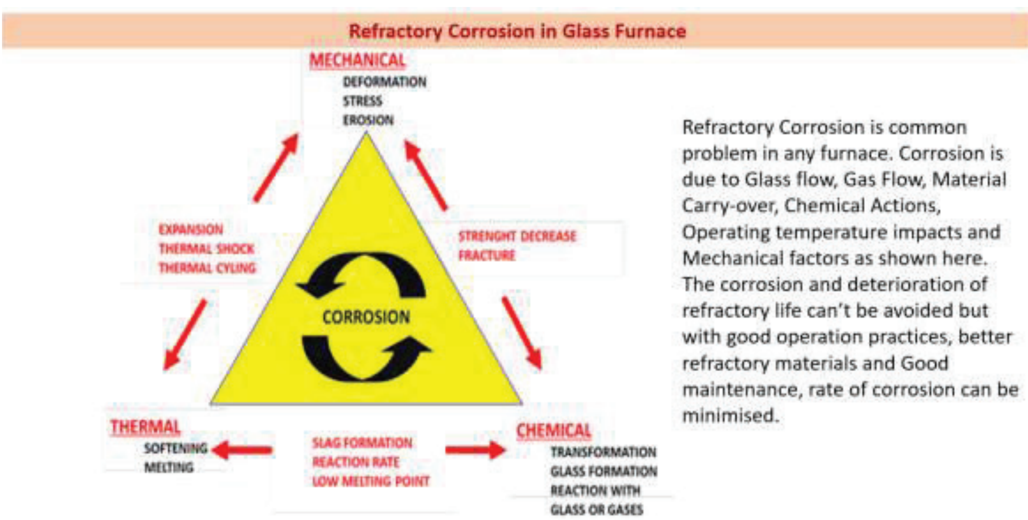


Figure 3.36

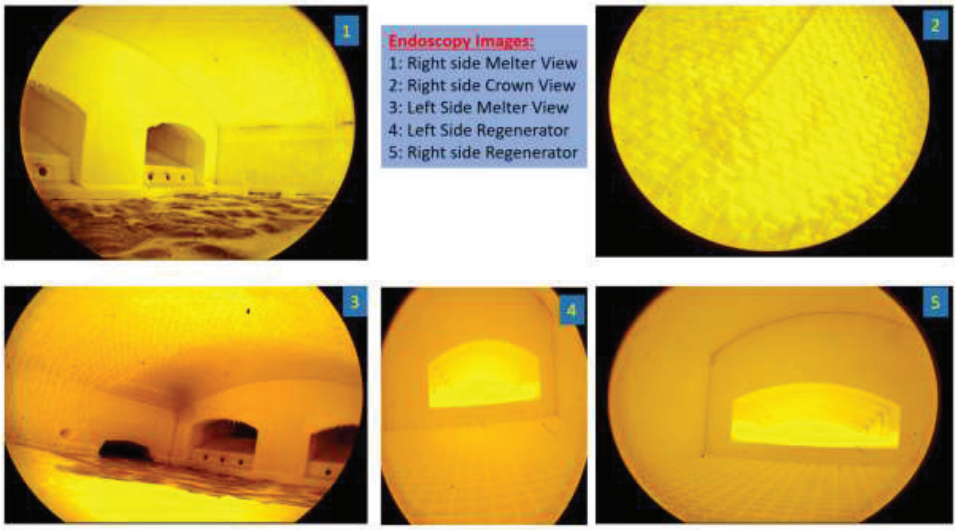


Figure 3.37

to remove the old overcoat carefully and then provide new overcoat over the original block.

5.7.4 Endoscopic inspection of furnace to gauge the refractory corrosions, blockages etc.: Regular endoscopic examination is always encouraged to monitor the inside condition of the furnace as it is not possible to inspect the entire inside area by operators and engineers. Figure 3.37 shows few pictures captured by endoscopy camera.

Endoscopy of furnace is to be carried-out as per following recommendation:

a) Immediately after furnace heat-up and commissioning – This is required to ensure that all the refractories are intact after heat-up and no refractories (especially crown block) dropped or misplaced.

b) Once in two years till it is achieved 6 years of life.

c) Once in a year there after.

d) If required, depending upon the condition of the furnace, the endoscopy can be more frequently carried-out.

There are few companies like Fosbel, SORG, HORN, SEPRO that do regular endoscopy and recommend actions if any abnormalities are observed. It is better to have an annual contract with them for proper inspection and analysis. If there are many furnaces in a factory, one can have their own endoscopy instrument and team to evaluate the result.

Endoscopic examination of furnace is a very good tool for good maintenance of furnace which will result in increased furnace life and produce good quality of glass. The findings can be rectified immediately by taking actions like ceramic welding of crown, cleaning the checkers etc. M/s Fosbel and other reputed companies can carry-out hot repairs by ceramic welding.

5.7.5 SmartMelter® radar inspection by Paneratech or other experts to gauge the Furnace refractory thickness (especially bottom and side wall): This kind of services may be obtained for inspection of furnaces to avoid major incidents like Glass leak from bottom, throat or side walls. The inspection can predict the block (refractory thickness) thickness and accordingly corrective actions, if required can be implemented. SmartMelter® can measure residual refractory thickness and make overcoat recommendations at the metal/flux line, throat, and electrode/bubbler blocks. Sensor range is up to 100mm on AZS and 150mm on high zirconia (depending on material). The digital furnace model will be used throughout the project to guide placement of sensors, analyse radar data, and report the condition of the furnace refractory block by block. One sample report is shown below for reference only (Figure 3.38).

5.8 Mechanical equipment maintenance: Similar to refractory maintenance, good attention to mechanical equipment's maintenance is also very important to increase furnace life and improve glass quality. There are many mechanical equipments in furnace but the following are very critical.

a) **Batch Charger:** Continuous trouble- free operation of batch charger is necessary to feed batch into furnace consistently, maintaining the correct glass level. For proper operation, good & reliable batch charger is to be procured & installed. M/s EME, ZIPPE, HORN are supplying good batch chargers. It is important that they are

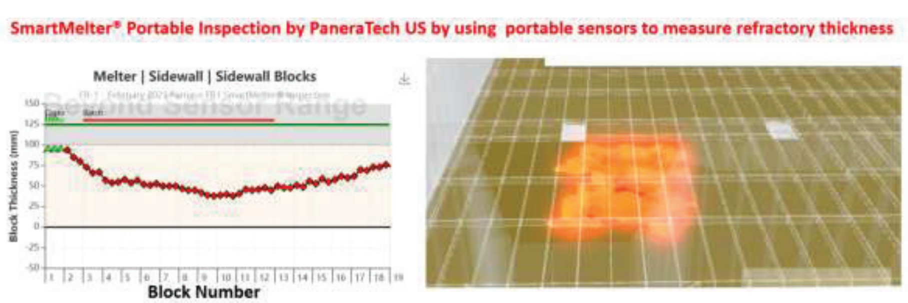


Figure 3.38

maintained well as per the SOP / maintenance manuals provided with the equipment.

Batch charger has to work continuously for months & years till the furnace is in operation, under severe working environment like hot & dusty atmosphere and high abrasion of pusher & pusher parts. Hence proper covering of dog house to prevent heat and dust is to be done. Also, the charger should have proper, good quality, continuous water cooling to minimise damage to it while pushing the batch. The controllers and the panels also should be installed with good cooling and sealing, to avoid damage to components.

Figure 3.39 shows pusher type batch charger of M/s HORN and EME make, indicating main components.

There are many types of batch chargers but simple pusher type with oscillation arrangement is commonly used. However, considering energy saving, performance and maintenance, different types of batch charger may be used. If there are two dog house in a furnace, at least one spare batch charger can be kept for use in case of breakdown. If there is only one dog house, one more standby batch charger should be kept ready in dog house platform for use, in case of breakdown of running charger.

Spare pusher and other essential parts should be always available for replacement in case of emergency. Proper lubrication of all the parts should be carried out regularly.

b) **Reversal system:** It is very critical equipment in a furnace. Generally, they work trouble free for the entire campaign of the furnace, provided they are maintained well. For smooth operation, the chains and moving parts should be lubricated regularly as per supplier's recommendation. The operating air supply quality has also to be good in terms of pressure & moisture content. The reversal valve should move smoothly without jerks. Periodic cleaning of reversal valves, flue deposits if any around the valves to be carried-out.

c) **Combustion & cooling blowers:** These blowers should be maintained as per SOPs and stand-by equipment should be operated periodically. These blowers should preferably be provided with UPS supply, in case of power interruptions.

d) **Chimney:** Most of the furnaces operates on natural draft created by chimney. Problems in the chimney or flue lines may create pressure in the furnace. Hence flue lines and furnace should be free from any flow restrictions.

e) **Water cooling system for chargers, boosting system:** Water quality is very important for charger, boosting system and bubblers. Quality of water is to be maintained as per the recommendation of equipment supplier. Regular maintenance of the system is recommended for smooth operations.

5.9 Instruments & controls maintenance: Furnace operation nowadays mostly depends on automation, measurements and auto controls. Operators generally monitor the furnace data in SCADA system, sitting in control rooms. With proper inputs and measurement data, he can adjust operation settings like temperature, pressure and flow. In the absence of proper data, he will not be able to operate the furnace to maintain consistent glass quality. Hence, proper working of all instruments is necessary in furnace. For this, good maintenance of all instruments is essential. All the good installation practices, correct operation & maintenance system are to be religiously followed. SOPs should be prepared and practiced by all. As the site equipments are subjected to hot atmosphere and dusty environment, protecting them for smooth functioning is very important for trouble free furnace operation.

5.10 Electrical equipment maintenance: The electrical equipments and power supply to furnace equipments should work smoothly to avoid operational issues in furnace. Any interruption can cause major problem to

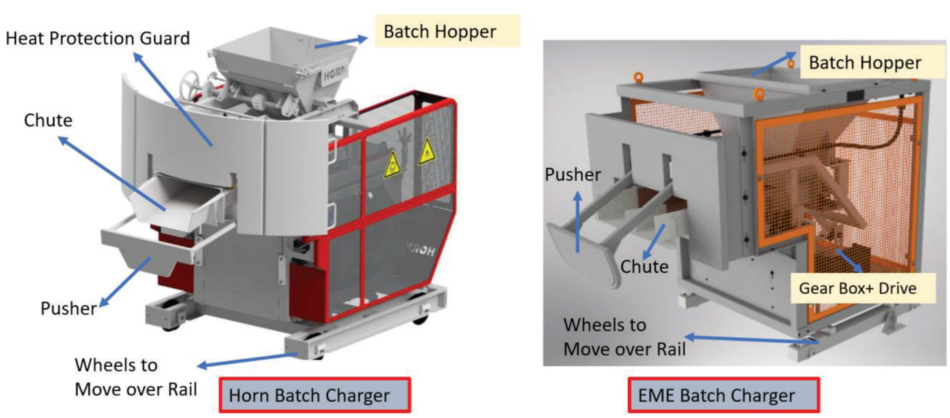


Figure 3.39

Table 3.6

Melting Problems, Causes and Remedies

Sl. No.	Problems	Causes	Remedies
1.	Seed Count too high	Melter Temp low Glass Pull high RM Grain is Couse / less cullet Moisture in Batch too much Water Entry from Pusher Water Entry from Booster Fining Chemical less in Batch Refractory or Foreign material in Glass Incorrect Hot-spot & Melter with high Scum	Check Temperature and increase if required Check the Draw and adjust Check Grain size of RM / Check Cullet % Check Moisture in Batch and set-right Check Pusher & replace if it is leaking Check Boosting Electrode Check Batch & do Glass analysis Check for Contamination in Melter & others Inspect Glass Surface & adjust Flame, temp
2.	SFC too much	Melter temp is very high CV of Fuel is abnormal High Excess air Low regenerator efficiency Low Excess air Low cullet RM Grain size high Furnace Pressure too high or very low	Check Temperature and optimize, if required Check the Fuel CV and take action Check Oxygen % in flue entering regenerator Check regenerator exit temperature & resolve Check Oxygen % in flue entering regenerator Check Cullet % in Batch Check Grain size and correct, if required Check Melter pressure & validate
3.	Yellow lines in Glass	Contamination in Glass / RM Cullet Quality not good Foreign material in Melter, WE or FH Combustion issue in WE or FH Sulphur deposit dropping in WE, FH	Check Contamination in Glass, Lines (FH), WE Check Cullet Quality for Color, Contamination Check for Presence of foreign material Check Burners, clean for rust Check the deposits on dampers
4.	Furnace Pressure very high	Too Much combustion Air & High Firing Regeneratos clogged Pressure damper not working Flue Line clogged Pressure Controller setting incorrect	Check Oxygen % in flue and Fuel flow Check Regenerator Checkers & clean Check Pressure dampers Check Flue line passages Check & Rectify Pressure Controller
5.	Frequent Failure of boosting Electrode holders	Water Quality not good Water Temperature high Water Circulation not correct Continuation in Cullet, creates Short-circuit in Furnace bottom	Check Water and improve quality Check Water Temperature & Cooler Check Circulation and increase flow Control Metal contamination, use more magnet

furnace. Hence a good power back-up is required in case of emergency. Adequate UPS supply, emergency power supply, alternative supply sources have to be properly planned in discussion with user department and equipment suppliers. Regular equipment maintenance as per proven & effective SOPs is to be done religiously. Supporting equipments like air conditioners, UPS systems and emergency DGs should be serviced regularly.

5.11 General maintenance: For a smooth operation of furnace general maintenance is an important requirement. As furnace operation is very critical, the operation team should maintain certain equipments / facilities / manpower ready for use, in case of emergency. They are-

1. Emergency water system with hose pipes
2. Fire extinguishers and firefighting equipments
3. Emergency repair suits and equipments (tools, tackles)
4. Man cooling fans
5. Enough refractories, mortars for repair
6. Skilled masons / technicians / welders
7. Emergency batch feeding, cullet charging system in-case of problem with normal batch charging

In this chapter, we have covered basic furnace design, operations & maintenance for good understanding of processes involved in glass melting. There are many other topics like energy conservation opportunities, innovative melting systems and hot & cold repair of furnaces, which are not covered fully here. Few of the topics are covered in other chapters.

6. GENERAL MELTING PROBLEMS AND REMEDIES

The following chart in Table 3.6 shows some of the melting problems, causes and their remedies. One can use this as guidelines only as the reasons for problems may be many as there exist many variables in melting processes.

This is a sample problem, causes & remedy chart for glass melting problems. There may be so many other issues related to operations, maintenance and safety, for which factory team can prepare the more exhaustive chart for quick solution ■