PROTOTYPE DESIGN AND COSTRCTION OF A TWO-CHAMBER INTERMITTENT TANK FURNACE FOR SIMULTANEOUS DUAL STUDIO GLASS MELTING IN NIGERIA

BY

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with specialization in Glass Technology

DEPARTMENT OF INDUSTRIAL DESIGN
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DECLARATION

I, Fwatmwol Alexander Bishmang, solemnly declare that this thesis is an original work of mine and that it has not been submitted elsewhere for the award of any degree.

All references, both published and unpublished are duly acknowledged.

Signature:.....

Date:....18/12/92.....

CERTIFICATION

This thesis entitled "Prototype Design And Construction of A Two-Chamber Intermittent Tank Furnace For Simultaneous Dual Studio Glass Melting In Nigeria" by Fwatmwol, Alexander Bishmang, meets the regulations governing the award of the degree of Masters of Art Industrial Design (Glass Technology) of Ahmadu Bello University, Zaria and is approved for its contribution to knowledge and literary presentation.

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D E D I C A T I O N

This thesis is dedicated to:

Mr. Bishmang Fwatmwol (Late Father)

Mrs. Napilip Bishmang Fwatmwol (Late Mother)

Mr. Rena Bishmang Fwatmwol (Late Brother).

Your physical presence, though no more, your fatherly, motherly and brotherly affectionate love, kindness and comfort remain very fresh in my memory. May your souls continue to live in perfect peace till we meet to part no more, Amen.

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I can not do better than to end with a quotation from Shakespear:

> There is a tide in the affairs of men,
> Which, taken at the flood, leads on to fortune;
> Omitted, all the voyage of their life
> Is bound in shallows and in miseries.
> On such a full sea we are now afloat;
> And we must take the current when it serves,
> Or lose our ventures.

Adapted from Princess Elizabeth of Toro (1983); Originally from Julius Caesar (1959).

A B S T R A C T

An intermittent two-chamber glass tank furnace with a common flame apace has been designed and constructed for simultaneous experimental dual melting of both flint and coloured glass, fusing under the same atmospheric conditions. This was precipitated by the determination to give a new outlook with a view to solving some deficiencies identified, acknowledged and generally experienced with the conventional single-compartment construction of periodic tank furnaces employed for studio glass melting in general, and that used in Glass Technology Section of Industrial Design Department in particular.

The constructional materials used were exclusively imported standard refractory materials obtained from three Nigerian glass industries, and metal materials, locally obtained.

In the three separate experimental test melting of pairs of glasses carried out, most associated short-comings of the single-chamber construction were overcome. For example, it became possible to melt both coloured and flint glass simultaneously - an impossible and uncommon operation with tank furnaces, both continuous and periodic; provision of more working space for simultaneous studio glass practice

with accompanying increased productivity; and reduction in fuel consumption. The reduced height of the two-chamber unit and its longitudinal mode of firing ensured that the heat generated was brought closer to the glass melts and sufficient space provided for flame propagation. The strategic location of the port made it multi-purpose; it served as an inlet for fuel and combustion air, a view hole for both chambers, and acted as an avenue for sample taking of molten glass without materially tempering with the doors during firing operations. Closed packing of the furnace refractory bricks and judicious application of external backing insulation guaranteed uniformity of temperature distribution in both chambers; 1300°C remained the maximum temperature attained in all the three firing operations. Regulation of atmospheric conditions of the furnace space was aided by an adjustable "key-brick" of the chimney. The furnace was found economical in terms of fuel consumption and construction materials.

The preventive measures adopted to curtail some problems encountered in the first melting test yielded positive result – higher quality products were produced in the second and third melting tests.

The compositions of the glasses melted were of the soda-lime-silica family for the first two melting tests, and tableuare lead crystal for the third one.

The efficient two-chamber intermittent tank furnace has been recommended as suitable for simultaneous melting of both coloured and flint glass, two coloured glasses and flashed glass under studio condition.

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DEFINITION OF SOME RELEVANT TERMS

ANNEALING: A process of heat treatment meted to glass for stress relaxation.

ANNEALING LEHR: A furnace or an oven in which glass is subjected to heat treatment for the relief of stresses resulting from differential expansion or contraction as the glass is heated or cooled respectively.

BALLAST: Incombustible elements of fuel, usually moisture and ash.

BLOATING: Permanent expansion accompanied by the formation of a viscular texture, which occurs when some types of clay or refractory bricks are heated.

BULK DENSITY: The ratio of the weight of a material to its total volume, including pores, expressed as g/ml or lb/ft^3.

CALORIFIC VALUE (C.V): Heat released by complete combustion of a unit mass of fuel; expressed as J/kg or Btu/lb for solid fuels, and KJ/m^3 or Btu/ft^3 on volume basis for liquid and gaseous fuels.

CHARGE: The content of a furnace.

CHIMNEY: An exhaust stack through which products of combustion are removed and dispersed at sufficient distance/velocity to keep pollutants away from the nearby environment.

DICHROISM: Variation of colour intensity with glass thickness, being more intense in thicker areas than in thin portions.

EUTECTIC: A composition having the lowest melting point in a series of two or more components.

INSTRUMENTATION: Industrial installations for the measurement and control of process variables and their operational mode. Their importance is the measurement and control of physical conditions for mass production of high-quality products.

JAMB WALL: A vertical structural member forming the side of an opening in a furnace wall.

KAOLIN: Also called "china clay" is a pure form of hydrated aluminium-silicate clay.

LEAD CRYSTAL GLASS: A cut glassware used for table wares and characterized by high brilliance. It is composed of silicon oxide, alkali and high proportion of lead oxide.

PLATE GLASS: A glass that is cast or rolled into a sheet and ground polished.

PORT: An opening in a furnace through which fuel and air enter or through which exhaust gases escape.

PYROMETRIC CONE EQUIVALENT (PCE): A method used in determining the refractoriness in which the test cone is heated in company of standard cone or cones which deform at the nearest temperature to that at which the test cone deforms.

RECUPERATOR: A continuous heat exchanger or accumulator in which heat is extracted from products of combustion for use in preheating incoming combustion air through metal or refractory walls.

REFRACTORIES: Materials consisting of high melting point oxides.

REFRACTORINESS: A term used as an index of the heat resulting properties of refractories.

REFRACTORINESS UNDER LOAD (RUL): A measure of the resistance of a refractory to the combined effects of heat and loading.

REFRACTORY CEMENT (MORTAR): A binding medium for refractories.

REGENERATOR: A cyclic heat exhchanger or accumulator which alternately extracts heat from combustion products to be used in pre-heating incoming combustion air or low C.V. fuel gas.

SODA-LIME-SILICA GLASS: The most common commercially produced and widely used family of glass, composed chiefly of silicon oxide, sodium oxide and calcium oxide.

SPECIFIC GRAVITY: The ratio of the weight of a unit volume of a substance to the weight of unit volume of water (relative density) mass per unit volume.

TANK FURNACE: A hearth furnace in which the charge is contained in a bath upon which the flame plays directly.

THERMAL SHOCK RESISTANCE: Ability to withstand sudden heating or cooling without cracking.

TWO-CHAMBER FURNACE: A furnace consisting of two glass baths or chambers.

WORKING FUEL: The fuel as supplied into the furnace.

Chapter 1

INTRODUCTION

1.1 Historical Development of Glass and Glass-Melting Furnaces

In a widely used but rather restrictive way, American Society For Testing Materials (ASTM) in 1945 defined glass in which it says "glass is an inorganic product of fusion that has solidified without crystallizing." According to Rawson (1980), this excludes organic glasses such as glycerol. Glass consists of oxides of silica, lime, alkali and a host of others.

Today, it stands out as one of the most common and versatile materials made by man; it comes into play in all facets of human endeavour. However, the date, place and how man-made glass was first produced still remains in obscurity.

Many writers including Debussy (1971) and Holloway (1973), have traced the historical development of the art of glass manipulation to the Stone Age Man. They contended that the first glass to be discovered in history was a naturally occuring one, originating from the mineral obsidian whose chemical composition is analogous to that of an ordinary window glass, and formed as a result of volcanic erruption. Foam glass known as pumice and fibrous glass are other forms of glass that are found in proximity to volcanoes. According to Holloway (ibid), this natural glass was utilized by the Stone Age Man to fashion utilitarian objects

such as knives, spear and arrow heads.

The date of the product of first man-made glass has remained a disputed issue among many authorities. Holloway (ibid) believes archaelogical findings have revealed that man-made glass dates back to 5000 B.C; Dickson (1951) dates it back to 2500 B.C; and Debusay (1971) has traced it further back to 3000 B.C in Eastern Mediteranean, presumably Mesopotamia or Egypt.

It is maintained that all glasses produced at these early periods composed generally of sand, lime and ash deriving from burnt plants since firewood was employed as fuel in melting. Similarly, it is maintained that all glass articles produced at the periods in question were solid objects such as beads and the like. It was not until 1500 B.C that events took a different dimension when for the first time, bottles employing the "sand core" technique made appearance. Subsequent development witnessed the production of bowls and containers of similar shape using the crude pressing technique. In about the first century B.C, the metal rod that was used in supporting the "sand core" got replaced by a hollow tube, and it was discovered that by blowing down the tube, hollow shape articles could be produced to mark the beginning of glass blowing which became an established art used up till the present day in studio glass production.

Even though there existed previously some sort of glass blowing practice, the Roman conquest and occupation of Europe was responsible for the widespread establishment of glass blowing all over Europe and Britain. The departure of the Romans left glass blowing in a state of decline and was only intermittently revived with the arrival of immigrant craftsmen, most especially the medieval Venetians.

Before the seventeenth century, very few bottles were produced. However, this period (the seventeenth century) was to witness very large quantities of bottles including lead crystal glass being produced in England and the colonies in West Indies and American glassworks had been set up. This assertion is supported by Philips (1981), when he opines that the bottles produced prior to the period in question were exclusively those for medicines and mineral waters. During the seventeenth century, however, those for wine and beer were being made, he concluded.

Though bottles constituted the major items, the seventeenth and eighteenth centuries equally witnessed the production of some window glass, where the cylindrical methods were employed.

Glass production by automate began in the nineteenth century, starting with a crude method using hinged moulds with manually operated foot levers. By the end of the same century,

use was made of semi-automatic bottle blowing machines. Going by Debussy (ibid), the beginning of the twentieth century, and especially 1903 was remarkable for the glass industry in that it witnessed for the first time, the development of fully automatic bottle blowing machine invented by Michael Owens in U.S.A and the development by Lubbers, the mechanical blowing of cylinders for window glass. He went on by stating that substantial developments were made in the next three decades in the manufacture of both bottles and window glass. These developments had led to the process which are in use today, he concluded.

With glassmaking firmly established, this period up to World War II witnessed the development of various glass articles produced by automates, ranging from tubing, glass fibres, invention of corning ribbon machine for producing electric bulbs, "pyrex" glass for laboratory ware and oven ware, plate glass, float glass, glass-ceramics and chemical toughening of glass, surface coatings of glass for a variety of purposes.

Synthesising assertions by Holloway (ibid), Philips (1981), Dickson (ibid) and Scholes (1974), it becomes apparent that the rapid development the glass industry has undergone in modern times is brought in part, by increasing scientific, technological and engineering knowledge, and partly by the impact of development

taking place in other industries, coupled with the effect of World War II. Philips (ibid), in elaborating said that the sciences of chemistry, physics and engineering have given an insight into the nature of glass, the mode of its formation and its physical and chemical properties. Without stopping, he detailed "Research and development in combustion of fuels, heat transfer, furnace construction and new refractory materials have enabled the glass industry to make great progress."

The inability to attain the founding temperatures demanded by most glasses ($1300^{o}C$ - $1600^{o}C$) in the past was attributable to a number of factors such as the use of solid fuels in form of firewood, lack of satisfactory and durable refractory materials for making the pots inside which the glass was melted, and the absence of devices for retrieving heat from the furnace outgoing waste gases for preheating purposes. Obtaining higher temperatures in the glass furnace became possible in the seventeenth century when coal replaced firewood as fuel and the employment of high-grade fireclay for the pots in which the glass was melted. However, up to the middle of the eighteenth century, American glassmaking furnaces were still run on firewood as fuel, and this practice was only stopped with the discovery of increasing non-availability of suitable firewood for the purpose. Affirmative of this, Scholes (1974) states:

> Up to the middle of the eighteenth century when the English began burning coal, furnaces for melting glass were wood-fired. The huge quantities of ashes produced formed the source of potash for the batch. The early American glass furnaces were wood-fired, but because of the increasing scarcity of suitable wood, and the discovery and development of better fuels, wood is no longer of any importance in American glass-melting.

In his further contribution, Philips (ibid), said that the consequence of non-attainment of high melting temperatures is that glasses produced at that time were soft ones containing high alkali content. He concluded by saying that today a solution to this problem has been found by use of more versatile oil or gas fuels with higher heating value, designing and constructing modern and durable furnaces with suitable refractories, and methods of heat regeneration and recuperation used by most furnaces.

The generation of high melting temperatures demands that the furnace refractories must be of high quality if it were to last long and for the production of glasses free from defects. Some basic requirements of a glassmaking furnace are again provided for by Scholes (ibid) when he maintains:

> The glass furnace demands of its refractories that they shall be able to withstand temperatures of 1620°C or even higher in some cases. While the interiors of the walls must be able to endure for long periods temperarures of this sort, the walls themselves must be able to retain, without too great loss, the heat of the

> furnace. Finally, the furnace walls must be able to sustain the weight of its own bricks at high temperatures without appreciably settling or sagging.

Therefore, refractories for glass-melting furnaces should be resistant to high temperatures, and their refractoriness under load (R.U.L.) should also be high. Both these requirements and others are satisfied by most modern refractory materials.

Here, an addition can be made that the rapid development undergone by the glass industry in recent times was as a result of the impact of development taking place in other industries. Glass-consuming industries like those for beer, wine and soft drinks, automobiles, electronics, medicine and pharmaceutics, and many others are responsible for its attaining great heights of development. This led to the production of a variety of glass ware during the seventeenth century up-to date.

The effects of World War II (1939 - 1945) were to further catalize the rapid development of the glass industry, as it brought about the manufacture of bullet-proof glasses for military vehicles, pressure and birds impact resistant glasses for fighter jets, mirrors and astronomical lenses for telescope and cameras.

The researcher again finds it necessary and worthwhile concluding that the sweeping development that has taken place in the glass-producing sector of the economy in the world over would have never occured at all if not because of the step by step

development stages that have been witnessed in furnace technology, beginning since time immemorial, and the discovery and development of versatile modern liquid and gaseous fuels.

The evolutionary date of glass-melting furnaces remains unknown just like the uncertainty that beclouds the date of the first man-made glass. It is however evident that our ancestors were conversant with the fact that firing clay containers in the open fire could improve on their mechanical strength and made them water resistant. Equally too, they were aware that glass could be formed when wood ash and sand were melted together.

At the onset, glass-melting was carried out in the open fire, but subsequent developments were to bring about glass-melting in an enclosure, marking the development of ground-built solid fuel utilizing kiln for glass-melting; and the fire clay pans formed the prototype of pots in modern periodic glass-melting pot furnaces. Thus glass was first melted in ceramic kilns before the advent of the glass-melting furnaces, and the pot furnace is the forerunner of the tank furnace.

Available records show that the ancient Egyptians are known to have constructed prototype pot furnaces as far back as 1600 B.C. Traces of old glass-making handicraft discovered at this period

as contained in two separate old documents are sufficient evidence to make Bulavin et al (1986) to suggest that the ancient Egyptians made glass by a two-stage technique owing to the prevalent low temperature of the fire, and that melting was carried out in clay pans.

The two-stage melting of glass was first carried out in two separate pots, with a third one for annealing the glass articles produced. Under this process, a preliminary melting of the batch was first carried out and the unmelted constituents removed. Next, the solidified melted product was crushed to smaller particles to make it suitable and affordable for melting at the temperature attainable at that time using dry firewood as fuel.

The two sources from which Bulavin et al derived his information are the old manuscripts of Theophilus (twentieth century) and that of Agricula (sixteenth century).

The pots or crucibles that were made before the middle of the nineteenth century were small-sized. However, in about the mid nineteenth century, there arose the need to construct for economic reasons, especially in England, later in France and Belgium relatively large pots. Gunther (ibid) talked of a single pot built by P. Flamm with a capacity of eight to twelve times that of an ordinary size pot. From the traditional single pot

furnaces came the multi-pot ones containing as many as 16 pots. It is on record that a man called Morlot had constructed a not very successful oval-shaped two-compartment continuous pot furnace, and a similar one recommended by Imbert in 1859.

In the 1860s, Friedrich Siemens invented a three-compartment pot that could be employed for continuous production of all kinds of glass, including coloured. However, the high cost of manufacture and the lack of possibilities of repair hindered similar development on a larger scale. The three compartment were linked to each other by channels and passages. The individual chambers were those of melting, rifining and working respectively. Siemens' idea about such a construction stemmed out from the observation that the specific gravity of molten glass increases as the melting process proceeds towards completion.

During the nineteenth century, the following faults were acknowledged and generally experienced:

1. Inefficient utilization of the furnace melting space — heat transfer for melting is by conduction through the pot wall which retarded the melting process. Cold stirring also caused part of the heat to be lost.

2. The periodic reduction of melting temperature of glass to that of the working temperature also had an adverse effect on the furnace refractories.

3. The unavoidable breakage of pots led to considerable loss of glass, the pot itself and drop in production. Under the best operating conditions, there was 15 per cent unavoidable glass lose.

The evolution of the glass-melting tank furnace emerged from the tireless continuous endeavour to eliminate these deficiencies. Gunther (ibid) credited the success of overcoming these problems to the German Siemens brothers who worked independently, and sometimes, jointly. These five brothers were Friedrich Siemens working in England and later in Germany, Karl in Russia, Hans in Germany, Wilhehn in England and Wesner (the real initiator and adviser of his brothers' works from the steel industry to the glass industry).

Particular reference is made to the independent works of Hans and Friedrich for developing the tank furnace in 1959. Gunther (ibid) said such a tank is best described as "periodically operated" going by present day conception. However, from the source of information at disposal, it is difficult to say who among the two brothers credit should go where the development of the tank in question is concerned.

Moved by the success he recorded with the continuous pot, Friedrich Siemens, while in the glassworks at Dresden, on October 1, 1967, succeeded in converting for the first time, the intermitten

tank to a continuous one. With the invention of this continuous glass-melting tank, all the aforementioned problems were overcome. The significance of this double discovery was that it became possible to melt glass continuously and pots were dispensed with altogether.

The furnace consisted of three main parts, viz the melting chamber, the refining chamber and the working chamber (cooled by air to retard the effect of heat and the corrosive action of molten glass. It had a tranverse flame.

Friedrich even effected improvement on his tank furnace to make for easy repair and part replacement, and to ensure durability of the refractories. His success was to arise interest in many furnace technicians on a wider dimension and led to the wide distribution of tank furnaces.

1.2 Background of the Study

Glasses produced in small quantities are either melted in pot furnaces or periodic tank furnaces. Conventionally, periodic tank furnaces consist of a single chamber, which are capable of melting only a glass composition at a given time. Available documentary evidences like those of Gunther (ibid), De Bussy (ibid), Scholes (ibid), Doyle (ibid) and Bulavin *et al* (ibid) have consistently associated periodic glass-melting

tank furnaces such as day tanks as essentially consisting of not more than a single chamber which gives credence to this assertion. These writers including Kirk-Othmer (1966) and Philips (1981) have identified two-chamber glass tank furnaces with only continuous tank furnaces employed for large scale production. Even in such cases, they contended, the two compartments, namely, "melting end" and "working end" are employed for melting just one glass composition at any given time. They simply serve as temperature zones, charged with differential functions. The "melting end" is associated with melting the glass batch into a mutually homogeneous molten glass and the elimination of evolving gas bubbles; and the "working end" with cooling, preheat conditioning and absolute disappearance of gas bubbles by dissolution with falling temperature.

Reference materials by the aforementioned researchers have only pointed to the practice of simultaneous dual melting of separate glass compositions for flint, coloured and specialized forms of glasses as exclusively carried out in pot furnaces. In tank furnaces, this can only be done in sequence and not simultaneously which requires a change-over time.

It has been observed with keen interest that in consonance with established principle of tank furnace

construction, Glass Technology Section of Industrial Design Department, established in 1981 has continued to melt glass in the single-chamber periodic tank furnace, constructed as far back as 1985.

Like in similar structures the simultaneous dual melting of both flint and coloured glasses is out of question. For the same reason, it is practically impossible for more than one student to conveniently carry out studio glass practice at a time; they have to wait for long in turn for each other. This limits their participation and productivity. Under the prevailing circumstances, the situation is becoming aggravated, especially with the "course crédit system" recently introduced in Ahmadu Bello University, which encourages students' mobility, both within and outside the department, coupled with the reversion of "Glass Technology Programme" from B.Sc to B.A, which lay greater emphasis on production.

The researcher has also observed that the single-compartment structure contains a number of cracks and that it is greatly corroded and erroded, an indication that its lifespan is complete. The operational mode of periodic heating and cooling with accompanying periodic expansion and contraction of the refractories respectively, coupled with apparent glass

level fluctuations are all conditions which are favourable for furnace failure.

The underlying factor behind this study therefore is the desire and quest for simultaneous dual melting of glasses, both flint and coloured for economy of time and material, increased students' participation in studio glass practice and productivity. It is felt that the two-chamber constructional design of an intermittent tank furnace will accomplish these objectives. Also, it is felt that this will be interesting and beneficial to small-scale producers of glass. This is highly desirable and fits in well in the "National Directorate of Employment" programme embarked upon by the Federal Government of Nigeria which encourages and funds the establishment of small-scale industries by individuals for self-employment and self-sufficiency.

1.3 Statement of The Problem

Researchers, furnace designers and technicians have always preoccupied themselves with designing and constructing periodic glass tank furnaces to comprise a single chamber. Accordingly, no attempt has so far been made to construct the two-chamber one whereby both flint and coloured glass could undergo simultaneous dual melting operation under studio

condition whenever the need arises. Available literature or published report in respect of the existence of such a two-chamber periodic tank furnace are virtually absent.

Invariably, the worn-out day tank furnace employed for studio glass melting in Glass Technology Section of Industrial Design Department is based on this conventional single-compartment principle. Consequently, studio glass practice has become fuel and time consuming for the increasing number of students, thereby limiting their participation and productivity.

1.4 Purpose of The Study

The objectives of the study emanating from the research problem are:

1. To examine and determine the limitations associated with the use of a single-chamber periodic tank furnace used for melting studio glass in general and that employed in Glass Technology Section of Industrial Design Department in particular.

2. Designing and constructing a replacement two-chamber intermittent tank furnace for the existing single-compartment one for optimum service performance and thermal efficiency.

3. Determining the extent of differential fuel consumption of the two furnaces in relationship to the quantity of glass melted.

4. To find out the feasibility of simultaneous dual melting of both coloured and flint glass in the two-chamber intermittent tank furnace.

5. For assessing the advantages of the two-chamber periodic glass tank over the single-compartment type.

1.5 Research Questions

The problem statement raises the following questions:

1. Will it be possible to melt simultaneously both flint and coloured glass in the two-chamber intermittent tank furnace?

2. What are the potentials of the two-chamber periodic tank furnace in terms of accommodating students for studio glass practice.

3. Will one burner or a set of burners be capable of firing the glass batch compositions in the two-chambers of the tank at once, or do they (the chambers) need to be fully separated for individual melting and temperature control?

4. What is the quantity of the glass melted in the two-chamber intermittent tank furnace?

5. How is the quality of the glass melted in the two-chamber intermittent tank furnace?

6. Will the two-chamber structure be economical in terms of fuel consumption and constructional materials?

7. Will the temperature attained in both chambers be the same?

8. Is it going to be possible to have a clear view of the melting conditions prevailing in the two-chambers of the furnace?

9. As a preventive measure against heat loss during furnace operation, in which way can sample-taking of molten glass be ensured without necessarily having to open the doors of the two chambers?

10. Will there be a way of regulating the atmospheric conditions existing in the furnace space?

11. What relationship exists between good furnace design such as close packing of refractory bricks, proper insulation, increased flame space and the efficiency of its service performance?

1.6 Significance of The Study

The immediate identifiable justification of the study when conducted to successful conclusion is that Glass Technology Section of Industrial Design Department, Ahmadu Bello University, Zaria, will for the first time, be melting its glass batches in a two-chamber intermittent tank furnace instead of the single-compartment one in previous use. The significance of this developmental strategy is three-fold. First, it will now be feasible to melt both coloured and flint glass at the same time, an impossible and uncommon operation with tank furnaces, and of universal relevance to the production of coloured glasses. The usual practice in the world over is that coloured glasses are melted either simultaneously or in sequence in multi-pot furnaces with each pot containing a coloured glass. Secondly, the two-chamber furnace rather than the single-chamber one will provide more working space and sufficient quantity of glass for studio glass production, thus providing the increasing number of students with sufficient practice and production capacity. Thirdly, the common-flame space of the two-chamber unit will minimize fuel consumption since one burner could be used to fire both chambers simultaneously and more flame space will be made available for optimum heat utilization.

The adoption of the constructional design for small-scale glass production will be beneficial to small-scale glass practitioners/industrialists, a step forward in self-engagement and self-sufficiency in glass production. This is envisaged as being in line with the Federal Government of Nigeria's programme of National Directorate of Employment.

The absence of available literature in support of the existence of two-chamber intermittent tank furnace of this nature opens a new chapter and marks a turning point in the history of furnace design and construction.

Accordingly, this will build up on the teaching and learning process on "glass-melting furnaces" as a course unit in Glass Technology Section of Industrial Design Department. Finally, it will serve as an information source elsewhere, most especially, to enterprising small-scale glass industrialists and related organizations.

1.7 Delimitations

The scope of the study has been delimited to experimentally designing and constructing a replacement two-chamber periodic tank furnace using imported standard refractory materials obtained from some Nigerian glass

industries that constitute the only source. The manufacture of these items is beyond the scope of the study. Similarly, no waste-heat recovery device has been constructed. Burner design is excluded from the study.

The study has therefore been delimited to designing and constructing a two-chamber intermittent tank furnace, carrying out melting tests as a means of evaluating the success or failure of the research; its service performance and advantages are weighed over those of the single compartment one already in existence.

1.8 Limitations

The limitations imposed on the study is non-availability of suitably sized refractory bricks for the furnace construction, absence of faciilities for their local manufacture, and the practical difficulty involved in size-reduction of such imported standard manufactured bricks as they are cast and electromelted. The direct consequence of this is that they have to a large extent determine the dimension of the furnace, and thereby limiting the researcher's control where same is concerned.

The researcher had to rely on the few glass industries for obtaining the refractory materials as they could not be

found elsewhere in the country, and their specifications were specially made to suit the needs and requirements of the individual plants. The researcher was therefore compelled to resort to painstaking management of the scarce resources. The crown of the furnace, for example, was constructed with enormous difficulty. Again, absence of processing and manufacturing equipments like quarrying machine, pneumatic pressing device, high-temperature heating device under carefully controlled presure, vacuum and well equiped laboratory for analysing the raw materials unavoidably prevented the local manufacture of refractory bricks of the desired dimensions. These factors put together caused the original dimension of the furnace to be reduced due to lack of silica crown bricks to go across the width of the furnace.

The use of low-melting glass batch compositions follows the fact that experience has shown that the gas burner used in the section is of low heat input, and therefore cannot melt hard borosilicate and aluminosilicate glass batch compositions. Use was made of available raw materials in the section, both synthetic and locally sourced ones.

Only very limited materials are available for literature review on glass technology as an area of study in Nigeria.

Absence of facilities for testing some of the combustion variables poses great constraints to the study.

1.9 Basic Assumptions

In the course of the study, the following assumptions are made:

1. That the refractory bricks used meet all expectations demanded of them.

2. That no discrepancy exists in the frit, and that the degree of homogeneity obtained during mixing are the same.

3. That operationally, the melting conditions prevailing in both the furnace atmosphere as well as in the glass melts of both chambers are identical.

4. That the rate of fuel consumption during all the melting operations are identical, and that the air/fuel mixture are stoichiometric in each case.

5. That the regulation of the variables were carried out to the same level and at the same time interval.

Chapter 2

RELATED LITERATURE REVIEW

Glasses, either industrial or studio are melted in furnaces, sometimes refered to as glass houses. Thring (1962), in his definition said "a furnace is an industrial appliance constructed to heat a material through a cycle involving temperatures exceeding 400^{0}C."

The researcher is of the view that this definition is rather restrictive in that it is narrowed down to industrial furnaces. A more general and flexible definitive approach is presented by Bulavin et al (1986) when they refer to "furnaces as thermal plants or installations in which the starting materials or shaped-finished products are heated by organized evolution of thermal energy to obtain materials or finished products of the specified properties."

Therefore, the main function of a glass furnace is the transformation of its charge into a mutually homogeneous melt, and to carry out all other processes associated with that of melting such as fining, homogenizing and heat conditioning of the molten product.

2.1 Types, Characterization And Application Of Glass-Melting Furnaces

There exists various ways of furnace classification with a lot of overlapping in the basis of classification, but two distinct

types can be identified - pot furnaces which are periodic and tank furnaces which may be periodic or continuous. To this end, Scholes (1974), states:

> Two general types of furnaces are in use. In one the glass is contained in separate pots and each furnace may contain a pot or as many as twenty. In the second type called the tank furnace, the glass forms a pool in the hearth of the furnace, across which the flames play directly upon the raw batch and the molten material.

This study is concerned with the latter type. Among the various ways of classifying modern glassmelting furnaces, especially that presented by Bulavin et al (ibid), the ones that bear relevance to this study are those based on the "operating principle" and "design of furnace space", as well as "method of division of the tank and flame space." Other ways contained in their classification include method of heating, direction of gas motion relative to glass flow and method of heat recovery from outgoing waste gases.

Accordingly, glassmelting furnaces can be grouped into "periodic" and "continuous" types. The periodic forms comprise all pot furnaces and some tank furnaces, notably day tanks, while the continuous ones are exclusively tank furnaces that operate on a continuous basis. Obviously, this classification is based on their operational mode of heating.

On the basis of the "design of furnace space" and "direction of gas motion", distinction can be made between pot furnaces and tank furnaces.

Based on the "method of heating", distinction can be made between flame furnaces, electric furnaces and flame-electric furnaces with dual or combined method of heating.

Where the classification is on the "way of heat recovery from outgoing exhaust gases", division can be made between regenerative and recuperative furnaces.

With due regards to the "mode of division of the tank and flame space", glassmaking furnaces may have a common tank or two individual tanks, melting and working ends, separated by either a working boat or throat. However, it is important to bear in mind that this division, though of particular importance to this study, it is applicable only to continuous tank furnaces.

2.1.1 Periodic Furnaces

Whereas in continuous furnaces, melting operation and glass production are carried out non-stoppage, periodic furnaces operate intermittently. Periodic furnaces here encompasses pot furnaces and day tank furnaces in which all stages of glass melting take place in the same pot and the tank as the case may be; with the various stages separated only in time and not space.

Their applications are to be found in melting either specialized forms of glasses, coloured glasses or lead crystal glasses, produced on a small scale that does not necessitate the use of continuous furnaces. Day tank furnaces are however used for melting larger quantities of glass that cannot be contained in a pot furnace. Since production is in small quantities, glass working is done manually otherwise known as "offhand" working where pot furnaces are concerned, and offhand or by use of semi-automatic machines in the case of day tank furnaces.

Open pots are used in optical glass production and for a variety of purposes where access to the entire surface is desirable. The principal aim in designing covered pots for glass melting is associated with that of protecting the content from contamination of the furnace atmosphere, but at the same time, make them accessible for charging and working. In the same way, they allow the cooling of glass to the gathering temperature without materially affecting the other pots in the furnace. In the early part of the twentieth century, open pots, the oldest forms of glass melting containers, were employed mainly for the manufacture of plate glass by casting process, but today, they have been largely replaced by large tank furnaces for continuous rolling operation.

The number of pots that can be contained in a pot furnace ranges from one to as many as twenty. This is partly attested to by Bulavin et al (ibid) when they state "single- and two-pot furnaces are used for making optical and industrial glass and multi-pot ones for making coloured and crystal glass." By inference therefore, single- and two-pot furnaces are made up of the open-type. In pot furnaces, then it is feasible to melt twenty different glass compositions at a time, with each in a separate pot - the more reason for their being employed in melting coloured glasses.

The mode of heat transfer in a pot furnace is largely by conduction through the walls of the pots as the flame produced never comes into direct contact with the charge, but goes round the pots. In the charge itself, further heat transfer is by convective flow set up as a result of temperature gradient along the height of the pot. In periodic tank furnaces, attainment of higher melting temperature is possible than with pot furnaces as firing takes place directly over the charge. The regenerative type of periodic tank furnace is conceptually identical to the open-hearth steel furnace. Therefore, with the flame produced playing directly over the charge, heat transfer from it to the charge is by radiation and convective current set up as a result of temperature variation along the length of the furnace.

The major characteristic distinguishing feature between a pot furnace and a day tank furnace is that in the latter, the tank refractory forms glass bath, just in the same way as it is in a continuous tank, and can melt larger quantity of glass than it is possible in the pot furnace. In the pot furnace, the principal element consists of the furnace space, which may be rectangular, oval or cirular in shape. The large ones with greater number of pots from 12 - 16 are mostly rectangular and oval shaped. Single-pot furnaces have circular furnace space, which is favourable for obtaining uniformity of temperature. The furnace space of a pot furnace is made up of the bottom, crown and side walls with doors for inserting the pots, charging and offhand working.

The periodic tank furnace, typified by the day tank furnace is a melting unit described by Scholes (ibid) as consisting of a rectangular tank with sidewalls not exceeding 60.96cm in height. Gunther (ibid) maintained, however, that the shape could be circular, oval or rectangular and employed for melting special and coloured glasses in relatively small quantities. Bulavin et al (ibid) further described the furnace space of a periodic tank furnace as essentially a bath or tank, laid from durable refractories, and that the sidewalls and crown of the furnace make up the furnace space above the tank. Undoubtedly, this too suggests

and confirms the singular nature of the periodic tank furnace. Other informed sources express similar views. This implies that only one glass batch composition could be melted and worked out at any point in time.

This forms one of the many reasons that has prompted this study, to come out with a new design capable of dual melting operation so that both coloured and flint glass could be melted and worked out simultaneously.

In utilizing heat from outgoing waste gases, regenerative pot furnaces predominate recuperative single-pot furnaces. Scholes (ibid) maintained that the simpler and smaller glassmaking pot furnaces are direct fired, without provision for preheating air or fuel gas. Regenerative pot furnaces operate with lower flame for low-melting glasses and upper flame for hard glasses. At the end of the melting period, the glass is subjected to bubbling or mechanical agitation for attainment of homogeneity; and then cooled to the working temperature. Constant temperature is maintained during working period.

Glass pot furnaces operate on high calarific gas or liquid fuel. The hearth of the furnace is laid from fireclay or Bacor plates to form burner ports; the crown and the walls are laid from silica bricks and blocks. In overcoming the problem of higher

wear of pots as a result of glass-level and temperature fluctuations, platinum has been used as pot refractory.

Bulavin et al (ibid) asserted that melting time in periodic tank furnaces constitutes 24 - 48 hours; in pot furnaces it is 16 - 24 hours. Like pot furnaces, periodic tank furnaces run on gaseous or liquid fuels, and combustion air is preheated in regemerators.

The desirable features of periodic tank furnaces are more efficient utilization of the furnace space and the obviation of troublesome care of pots. The size of the periodic tank furnace varies with the required furnace productivity - unit yield of molten glass in kg/m^2.

"Periodic tank furnaces may have tranversely directed flame or U-shaped flame", stated Bulavin et al (ibid).

2.1.2 Continuous Glass Melting Tank Furnaces

All glasses produced on an industrial scale are melted in continuous tank furnaces which vary in size, shape and construction according to the method of heating, the type of glass to be produced and the mode of production as well as the furnace productivity. Writers like Gunther (1958), De Bussy (1971), Scholes (1974), Doyle (1979), Bulavin et al (1986) maintained that such tank

furnaces are being employed for the manufacture of a variety of glasses such as sheet glass, container glass, tubing, fibre glass and a host of others on a continuous basis.

Gunther (ibid) emperically stressed that the difference lies mainly in the manner of separating the melting end from the working end, the size and shape of the working end, and the method of heating employed. Evidently, the continuous glass tank furnace is adapted to mechanical production which allows large quantities of glass to be delivered at a constant rate. To effectively accomplish this, glass-level is maintained constant, which means that the rate of frit charging must proportion or equal that at which molten glass is being worked out or withdrawn. It is for this reason that the glass-level controller is synchronized with the batch charger.

Where continuous tank furnaces are concerned all stages of glass melting occur simultaneously in different sections of the furnace. This is unlike in periodic tank furnaces where they take place in the same furnace space but with time difference, stated Doyle (ibid) and Bulavin et al (ibid). Heat transfer from flame to charge is largely by radiation, and convective currents set up as a result of local temperature variation along the length of the melting bath, which is aided by escaping gases to ensure a non-heterogeneous glass melt.

Stressing from the view point of waste heat retrieval, Kirk-Othmer (1966) found that "glass-melting furnaces and tanks are usually provided with regenerators for heat recovery from flue gas before it is passed to the stack." While all of them use either liquid or gaseous fuels, there are as well those that are direct-heated.

In continuous tank furnaces, the direction of gas motion relative to the flow of glass may be transverse, longitudinal or U-shaped.

Large regenerative furnaces with melting area in excess of $50m^2$ have as a rule transverse flame which ease temperature control. Preference is given to the U-shaped direction of gas motion in the case of those with melting area up $50m^2$. In the recuperative furnaces, the direction of gas motion may be U-shaped, longitudinal or a combination of the two.

The Bridge-Wall Tank With Throat: Gunther (ibid) describes this type of a glass furnace as consisting of a rectangular bath divided into two separate tanks of unequal sizes by a double wall built at right angles to the furnace length, covered by a common crown. Scholes (ibid) adds that the bridge-wall is usually doubled, with an air space inbetween for air cooling and corrosion retardation. The larger bath with its crown is the melting end and the smaller one with its crown is the working end. A combination of the walls

and the cross blocks is what is refered to as the "bridge." The bridge wall functions to separate the hotter glass of the "melting chamber" from the cooler and more homogeneous glass of the "working chamber", and to prevent partially melted batch and unrefined glass from the latter.

A narrow, enclosed rectangular channel, constructed of refractory blocks, exiting through the bridge wall, and which may be submerged, non-submerged, elevated or inclined, links the two chambers.

The unheated nature of the throat, coupled with its location at or close to the tank bottom, produces a distinctly cooling effect on the glass temperature as it passes onto the working end. This is achieved by immersion in the deeper zone and by reducing to zero the convective flow of the glass. To obtain the same cooling effect in the absence of both bridge wall and throat, it is necessary that the length of tank be increased considerably.

It is worth noting that the temperature in the working tank is kept much lower than that in the melting tank. Affirmative of this, Scholes (ibid) states "The temperature of the working chamber is normally about 300^{0}C lower than that of the melting chamber." For easier and proper control of thermal conditions in both chambers in the absence of dividing wall, the two tanks are fully separated and provided with individual heating and gas removal.

A more recent trend lends itself to reducing the size of the working tank to a large extent in favour of the melting tank or replacing it with channels that link the melting tank with glass working devices. Bulavin et al (ibid), in highlighting the overriding aim behind this development asserted "decreasing the size of the working tank makes it possible to increase the melting tank and thus increase the furnace productivity and improve the quality of the molten glass."

In terms of application, the bridge-wall tank with throat remains the most common form of tank employed for the manufacture of a diversity of glass ware such as elctron-tube glass, perfumery, medical glass and hollow ware in general, most especially flint, amber and green containers, service glasses (table ware) bottles, apparatus glass and a host of others.

In a construction form with a partition described as "shadow wall", the tanks share the same furnace space above glass surface and covered by a common crown to form one constructional unit.

The working chamber for holloware tanks of this nature are for most of the time circular, but sometimes rectangular.

For plate glass (rolled glass) which equally employed the same tank, the working chamber is rectangular.

Gunther (ibid) found the Germans cautious in their use of the terms "compartment" and "chamber" as they relate to tank furnaces. In Britain and America, the two seem to be used interchangeably. Gunther (ibid) confirms that in Germany, "the term 'chamber' refers to the bath; and that "the designation 'compartment' relates to the superstructure above glass bath. Thus in that country, the term "single-compartment" refers to tanks with a common furnace space above both melting and working chambers, and the term "single-chamber" describes tanks with no rigid separation between the ends (bridge or other division).

Accordingly, a "two-compartment" tank refers to a furnace in which the tanks are fully separated from each other including the furnace space. They are linked only by a narrow channel corresponding to the throat of the single compartment and lies almost at the level of the tank bottom. The desirable features of these tanks is that they permit separate temperature control and offer greater freedom of choice of shape and form of working chamber.

However, Gunther (ibid) pointed out that their construction cost is greater than that of a single-compartment type, owing to the separate firing operation of the working chamber. The direct consequence of this, he went further, is that this form of construction is no longer favoured.

If this is so, then one wonders why the two-compartment construction form is adopted for all the four hollow ware producing Nigerian glass industries, namely CMB Toyo Glass Nigeria Ltd - Lagos, West African Glass Industry (WAGI) Ltd - Port Harcourt, Delta Glass - Ughelli and Ballarpur Glass Industry Nigeria Ltd - Kaduna (now closed down). The fifth one, Oluwa Glass Industry - Igbokoda produces sheet glass by Fourcault method, and therefore exempted from this classification. The Abba International Glass Industry to produce different types of glasses is yet to go into production. The choice of the two-compartment construction must have been guided by other considerations, probably simplicity of construction and operation.

All said and done, the successful performance of the Hartford Empire Co. Unit Melter, though a two-compartment furnace makes it compete with small regenerative tanks in terms of efficiency.

The Potette Tank: This is a special form of single-compartment continuous tank employed for hand production. It has no dividing wall, and working end is completely absent. However, each individual working-hole is separated from the rest of the glass tank by a fireclay element, the potette. Gunther (ibid) describes the function of the potette which is deeply immersed in glass as synonymous to that of a throat. The importance of this tank has wane away with the upward decline in hand production.

especially that the potettes are less durable and less efficient than a bridge with throat. (See Appendix A, figure 2.1).

Bottle Tank With Ring Floaters: This tank is German in origin, used in the manufacture of green bottle-ware. The rapid increased viscosity with tank depth of green glass makes such tanks to be constructed with no internal barrier as required by colourless glass tanks as convection currents are slight. As far as the open type of bottle glass tank is concerned, the working chamber is usually semi-circular in shape with ring floaters in the working chamber (See Appendix A, figure 2.2).

Bridge Tanks And Constricted Tanks: These constitute the earlier forms for all sorts of hollow-ware (they were used before the advent of the throat). In such tanks, either floaters or constrictions were used as a means of partitioning the melting chamber from the working chamber. Depending on glass viscosity, floaters have an immersion depth of 30.48cm - 71.12cm; due to high viscosity of some green glasses, the immersion depth was reduced to 30.48cm. Owing to their relative ineffectiveness and difficulty of construction, they have given way to the throat tank furnace. Gunther (ibid) however maintained that such tanks still find occasional application in continental Europe.

Partitioning by constriction consists of narrowing the sidewalls of the tank between the melting and the working chambers

to form a narrow passage. The glass surface in the constricted portion of the furnace is frequently divided off by a floating fireclay block. It was formerly used for colourless glass melting and the design constitute the forerunner of the present day throat, Gunther (1958). For both tanks, see figures 2.3 and 2.4

Continuous Sheet Glass Tank Furnaces: These differ significantly from bottle tanks, both in size and design. They are employed for various methods of sheet glass production - vertical drawing, horizontal drawing or rolling operation. In sharp contrast to bottle tanks, they comprise a single chamber without bridge wall. This is clarified by Scholes (1974) when he opines that radiation from the combustion chamber is cut down from reaching the flowing or drawing chambers by jack arches which are a solid wall spanning across a constricted width of the tank. However, a slightly conflicting view is expressed by Bulavin et al (1986) when they maintain that sheet glass is melted in both tanks (with or without bridge-walls), but that precedence is given to those without bridge-walls in present-day practice. A suspended wall, hung from above the crown serves the same purpose as the jack arches.

Sheet glass is expected to be superior in quality to bottle glass — freedom from bubbles and other forms of inhomogeneities like stones, striae and cords. In this connection, sheet glass

tanks constitute the largest - they are constructed longer and deeper. Further effort in realizing this objective manifests itself in the use of floaters, made of refractory clay and slotted to float on the glass. Their prime responsibility is that of preventing unmelted and partially melted batch constituents, scum, poorly melted and unrefined glass from drifting along the tank towards the mirror glass of the working end.

In the open types of the tank, heat conditioning can only be effected by radiation from the glass to the unfired working end, which under these operating conditions, it is termed "standing-off end." Since internal barriers are virtually absent, intensive convective currents are freely and easily set up in such tanks. Gunther (ibid), while stressing the adverse effect of convective currents as retarding the cooling of glass, he quickly pointed out that high-quality glasses like sheet glass necessarily demand strong glass circulation for the elimination of inhomogeneities. The elongated nature of the drawing channels in sheet glass tanks ensures that glass is cooled to the drawing temperature.

Waste heat recovery from sheet glass tank furnaces is carried out in regenerator and utilized in preheating incoming combustion air and low c.v. gaseous fuels (producer gas and coke-oven).

Cross-firing remains the standard practice in operating sheet glass tank furnaces, though many small and medium-sized continuous tanks are end-fired. The horse-shoe-shape or U-shaped flame path produced by these furnaces ensures complete combustion, which becomes more difficult with transverse flame of the cross-fired tank. In any case, the longitudinal distribution of temperature is relatively more difficult to control with the end-fired tanks.

It is more economical in terms of construction cost to build an end-fired tank than a cross-fired regenerative tank of comparable size and its thermal efficiency is better.

The idea of constructing a partition between the melting and the refining zone was introduced by Siemens, but abandoned owing to lack of suitable refractory materials at that time in point. For a variety of sheet glass tanks (see Appendix B).

The Hartford Unit Melter (Direct-Fired): This is a particularly elongated narrow well-engineered, direct-fired tank. The ratio of width to length ranges from 1:4 to 1:6 (0.3048m x 1.2192m to 0.3048m x 1.8286m). Unit melters are equiped with a device for mixing warm air drawn from below tank with cold air from the surrounding atmosphere in definite ratios for maintenance of constant temperature of combustion air. For the diagram of the Unit Melter (see Appendix C).

There is excellent temperature distribution along the length of the furnace, provided for by numerous small burners arranged along the longitudinal sides of the furnace. Maximum heat is given up to cold batch as in cascade melting as the flame and hot waste gases flow back to be exhaust through a stack located over the dog-house. It is simple and uniform to operate, and its construction cost remains small. Furthermore, the change-over to a new grade of glass is made more rapid than in deep tanks.

It becomes apparent from the foregoing that with pot furnaces, it is possible to melt as many as twenty different glass compositions at a given time, with each composition contained in a separate pot. For this reason, they are used in melting coloured glasses simultaneously or in sequence. Though continuous tank furnaces may consist of two separate compartments, such are used for melting a glass composition at any time, and a change-over time becomes necessary for a new grade of glass to be produced. Periodic tank furnaces comprise generally a single chamber which makes melting more than one glass composition at a time practically impossible.

Chapter 3

METHODOLOGY

3.1 Sources of Materials Sampled

The constructional materials required for the experiment research can be basically grouped into two — refractory materials and metal materials.

It was observed that the few Nigerian glass industries constituted the only source for obtaining the refractory items. Hence, the sampling of the materials was a purposive one. For the metal materials, these were obtained from Sabon Gari market Zaria, and also, scraps picked from around its environs.

To get the refractory items therefore, it became imperative that the researcher undertook a number of trips to some of the glass industries. The three glass industries mapped out and visited include:

-- CMB Toyo Glass, Lagos.

-- West African Glass Industry (WAGI) Ltd., Port Harcourt.

-- Ballarpur Glass Industry Ltd., Kaduna (now closed down).

From these, the following categories of refractory materials were obtained:

-- Standard refractory bricks for the furnace proper.

-- Standard insulating bricks of different types.

-- Refractory cement (mortar).

-- Composite fibre glass wool.

In carrying out the trips, Ballarpur Glass Industry was visited first due to its proximity to Zaria; followed by CMB Toyo Glass; and lastly, WAGI.

3.1.1 Sampled Materials From Ballarpur

After a number of trips, only 28 insulating bricks were given. However, their chemical composition was not given. This might have not been unconnected with industrial secret policy.

3.1.2 Sampled Materials From CMB Toyo

It was here that the bulk of the refractory materials were provided which include the following:

1. 20 SGT 75-70 x 350W arch silica bricks with the chemical composition 96% SiO_2, 0.7% Al_2O_3 and 0.7% Fe_2O_3. These were employed for the furnace crown.

2. 20 SOR 75-70 x 300W arch silica bricks with the chemical composition 96.6% SiO_2, 0.5% Al_2O_3 and 1% Fe_2O_3. These could not be used for the crown of the furnace due to their shorter length.

3. 60 A2x - 10 70 x 230S (Zircon bricks) with the chemical composition 13% SiO_2, 50 Al_2O_3, 35% ZrO_2, 0.5% Fe_2O_3 and 0.15% TiO_2. Despite their outstanding properties, these could not be used due to lack of cutting machine to get them to the desirable sizes.

4. 30 High-duty silica insulating bricks. These were used mostly for insulating the crown of the furnace due to their chemical compatibility with the silica crown bricks.

5. 25kg silica M SOR cement with chemical composition similar to that of SOR arch silica bricks above.

6. Composite glass fibre wool measuring about 840mm by 460mm.

3.1.3 Sampled Materials From WAGI

Here, the following refractories were obtained:

1. 45 Stein 45D (fix dense low-iron aluminous fire bricks) with the chemical composition 51.5% SiO_2, 45% Al_2O_3, 1.1% Fe_2O_3, 1.6% TiO_2, 0.3% CaO plus MgO and 0.5% $Na_2O + K_2O$.

The properties accompanying the fire brick as provided for by WAGI are 1780^{0}C Pyrometric Cone Equivalent (P.C.E.), apparent porosity of 12.5%, 2.36gm/cm^3 bulk density and its cold crushing strength was given to be 680kg/cm^2. These bricks were employed for the floor and walls of the furnace proper.

The properties that precipitated the choice of this category of refractory are its high refractoriness (generally between 1600^{0}C and 1750^{0}C), and most especially, its high thermal shock resistance which is better than

that of silica brick, though its R.U.L is lower owing to the fact that its fire strength is due to the glassy bond. This high thermal shock resistance was deemed essential, considering the periodic mode of heating and colling the furnace was to be subjected to. It is as a result of some of these desirable features that fire bricks find most application in the glass industry.

2.40 Amberite insulating bricks (castaules) with the chemical composition 31% Al_2O_3, 51% SiO_2 and 6% Fe_2O_3. Its service temperature limit was given as $1350^{o}C$.

3.1.4 Metal Materials Sampled

These included angle irons sizes 7.5cm x 7.5cm, 5cm x 5cm and 4cm x 4cm, iron rods, nuts and washers. Others were metal sheet and welding electrodes.

3.1.5 Expectations of Furnace Refractories

The requirements of furnace refractories as demanded by the furnace designer are many and varied that it is impossible for any single refractory material to fulfil all. In this connexion, Thring (1962) stated that as a consequence of this, the selection of a refractory for a given application is frequently governed by compromise in which the properties considered essential are opted for at the expense of the less

essential ones. In order to aid the furnace designer in making such a selection, various standardized laboratory tests have been deviced for determining these properties.

Some general requirements of furnace refractories are presented below:

1. The ability to withstand high temperature ranges without fusion or deformation under plant conditions.

2. The ability to withstand the corrosive action of molten materials, both basic and acidic in nature like metal, slag and glass, fumes and vapour of fluxes which wear it by dissolution or penetration.

3. Capability of withstanding the accelerated action of erosion which is mechanical in nature such as fast moving gases carrying liquid or suspended particles, or impact of rapidly moving stream of molten metals or glass.

4. The ability to withstand mechanical loading at high temperatures by its charge or by the surrounding structures. This is known as refractoriness under load earlier mentioned in chapter one.

5. The ability to withstand sudden temperature changes (thermal shock), which causes stresses to be set up as a result of differential expansion and contraction leading

7. Low porosity and permeability are properties demanded by refractories used for the furnace lining. Due to the nature of manufacture, pores both closed and open are formed in them, and firing only reduce their volume and not eliminate them. Open pores are interconnected and are responsible for gas and liquid permeability.

8. Low thermal conductivity and high porosity are desirable in external furnace walls for backing insulating refractories to prevent excessive heat loss. Backing insulation is however avoided or minimized in critical temperature regions as it leads to accelerated wear of the hot face refractory. Accordingly, roofs and walls of open hearth furnace are never insulated or only lightly insulated. In some applications, the furnace may be expected to serve as store house for heat in which the hot face of the furnace itself may be built of porous insulating materials which reduce the heat capacity of the walls, provide low thermal conductivity and so minimizes heat loss. This is good for intermittently heated furnaces, but the practice is only suitable where there is absence of slagging effect as insulating materials are generally of high porosity and therefore of low resistance to slagging.

9. Where refractories employed for the manufacture of crucibles, recuperator tubes, wire wound furnaces (electric furnaces), thermocouple shealths or for constructing coke-oven and muffle walls are concerned, high thermal conductivity is a desirable feature. For this reason, such refractories are made of high heat conducting materials like silicon carbide and graphite.

Generally, the choice of the sampled refractory materials used in the furnace construction was guided by availability and properties as presented below:

Aluminous Fire Bricks: As stated earlier, these were used for the floor and walls of the furnace lining. Fire bricks are a group of alumino-silicate materials with 24 - 45% Al_2O_3, the remaining balance being essentially SiO_2 with small amounts of Fe_2O_3, CaO, MgO and alkali.

Other ranges under this broad group include sillimenite with 45 - 65% Al_2O_3, mullite ($3Al_2O_3 \cdot 2SiO_2$) with 65 - 75% Al_2O_3, boxite base (aluminous) with 75 - 90% Al_2O_3 and corundum with 90 - 100% Al_2O_3.

Generally, their refractoriness is found to be a factor of silica-alumina ratio, nature and quality of the fluxing

materials present, either as an impurity or as a deliberate additive. The refractoriness which is found to increase with increasing alumina content rises from 1550 - 1750°C as far as the 25 - 45% Al_2O_3 range is concerned, but generally, it is between 1600°C and 1750°C. Their load bearing ability at high temperatures (R.U.L) and their maximum working range is considerably less than their refractoriness, about 1500°C or even lower. It has a good spalling resistance, and is better the higher the alumina content. Slag resistance is weak, but thermal shock resistance is better than for silica bricks. This last property was considered very essential.

Trinks (1953) classified fire bricks as super-duty, high-duty, medium-duty and low-duty bricks.

Sillimenite Refractories ($Al_2O_3 . SiO_2$): These have an alumina content of 62 percent with a melting point of 1850°C. Its working range is analogous to that of silica brick (up to 1700°C); has good R.U.L., but not as good as that of silica brick, though with better thermal shock resistance. It is used at elevated melting temperatures where fire bricks are found unsuitable. Its slag resistance makes it suitable for glass melting tanks.

Mullite Refractories ($3Al_2O_3 \cdot 2SiO_2$): These contain 72% Al_2O_3 and the refractoriness ranges from 1800°C - 1850°C. Its high mechanical strength at elevated temperatures is as a result of its interlocking needle-like crystals. There is uniformity of expansion and good thermal shock resistance, extremely high cold crushing strength, and therefore may be used where there is high mechanical wear or abrasion, not necessarily at high temperatures.

Its application is to be found in the crown of electric furnaces, in the hearth of reheating furnaces, brass melting, reverberatories and alumina melting. Non-metallurgical uses are in glass melting furnaces, cement, pottery and enamel industries.

Alumina Refractories: They contain 90 - 100% Al_2O_3 with a melting point of 2050°C. Depending on the alumina content, their maximum working range lies in the region of 1700°C - 1900°C. Owing to its high refractoriness, hardness, mechanical strength, thermal shock resistance, resistance to chemical attack and its electrical properties, pure alumina remains the most widely used pure oxide.

The silica-alumina phase diagram presented in appendix D demonstrate two things:

1. The damaging effect of small amounts of alumina on the refractoriness of silica bricks.

2. That the most refractory mixtures are those between seventy-two and hundred per cent alumina.

The addition of 5% Al_2O_3 to pure SiO_2 reduces the melting temperature from 1710°C to 1545°C for pure silica. Further addition however results in an increase in melting temperature. The composition 95% SiO_2 and 5% Al_2O_3 is the composition of eutectic (where the most damaging effect on silica refractory is felt). The composition consisting of 72% Al_2O_3 and 28% SiO_2 is mullite ($3Al_2O_3 \cdot 2SiO_2$) with a melting point of 1870°C. All mixtures containing less than 72% Al_2O_3 first form liquid at 1850°C or higher.

The silica alumina ratio of an alumino-silicate is therefore a good guide to the likely refractoriness of the material, though the melting temperature indicated by the phase diagram will not be exact since the actual alumino-silicate refractories are never pure. The presence of small amounts of impurities, particularly fluxes like alkali and alkali earth compounds, iron oxides and titania will reduce the refractoriness. The true refractoriness is best found by laboratory testing. The siliceous refractories will fall to

the left hand side of the phase diagram, while the aluminous ones to the right hand.

Silica Arch Bricks: The silica arch bricks with 96% SiO_2 described under 3.1.2 above were employed for the crown of the furnace, except for the chimney L-shaped brick and its key-brick which are of the aluminous fire brick.

The outstanding properties of silica bricks are to be found in their:

1. Very high R.U.L. to within a few degrees of melting point (1710 - 1730°C).
2. Freedom from shrinkage at operating temperatures (1600 - 1700°C).
3. Relatively high resistance to attack by oxides of iron and alkalis.

Property 1 was considered very crucial for its use at the crown of the furnace. The most valuable property of silica bricks is the very high R.U.L. resulting from the tridymite bond. It is pertinent to note that bonding in silica brick particles is mainly by formation of calcium-silicate glass and partly by interlocking between tridymite particles.

However, silica bricks are of poor thermal shock resistance, a factor responsible for their failure. Their thermal shock resistance is to be found at temperatures only above 600^{0}C.

As has been mentioned earlier, the refractoriness of silica bricks is greatly lowered by small traces of impurities such as alumina. The main difference between silica bricks and super-duty silica bricks is not in their refractoriness, but in load bearing ability at high temperatures. Super-duty silica bricks are of higher R.U.L because the impurities have been beneficiated.

3.1.6 Brick Cutting To The Desired Dimensions and Shapes

The stein 45D (fix dense low-iron aluminous fire bricks) obtained from WAGI, and measuring 30 x 15 x 6.5cm were cut into a number of sizes. Some were cut into three equal parts across the length to form smaller constructional units measuring 15 x 10 x 6.5cm, with the original width now serving as the new length. A few more were cut to the size of 20 x 15 x 6.5cm (two third of the full length). Two others were cut into L-shape by removing out a portion measuring 14cm along the length from one end by 9.5cm along the width. The cut out portion became the key brick. Three of the remaining bricks were left full length (See appendix E).

The Cutting Procedure: This was carried out at WAGI plant from where the bricks were obtained using the brick cutting machine, driven by an electric motor. The torque produced by the electric motor is transmitted through an over-head arm of the machine onto which the diamond blade disc is fixed to be rotated.

The brick-cutting machine is permanently mounted on a metal table with a hole on its flat surface through which the diamond blade passes in during the cutting process. The marked out area to be cut was perfectly placed along this hole. As the machine was switched on, the arm was lowered until the blade was in contact with the brick when the cutting was initiated. The brick was held in position while the arm was lowered, until the brick was neatly cut out when the arm was raised up to its rest position, ready for the next cutting operation.

3.1.7 *Preheating The Bricks*

All the dense bricks, both cut and uncut were taken up for preheating on top of the operating furnace forehearth for a period lasting about 12 hours. Here, the bricks were exposed to a temperature range of 700 - 800^{o}C (the surface temperature of the forehearth). The temperature of glass in the forehearth ranged from 1118^{o}C - 1120^{o}C.

After the said period of time, the bricks were brought down and allowed to cool to ambient temperature. The cut bricks were given finishing touches by chipping off the badly finished edge with a hammer. The essence of preheating the bricks was directed at driving off hygroscopic water to avoid shattering during furnace operation.

3.2 Metal Table Construction

Having come out with a detailed paper plan of the two-chamber periodic tank furnace, the metal table measuring 141cm x 86cm x 51cm was constructed to carry and accommodate the furnace.

The constructional materials used were exclusively angle-irons and metal sheet as pointed out under 3.1.3. Both powered and manual hack-saw were used in cutting the metal materials.

The table was constructed to comprise of six legs measuring 50cm in height. Each pair of legs was reinforced with a 7.5cm x 7.5cm angle-iron, stretching 81cm across the width of the table.

By using instruments like a scrapper, Tri-square metal set-squre and a manual hack-saw, V-shaped lines and marks forming a 90° angle were obtained at appropriate distances on the 5cm x 5cm angle-iron, making the table edges with a total

length of 4.54m. By cutting out these V-shaped lines and marks using the hand hack-saw, only one joint was created as the angle-iron was bent to form the four corners of the table edge.

The legs were welded to the table edges at right angles, and the reinforcements also welded to the pair of legs at right angle to each other.

In order that the table top be able to carry the weight of the furnace without deformation or sagging, six angle-iron pieces measuring 81cm were cut and equi-distantly spaced out on the inner surface of the table edges. The placement was done at right angle to the table edges. They too were welded across the length of the table. Thus besides serving as reinforcement component parts, these cross angle-iron also performed the function of absorbing the downward pressure exerted by the furnace.

3.3 Furnace Design And Construction

A comprehensive and detail paper design preceded the furnace construction. The initial plan of the furnace measuring 115cm x 60cm x 49cm was abandoned because the silica crown bricks could not go across the 60cm width. This necessitated looking for fresh refractory bricks for the

furnace lining and cutting them to smaller construction units as described under 3.1.6 to match the new design (see appendix VIII).

3.3.1 Fundamentals And Basic Considerations In The Furnace Design And Construction

Factors that were considered in designing and constructing the furnace are:

1. Type, availability of fuel and combustion equipment.

Trinks (1953) stated that heat is generated in a furnace either by combustion of fuel or by conversion of electric energy into heat energy. Further, that the combustion types of furnace are more numerous, but the electric types are prefered for many purposes. Nigeria has abundant energy sources that can be fully used in glass melting. These include among others, electricity, liquid fuels such as diesel, heavy fuel oil and kerosine, gaseous fuel like liquified petroleum gas (L.P.G), and in the near future, natural gas (N.G).

Electricity supply was considered sporadic, unreliable and costly, while the liquid fuels were dropped on lack of suitable supply equipments for preheating, atomization, and combustion process. L.P.G was opted for because of

availability of gas burners in Glass Technology and Ceramic Sections of the Department and the relative cheapness of the fuel itself.

2. Refractories choice. This was guided by what could be obtained from the few Nigerian glass factories visited coupled with their desirable features as earlier discussed — hence the purposive sampling of the construction materials.

3. Viewing from the perspective of capital and maintenance cost, the direct-heated furnace surfaced as recuperators and regenerative chambers were dispensed with.

4. In view of the smallness of the furnace size, the longitudinal flame and direction of gas movement was provided in preference to the U-shaped (horse-shoe) or transveree flame.

5. Design of furnace space. Here, the tank furnace was opted for in preference to the pot furnace in view of the proper utilization of the furnace space. This also took into account the method of glass-working (off-hand) since it is studio glass practice.

6. Simplicity of construction, operation and parts replacement necessitated the choice of the rectangular type of periodic tank furnace in preference to the more

complicated circular or oval-shaped types.

7. The size of the furnace and furnace productivity which took into consideration capacity of the combustion equipment available. Attention was paid to the furnace height and working space.

8. On the score of the method of division of the tank and flame space, the two chamber type with a common flame space as a means of achieving the prime objective of the study came to mind - that of simultaneous dual melting of both coloured and flint glass using a burner for fuel economy.

3.3.2 Furnace-Proper Brick Laying

The first stage involved in the construction process was the central spreading of the composite sheet of glass fibre on the metal table. This served as an insulating medium between the hot base of the furnace and the cold surface of the table top. On top of the glass fibre, the floor bricks were laid, followed by the side walls, and lastly, the crown bricks.

The plain straight packing of bricks was generally adopted for the furnace lining. These were closely fitted

together as much as possible to minimize the amount of gaps created inbetween brick joints. Lack of cutting machine at hand during the construction process unavoidably prevented the use of stringer course packing which would have otherwise provided for maximum mechanical strength. The little spaces created inbetween the construction units served as a natural expansion gap during furnace operation. Gilchrist (1977) stated that in constructing a furnace, spaces should be left inbetween bricks to accommodate their thermal expansion so as to avoid distortion of the steel framework as the expansion of refractories is likely to be three to four times the elastic strain in steel.

As it is customary in tank construction, no mortar of any sort was used to seal up the brick joints. Therefore, the solidification of glass in the joints was all that prevented leakage.

3.3.3 Elements of The Furnace

The main component parts of the furnace comprised the following:

The Floor or Base: The floor bricks were laid in double course, one on top of the other. They comprised eight double bricks along the length of the furnace and two double bricks

along the width of the furnace to give a dimension of 80cm x 30cm with a height of 13cm (from the top of the glass fibre), see plate I for the arrangement of the bricks).

along the width of the furnace to give a dimension of 80cm x 30cm with a height of 13cm (from the top of the glass fibre), see plate I for the arrangement of the bricks).

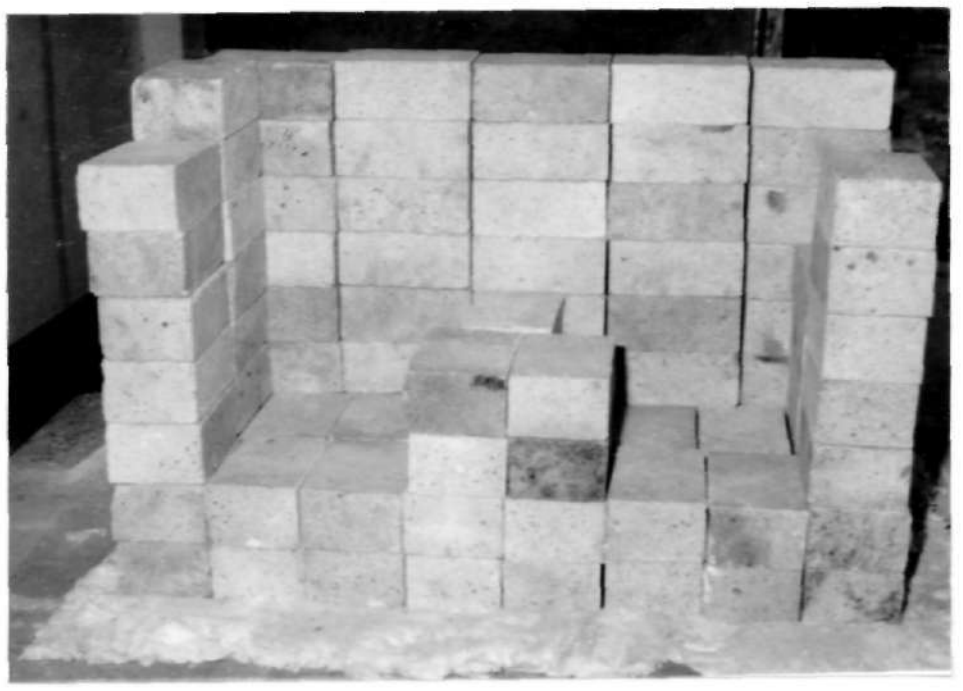


Plate I: Arrangement of Refractory Bricks for the Base Including the Partition, Lower Portion of the Central Pillar, End Walls and the Back Wall of the Furnace Proper.

The Walls, Doors and The Central Pillar: The end walls bricks, numbering two, were arranged lengthwise, stretching the width of the furnace and on top of the double course floor bricks.

Along the front longitudinal side of the furnace, a central pillar measuring 20cm side, 32.5cm high and extending 15cm into the furnace interior was constructed. This served two

purposes - as a division for the doors of the two chambers and as a support base for the top door bricks and crown bricks. On top of the pillar is a brick centrally situated and extending lengthwise (15cm) into the furnace in the same manner as the pillar bricks themselves. From either side of this central brick are the top door bricks that extended to the extreme top ends of the furnace. They are full length (30cm x 15cm x 6.5cm).

These, plus the central brick on top of the pillar served as the base on which the crown bricks, the chimney L-shaped brick and its key-brick rested.

On either side of the central pillar (beginning from the top of the floor bricks) were two bricks arranged vertically lengthwise (15cm), 20cm wide and extending 6.5cm into the furnace interior to give the maximum height of the furnace chambers. They were bounded by the central pillar and end walls bricks.

The two rectangular doors, each measuring 20cm wide and 17cm high were bounded by the twin bricks described above, the central pillar, the end walls and the support base of the crown bricks. The two functioned as inlets for batch charging and outlets for glass working. Pyrometric cones were also

arranged at their base for temperature determination. For the front view of the furnace lining, see plate II.

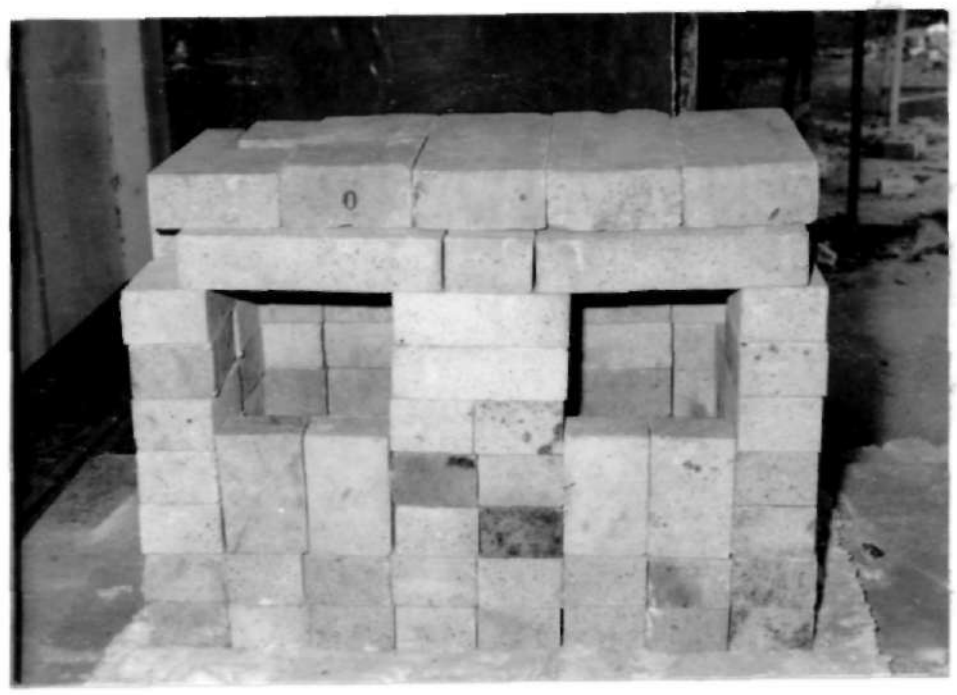


Plate II: Front View of the Furnace Lining with the Doors, Central Pillar, the Twin Bricks, the Crown Bricks and their Support Base Bricks in Perspective.

The bricks constituting the rear longitudinal side wall were packed lengthwise, starting from the very bottom of the tank (directly on top of the glass fibre wool). Under this arrangement, the number of bricks totalled five along the length and eight vertically to give a dimension of 75cm long and 52cm high (see plates III and VI).

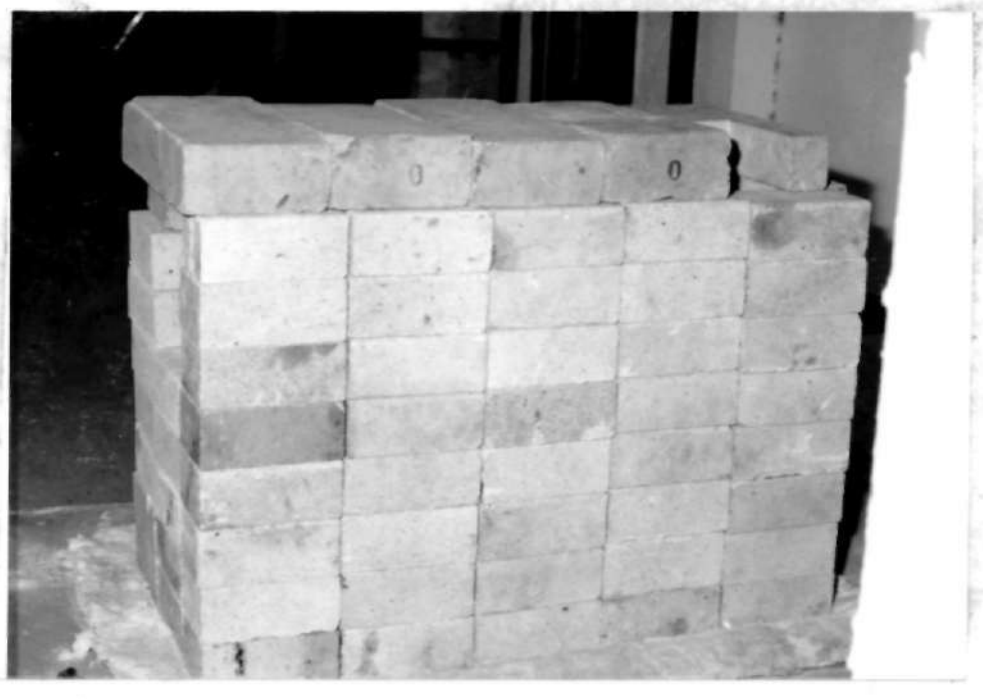


Plate III: Furnace Proper Refractory Bricks set up, Closely Fitted Together as Viewed from the Rear Side Wall.

The Partition: The partitioning of the single-chamber into two-chamber furnace was effected by placing lengthwise, two bricks, one on top of the other going the width of the furnace chamber to divide it into two equal parts. The placement of the partition bricks was done in such a way that they formed an extension of the central pillar in the middle portion and extending to touch the bricks of the back longitudinal wall. They measured 15cm stretching the width of the chambers, 10cm going along the length of the furnace and 13cm high. The minimum height of the furnace chambers were therefore determined by the height of the partition.

The differential width of the partition brick and that of the central pillar resulted in two adjacent "dead corners" being created, one within each of the two chambers. They each measured 5.0cm wide. The partition was essentially an extension of the central pillar from the floor of the furnace (see plates I and IV for the arrangement of the partition bricks).



Plate IV: The Partition Bricks as Viewed from the End View, with the Chimney L-Shaped Brick in Perspective.

Crown of The Furnace: The SGT 75 - 70 x 350w silica arch bricks were packed lengthwise going on top of the furnace width to give it a total external height of 59 ± 0.5cm (that is 52cm plus 7 ± 0.5cm). These bricks were four in number plus a fifth one consisting of the L-shaped low-iron aluminous fire brick to form the chimney brick. These were closely fitted together. The "key-brick" or "lock-brick" was slotted in the L-shaped brick to make for adjustment of the chimney opening (see plates II, III, V and VI for the arrangement of the crown bricks).

The Burner Port: An end-port with an original dimension of 19.5cm high and 15cm wide was provided opposite the chimney. The construction was carried out in such a way that it was 6.5cm above the partition so that the latter did not obstruct the flame path during firing operation.

In the course of insulating the furnace however, the original size of the port was reduced to 18cm high, 7.5cm wide (at the bottom) and 7.0cm wide (at the tapering top). The tapering at the top came about as a result of the use of silica crown brick (of size 60 - 70 x 230w), vertically placed on one side of the port. The reduced size of the port ensured that stoichiometric fuel/air ratio was maintained during

combustion. The distance from the front of the furnace to the beginning of the port measured 15.0cm and that going to the back end stood at 17cm.

The port functioned as an inlet for gas and combustion air (see plates V and VII for the initial and final size of the burner port). It also served as a "peephole" or "sighthole." Its location makes it an "end-port" and avenue for sample taking of molten glass.



Plate V: The Initial Size of the End-Port, Before the Application of External Backing Insulation. The Bottom Structure can be Seen Sinking in the Composite Glass Fibre Wool, Centrally Spread on the Metal Table.

The Chimney: The L-shaped brick placed as the last crown brick together with its key-brick formed a rectangular chimney for the furnace. The placement of the L-shaped brick was done in such a way that the narrow strip side was rested on the end brick. In this manner, the top of the end brick in the cut out area was caused to extend 2cm inward. This inward extension served as a base on which the key-brick threw its weight (see plate VI).



Plate VI: An Aerial View of the SGT 75-70 x 350W Silica Arch Bricks, with the Stein 45D L-Shaped Fire Brick and its Key-Brick in Perspective.

The outward extension of the chimney cut out part of the L-shaped brick and its key-brick reduced the chimney hole to measure 9 x 6cm. The depth of the chimney amounted to 21cm after insulation. The chimney hole is adjustable by the

key-brick by sliding it to and fro at the rear or through one of the doors, and can even be shut up completely. By sliding it backward, the chimney hole attained its maximum dimension of 9 x 6cm.

While the key-brick functioned as a regulating equipment for the control of atmospheric conditions, the chimney itself provided an exit for flue gases.

3.4 Insulation and Surface Finishing

3.4.1 Backing Insulation

The straight plain packing of the component parts of the furnace refractory lining, closely fitted together was accompanied by external insulation using insulation bricks laid in stringer course for increased strength. The standard insulating bricks obtained from the three glass industries measuring 23 x 11 x 6.5cm and the ones made in Ceramic Section of a much larger dimension were employed for the same purpose.

Clay mortar, a mixture of kaolin and saw dust in the ratio 1:1 was used as a binder for the bricks as well as for filling inequalities in the construction. Water was added until the right consistency suitable for the purpose was obtained. This was left in the container over four nights and stirred three times each day for proper homogenization of

the mixture. Ewule (1988) used the same proportion of mixture for his ceramic kiln construction, and is found quoting Rhodes (1968) as saying that the purpose of mortar is to fill cracks and makes for a more-air-tight structure rather than sticking the bricks together.

The application of the mortar was by dipping the bricks into the mortar and completed by hand application. Ewule (ibid) further reiterated Rhodes' suggestion that the bricks should be dampened as a preventive measure against quick sucking of mortar which makes it too stiff for achieving the desired result.

The stringer course laying of the insulation bricks necessitated cutting some of the bricks using power grinder and to some extent, hack-saw. The arrangement of the bricks was carefully carried out such that the vertical and horizontal joints were not allowed to lie directly to those of the furnace proper, but crossed each other for minimizing heat loss.

The desire and need to apply backing insulation to the furnace arose from the knowledge that no matter how properly designed a furnace is, considerable heat is lost to the surrounding atmosphere through the crown and walls of the

furnace, and through openings, largely by radiation and conduction. The transfer to these interfaces is further aided by convective currents set up in glass. This has prompted the provision of external furnace walls.

Doyle (1979) categorized heat loses into sensible heat in glass, stack loses and structure loses. Chesters (1973) said that the prime aim of insulation is best appreciated in the light of heat conservation; it halves the losses through certain structure so as to offset the material (fuel) costs involved. Furthermore, that the question of insulation is less attractive to the refractories engineer in view of the fact that it rarely adds to the refractory life, indeed it may be reduced. Scholes (1974) asserted that "insulation, judiciously applied, improves the thermal efficiency of modern glass tanks and increases the output of glass."

It is an established fact that the crown of the furnace radiates into the surrounding atmosphere 10 - 12 per cent of the total heat supplied to the furnace. By insulating, this amount of loss is halved, corresponding to a direct saving in the order of 5 - 6 per cent. Undoubtedly, 8 - 10 per cent fuel-saving is achieved as the crown insulation reduces by half the amount of heat lost.

The investigator was cautious in ensuring that the insulation bricks used on the crown of the furnace was chemically compatible with the silica bricks (porous silica bricks were used). An alternative to this is to use pure, alumina-free kieselguhr / bricks because alumina penetrates the joints of the silica crown bricks to form a low melting eutectic (it acts as a flux to silica). Where alumina-containing insulating bricks are used on the crown, it is advisable that a layer of quartz sand is first laid on the crown before applying the insulation.

Taking into account the expansion of the silica bricks, the crown was insulated in the cold state, which is a better practice than the hot crown insulation. In this case, the insulation is applied only after the crown must have been heated to the furnace operating temperature whereby all expansion joints and leaks are properly sealed up.

The horizontal joints of the silica crown bricks were first covered with composite glass fibre before applying the insulating bricks to avoid particles dropping into the furnace in the event of after-contraction during cooling.

In high-temperature tank furnaces, especially critical temperature regions such as the upper part of the flux blocks,

joints between port neck, skews, invert arches, the ports and the throat cover are subject to greatest wear, hence they are left uninsulated and cooled with water boxes and air jets. Breast walls, back walls, and refiner blocks may be insulated as well as the working chamber.

The efficiencies of glass melting tank furnaces is put at 15 - 25 per cent; and only in exceptionally good cases that this is exceeded. The average is however put at 18 per cent. In the early decades of this century, the efficiencies was put at 10 - 15 per cent.

Investigation has proved that the efficiencies of glass tanks may be improved to a limited extent by judicious application of thermal insulation to the exterior surfaces of the furnaces.

Insulation utilizes the property of poor thermal conductivity of air, hence thermal pockets are created in insulation bricks. Insulating materials derive their low thermal conductivity from their air pores, while heat capacity is determined almost entirely by the solid components in an alternate series of solid boundaries that give the insulating effect. The more pores present, and the less the solid, the lower will be the conductivity, and the higher the insulating property.

3.4.2 Surface Finishing

After the completion of laying the insulating bricks round and on top of the furnace crown, mortar was prepared and applied on the exterior surfaces of the furnace, essentially to seal and level up any identifiable inequalities. This was repeated after a week to give it a final touch.

3.5 Steel Frame-work

The furnace which had the metal table as its support base was supported at the vertical and horizontal edges by angle-irons. The backstays, measuring 75cm, rose above the furnace crown by 10cm and were fastened together at the top and bottom by tie rods measuring 1.12m (along the length of the furnace), and at the top and bottom by another set of tie rods, measuring 76cm (going along the width of the furnace).

The two projections at the front of the furnace were also supported vertically by a pair of shorter angle-irons.

The tie rods were threaded 5cm at both ends and provided with nuts which could be adjusted to allow for expansion when the furnace was under operation. The tie rods ran through a hole drilled in angle-irons, cut to a width of 3cm and welded to the supporting angle-irons in pairs at equal distances.

By virtue of their outward projection, sufficient clearance was provided for tension to be created.

The steel members and the tie rods, thus braced the entire structure together. Gilchrist (1977) asserted "furnaces usually have a cast iron or steel frame or case and refractory brick wall and lining."

3.6 Removeable Door Covers

The final stage of the furnace construction consisted of making two removeable covers for the two rectangular holes of the two chambers. Each was made up of a pair of insulating bricks closely fitted together by a square angle-iron, 22.8cm x 22.8cm, that were constructed in the same way as the metal table edges. They were each provided with a metal pipe handle measuring 50cm projecting horizontally outwards with a hole diameter of 3.3cm (see plate VII).

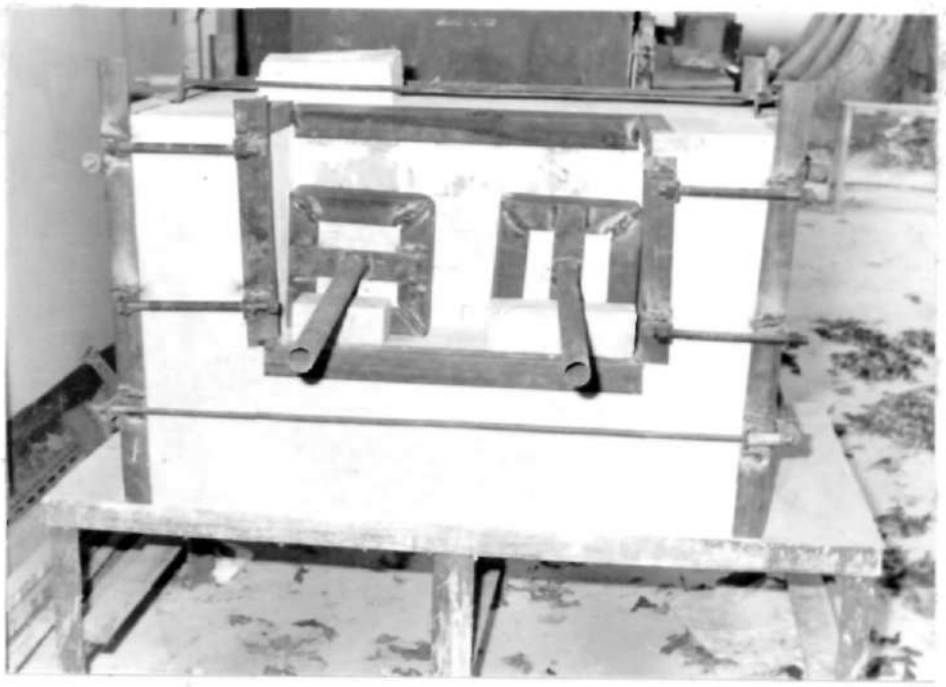


Plate VII: Front View of the Furnace After Insulation, Surface Finishing with the Steel Frame-Work in Position; the Doors are Covered with the Removeable Covers.

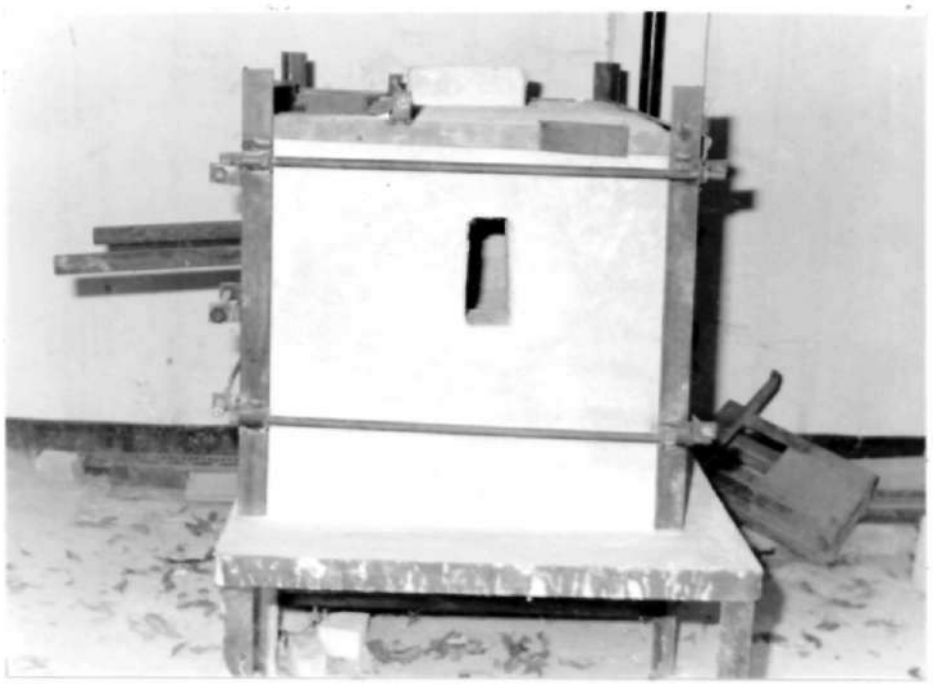


Plate VIII: The Final Size of the End-Port; the Handles of the Removeable Door Covers Projecting Outwards as they Remain Closed.

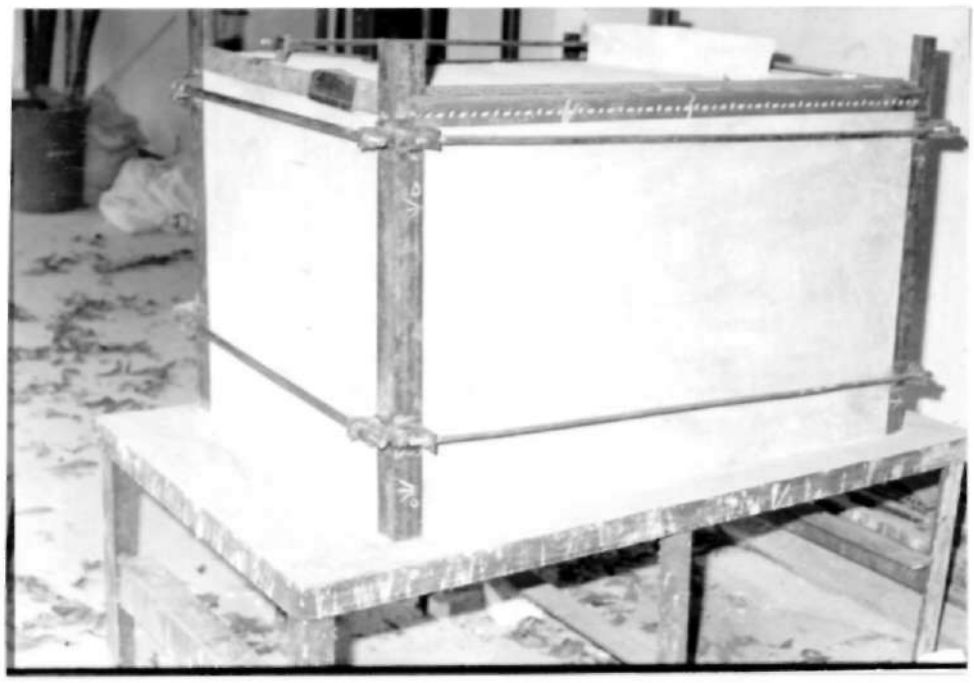


Plate IX: An Oblique View of the Structure After Completion.



Plate X: The Worn-out Single-Compartment Periodic Tank Furnace; Greatly Corroded and Erroded with Cracks.

Chapter 4

ANALYSIS OF FURNACE OPERATION AND EXPERIMENTAL TEST-MELTING OF GLASS

In order to determine the performance of the furnace, three separate test-meltings were carried out. In each case, two separate batches of the same quantity and composition were prepared, one for each of the two chambers. For easy reference, the chambers were numbered coloured glass chamber (CGC) or chamber one (CI) and flint glass chamber (FGC), otherwise refered to as chamber two (CII).

Coloured glass chamber was constantly used for coloured glass melting, while FGC was used for flint glass. Since the contents of the two chambers underwent simultaneous melting operation, it became necessary that all the materials making up the pair of batches were melted under the same conditions. For the same reason too, they comprised the same composition. On the score of consistency of result in terms of composition, the same method of batch calculation was used throughout — the simultaneous equation method of approach was adopted in this case.

The calculation was first based on 100kg of glass oxide, cross-checked, after which it was based on 21kg of glass oxide. Further, the result obtained was divided by two to get the capacity of one chamber of the furnace. Hence, the capacity of the two chambers totalled 21kg of glass.

For the pair of batches of the first test-melting, two main sources of silica (SiO_2) were used (quartz obtained from Ceramic Section, and Baure sand from Ballarpur Glass Industry). Owing to its relative high purity, the quartz was used for the flint glass batch, while Baure sand was used for blue coloured glass batch. In the subsequent two test-melting operations, sand was used for both pair of batches.

The compositions of the first two melting tests consisted of soda-lime-silica glass, while the third and the last one was lead crystal glass.

In view of the fact that no chemical analysis of the component ingredients of the batches was carried out in order to quantify their chemical compositions, especially the complex and the locally sourced raw materials, it was obvious that empirical assumption was made in this respect, based on existing theories, (see Appendix H).

4.1 Batch Calculation And Preparation

The glass composition (percentage oxides in glass) of the soda-lime-silica glass in the first two melting tests was worked out to comprise 65% SiO_2, 1.4% Al_2O_3, 6.6 CaO, 3.8% MgO, 20% Na_2O, 3.2% K_2O. In addition, 0.005% arsenious oxide (As_2O_3) and 0.005% antimonium oxide (Sb_2O_3) were included in

both pair of batches. These served both as fining agents as well as oxidants. Further, 2% cupprous oxide (Cu_2O) was added to the coloured glass batch. This constituted the colouring agent for the blue glass.

The prime aim of introducing both As_2O_3 and Sb_2O_3 adjunt saltpeter (KNO_3) was to aid in difficult fining problems. Both oxides (As_2O_3 and Sb_2O_3) are similar in chemical composition; they intercept oxygen gas released by nitrates at a lower temperature to be converted to the pentavalent state. At a higher temperature, they release oxygen gas bubbles which help in eliminating residual gas bubbles from glass. Sb_2O_3 is sometimes more effective than As_2O_3, probably because the reversion to the trioxide takes place at a somewhat lower temperature than for asernic; hence it is used as fining agent for soft glasses.

Asernious oxide provided the additional advantage of controlling the colouring effect of iron oxide in the flint glass batches.

The composition of the tableware lead crystal glass used in the third melting test consisted of 56% SiO_2, 29% PbO, 2% Na_2O, 13% K_2O, plus 0.4% As_2O_3 and 0.2% B_2O_3. For the coloured glass batch, 2% Cu_2O was introduced.

The percentage chemical composition and the quantities of the individual raw materials used in the first and third pair of batches plus the quantities of oxides they supplied are tabulated in tables 4.3 to 4.4. The tables for the second pair of batches are not shown because they are the same as the one in table 4.3.

Table 4.3: Theoretical Glass Composition (Oxides in Glass) And Chemical Composition of Raw Materials Used in Batch One For Chamber One (Coloured Glass Chamber)

Weight of Raw Materials (kg)	% Weight of Glass Oxides (kg)					
	65.0 SiO_2	1.4 Al_2O_3	6.6 CaO	3.8 MgO	20.0 Na_2O	3.2 K_2O
64.71 Sand	63.74	0.32	0.32	-	0.20	0.10
2.92 Felspar	1.26	1.07	0.58	-	-	-
17.47 Dolomite	-	-	5.24	3.76	-	-
0.89 Limestone	-	-	0.55	0.06	-	-
33.86 Soda Ash	-	-	-	-	19.64	-
6.77 Saltpeter						3.11
126.62	65.0	1.4	6.7	3.8	20.0	3.2
Raw Materials	Chemical Composition					
Sand	98.5	0.5	0.5	-	0.3	0.07
Felspar	43.2	36.7	20.2	-	-	-
Dolomite	-	-	30.0	21.5	-	-
Limestone	-	-	50.0	5.0	-	-
Soda Ash	-	-	-	-	58.5	-
Saltpeter	-	-	-	-	-	46.5

The bottom part of table 4.3 above shows the chemical composition of the various glassmaking raw materials used for the coloured glass batch in the first melting test as analysed in the laboratory. For example, 100kg of sand was taken to contain 98.5% SiO_2, 0.5% Al_2O_3, 0.5% CaO, 0.3% Na_2O and 0.07% K_2O.

The top part of the table shows the percentage of the individual oxides needed in the glass, the total being 100%. These are presented in the second horizontal column to the right hand side. For example, 65.0% SiO_2 is the total amount of SiO_2 needed in 100kg of glass. The extreme left vertical column of the table gives the weight of the individual raw materials; and going horizontally towards the right are the percentages of the various oxides supplied by each of them. For example, out of the total 100kg of glass oxides, 2.92kg felspar supplies 1.26% SiO_2, 1.07% Al_2O_3 and 0.58% CaO of the total 65.0% SiO_2, 1.4% Al_2O_3 and 6.6% CaO respectively. The last horizontal column of the same part of the table represents, at the extreme left, the total weight of all the raw materials (126.62kg); and going horizontally towards the right hand side are the total weight of the individual oxides as supplied by the various raw materials. Tables 4.4 and 4.5 can be understood in the same way.

Table 4.4: Theoretical Glass Composition (Oxides In Glass) And Chemical Composition of Raw Materials Used in Batch Two For Chamber Two (Flint Glass Chamber)

Weight or Raw Materials (kg)	% Weight of Oxides Supplied (kg)					
	65.0 SiO_2	1.4 Al_2O_3	6.6 CaO	3.8 MgO	20.0 Na_2O	3.2 K_2O
63.93 Quartz	63.61	0.19	0.05	0.38	0.19	-
3.23 Felspar	1.39	1.18	0.65	-	-	-
17.49 Dolomite	-	-	5.25	3.76	-	-
1.16 Limestone	-	-	0.65	0.001	-	-
34.16 Soda Ash	-	-	-	-	19.98	-
6.88 Saltpeter	-	-	-	-	-	3.2
126.85	65.0	1.4	6.6	4.1	20.0	3.2
Raw Materials	Chemical Composition					
Quartz	99.5	0.3	0.08	0.06	0.03	-
Felspar	43.2	36.7	20.2	-	-	-
Dolomite	-	-	30.0	21.5	-	-
Limestone	-	-	56.0	0.01	-	-
Soda Ash	-	-	-	-	58.5	-
Saltpeter	-	-	-	-	-	46.5

Table 4.5: Theoretical Glass Composition (Oxides In Glass) And Chemical Composition of Raw Materials Used in Batches Five and Six for Chambers One and Two (Coloured Glass Chamber and Flint Glass Chamber).

Weight of Raw Materials (kg)	% Weight of Glass Oxides (kg)			
	56.0 SiO_2	29.0 PbO	2.0 Na_2O	13.0 K_2O
56.85 Sand	56.0	-	-	-
29.68 Red Lead	-	29.0	-	-
3.42 Soda Ash	-	-	2.0	-
14.68 Potash	-	-	-	10.0
6.45 Saltpeter	-	-	-	3.0
111.08	56.0	29.0	2.0	13.0
Raw Materials	Chemical Composition			
Sand	98.5	-	-	-
Red Lead	-	97.7	-	-
Soda Ash	-	-	58.5	-
Potash	-	-	-	68.1
Saltpeter	-	-	-	46.5

Note that the impurity contents of the raw materials such as iron oxide in form of Fe_2O_3, titania (TiO_2) and loss on ignition are excluded in the chemical composition of all the batches. Also, auxiliary raw materials like fining agents (As_2O_3 and Sb_2O_3), colourent (Cu_2O) and boric oxide (B_2O_3) are not shown on the tables.

After cross-checking the batch calculation based on 100kg oxides, it was then based on 21kg of glass as has already been pointed out; the result obtained was further divided by two as seen below:

4.1.1 Obtaining 21kg of Glass for Batches One, Three and Four

From the operation, the following result obtained:

Sand $\frac{64.71}{126.62}$ .21kg = 10.732 ÷ 2 = 5.4kg Sand

Felspar $\frac{2.92}{126.62}$ .21kg = 0.482 ÷ 2 = 0.2kg Felspar

Dolomite $\frac{17.47}{126.62}$ .21kg = 2.897 ÷ 2 = 1.5kg Dolomite

Limestone $\frac{0.89}{126.62}$ .21kg = 0.148 ÷ 2 = 0.1kg Limestone

Soda Ash $\frac{33.86}{126.62}$ .21kg = 1.616 ÷ 2 = 2.8kg Soda Ash

Saltpeter $\frac{6.77}{126.62}$ .21kg = 1.123 ÷ 2 = 0.6kg Saltpeter

Plus 0.005kg of Arsenious oxide, 0.005kg antimonium oxide and 0.2kg Cupprous oxide (for the coloured glass batches).

4.1.2 Obtaining 21kg of Glass for Batch Two

From the same operation, the following result obtained for batch two:

Quartz $\frac{63.93}{126.85} \times 21kg = 10.584 \div 2 = 5.3kg$ Quartz

Felspar $\frac{3.23}{126.85} \times 21kg = 0.550 \div 2 = 0.3kg$ Felspar

Dolomite $\frac{17.49}{126.85} \times 21kg = 2.896 \div 2 = 1.5kg$ Dolomite

Limestone $\frac{1.16}{126.85} \times 21kg = 0.192 \div 2 = 0.1kg$ Limestone

Soda Ash $\frac{34.16}{126.85} \times 21kg = 5.655 \div 2 = 2.8kg$ Soda Ash

Saltpeter $\frac{6.88}{126.85} \times 21kg = 1.139 \div 2 = 0.6kg$ Saltpeter

10.6kg

Plus 0.005kg Arsenious oxide and 0.005kg Antimonium oxide.

4.1.3 Obtaining 21kg of Glass For Batches Five and Six

For the table ware lead crystal glass, the following result emerged:

Sand $\frac{56.85}{111.08} \times 21kg = 10.748 \div 2 = 5.4kg$ Sand

Red Lead $\frac{29.68}{111.08} \times 21kg = 5.611 \div 2 = 2.8kg$ Red Lead

Soda Ash $\frac{3.42}{111.08} \times 21kg = 0.647 \div 2 = 0.3kg$ Soda Ash

Potash $\frac{14.68}{111.08} \times 21kg = 2.775 \div 2 = 1.4kg$ Potash

Saltpeter $\frac{6.45}{111.08} \times 21kg = 1.219 \div 2 = 0.6kg$ Saltpeter

10.5kg

Plus 0.004kg Arsenious oxide, 0.02kg Boracic acid (H_3BO_3), and 0.2kg cupprous oxide (for the coloured glass batch).

4.2 Screen Analysis of Sand, Quartz And Crushing of Soda Ash And Saltpeter

It was observed that the Baure sand contained some foreign bodies like organic matter and broken pieces of glass. In order to get rid of these unwanted materials, the sand was sieved using British Standard Sieve (BSS) size 33. It is however, important to note that the sand was obtained already sieved and washed ready for use.

For the quartz obtained from Ceramic Section of Industrial Design Department, BSS sizes 22 and 33 were used.

Soda ash and saltpeter which are hygroscopic were crushed using pistol and mortar to reduce lumpy grains to tiny particles.

4.3 Weighing, Mixing And Charging

The various raw materials constituting the glass batches for the two chambers were separately weighed in definite proportions using scale pan (for raw materials required in larger quantities) and tripple-balance (for those needed in smaller quantities) and separately mixed . The weight of the

pan and the container used on the tripple-balance were predetermined and taken into account. The figures to the extreme right under 4.1.1 to 4.1.3 represent the individual raw material weight for the batches.

In ensuring a homogeneous mixture of the batches piled in heaps, the "corning" and the "quartering" method of mixing was adopted in which the two diagonal portions of the four divisions were brought together, thoroughly mixed and requartered. The two other diagonals underwent similar treatment. Finally, all the portions were brought together and mixed.

For raw materials needed in smaller quantities such as As_2O_3, Sb_2O_3, H_3BO_3 and Cu_2O, a preliminary mixing was carried out with 1kg of sand and quartz as the case may be, before the main mixing was done.

The mixing of the raw materials was done with plastic trowel, and the same used in charging the "frit" into the furnace chambers using cardboard paper as funnel.

The mixed raw materials prior to charging were kept in two separate containers and charged separately into the furnace chambers, one after the other. The partition wall determined the level of the charges.

In preparing the batches, adequate preventive measures were adopted, especially in mixing, handling and charging so as to reduce segregation. This was considered a necessary preliminary step in hastening melting process, and in promoting and sustaining homogeneity.

In view of the inconclusiveness of results of analyses of portions of batches as a means of determining their relative homogeneity, it was thought best to be pessimistic, and to try to improve on mixing the batch and in handling the frit.

The charging operation was carried out with utmost care to ensure that the batches or part of them did not enter the wrong chamber.

After charging, pyrometric cones were arranged at the doors of the chambers for temperature determination. The doors were covered with the removeable covers, and the openings at the door edges were properly sealed up with the wet mixture of kaolin and saw dust prepared.

4.4 Operating the Furnace

The furnace operation was carried out in three main stages:

1. Heating up
2. Firing proper
3. Closing down.

4.4.1 Heating Up The Furnace

The furnace was gradually heated up for the first three hours, with the heating procedure slightly increased after every hour. The essence of this tempering was the concern to allow for thermal expansion accompanying the refractories, especially the silica crown bricks having a more coefficient of expansion, (See Appendix G).

Scholes (ibid) explained that the usual practice of preheating a new furnace is to have it done while empty or to fill it completely or partially with cullet, depending on the choice of the individual plant. Gunther (ibid) asserted that the disadvantage of filling large tanks, especially those for window glass with cullet before tempering is that the floor of the tank remains cold long after the cullet must have melted down, resulting in sudden increase in temperature.

The tempering process was carried out essentially for the first 600^{o}C to accommodate the true expansion of the three main crystalline forms of silica. The two main temperature regions requiring that special care be taken are: 200^{o}C to 270^{o}C, where the low temperature to high temperature crystobalite inversion takes place, and 573^{o}C, where alpha quartz expands to beta quartz. These crystalline modification

forms of silica at these bottom temperatures involve considerable sudden expansion that could result in damage when carried out too rapidly. After attaining the presumed $600^{o}C$, the rate of heating was increased considerably without any detrimental effect. In the absence of device for determining the temperature rise, the only way the gradual heating up was ensured was by mere slight increase in the inflow of air and fuel at hourly interval.

The expansion of the refractory bricks caused the tie-rods to be progressively loosened. This was compensated for by slackening them.

4.4.2 Firing Proper

After hours of preheating, the temperature of the furnace raised considerably as a result of increasing the gas pressure and the rate of intake of fuel and air through the burner.

These increases in the variables manifested in flame rising through the chimney to replace the smooky flame noticed during the early stages of preheating period, an indication of rise in temperature as well as a manifestation of oxidizing atmosphere.

At hourly interval, the variables were increasingly readjusted until it became apparent that the flame was at its maximum when further adustment was halted.

Since the gauge of the gas was faulty, the pressure adjustment was done arbitrarily, but steadily.

Combustion Control: Henson (1974) defined combustion control as "burning the least quantity of fuel with the least amount of air necessary for complete combustion in the available combustion space." Complete combustion demands the fuel and air to be brought into contact under the right conditions and in the right proportions.

With the right proportions of air and fuel maintained, there remains the question of practical intermixing of the two within the confines of a given combustion chamber.

In operation therefore, the "three Ts'", viz time, temperature and tarbulence, have to be correct for the working fuel.

These three requirements, taken into conjunction with each other, was aimed at glass furnace to produce long, pencil-like flames of high temperature, giving maximum radiation from their whole length.

4.4.3 Closing Down The Furnace

At the end of each melting operation, the firing was drastically curtailed, and eventually stopped; openings were closed up so that the whole furnace structure cooled down slowly. This was a necessary preventive measure to avoid sudden drop in temperature that could have resulted in the refractories spalling as a result of the shrinkage accompanying the conversion and inversion of the high temperature modifications to the low temperature forms at the temperature regions earlier mentioned. The tie-rods were adjusted as the furnace cooled down.

4.5 Specific Melting Conditions

Different glasses are melted under varying melting conditions as a means of achieving the end result. For this reason, the different glass batches were melted under the specific melting conditions demanded by them.

The soda-lime-silica batches were melted under an oxidizing atmosphere, while compositions containing lead oxide were melted under a strongly oxidizing atmosphere so as to hinder chemical reduction of the lead oxide.

Coloured glasses are more complex in their demand regarding melting conditions. For example, copper oxide produces red glass under reducing condition, while under an oxidizing condition, blue glass is obtained, hence the two different glass batches were melted under this condition. Under neutral condition, no colour will be obtained (colourless glass will be produced).

Only a few of the glass oxides are insensitive to the atmospheric conditions under which they are melted. An example of such oxide is barium oxide (BaO).

Batches containing salt-cake need a reducing atmosphere. In the vicinity of the glass surface, unburnt particles of fuel are necessary to inhibit the formation of water gall. In the melt itself, it is imperative to convert sodium sulphate (Na_2SO_4) to the sulphide (Na_2SO_3) which reacts quicker with SiO_2 during glass melting process.

The specific melting conditions were effected in both the furnace atmosphere as well as in the glass melt. Gunther (ibid) stressed that for an oxidizing atmosphere to exist, it is necessary that small amount of false air is allowed into the furnace. This was ensured mainly through the port and through other smaller openings like existed

between brick joints. However, he pointed out that false air has the disadvantage of lowering the temperature attained in the furnace. Sting-out flame, a sign of positive pressure was used to prevent excessive "false" air infiltration. Further, that for oxidizing atmosphere to prevail, he recommends the range of 1.05 to 1.15 air/gas ratio, depending on the fuel used. Larger proportion of air will be required for producer gas that tend to produce a reducing atmosphere.

Gunther (ibid) however maintained that there can be no question of uniformity of furnace atmosphere, just as there can be no uniform temperature distribution in a furnace space - local variations always exist.

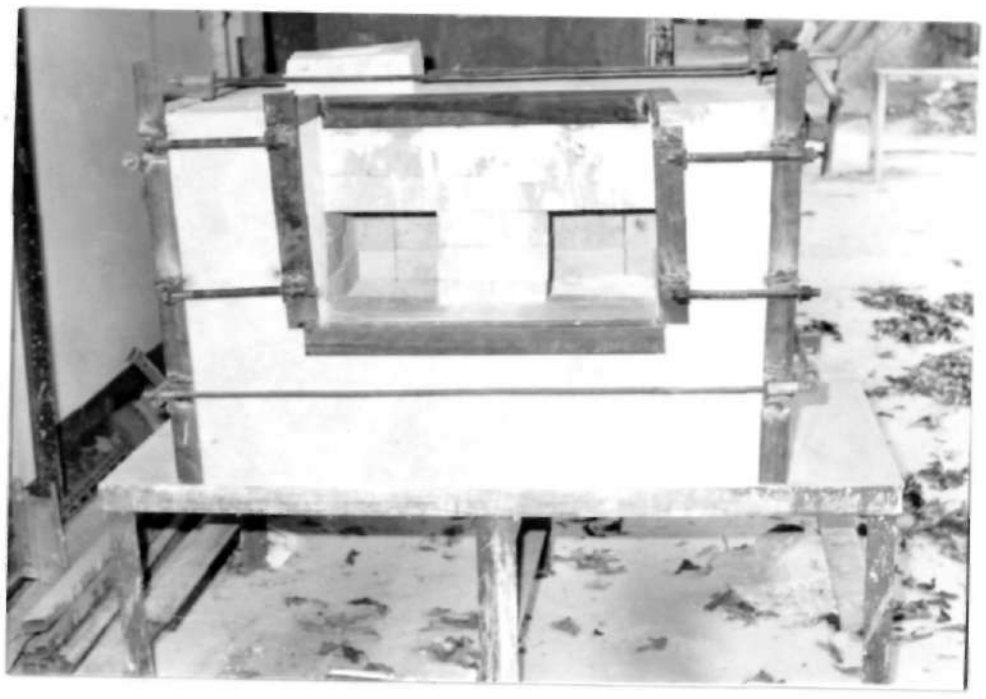


Plate XI: The Furnace, charged with both the Coloured Glass Batch (left) and the Flint Glass Batch (right), ready for Melting Test.



Plate XII: The Furnace Under Operation.

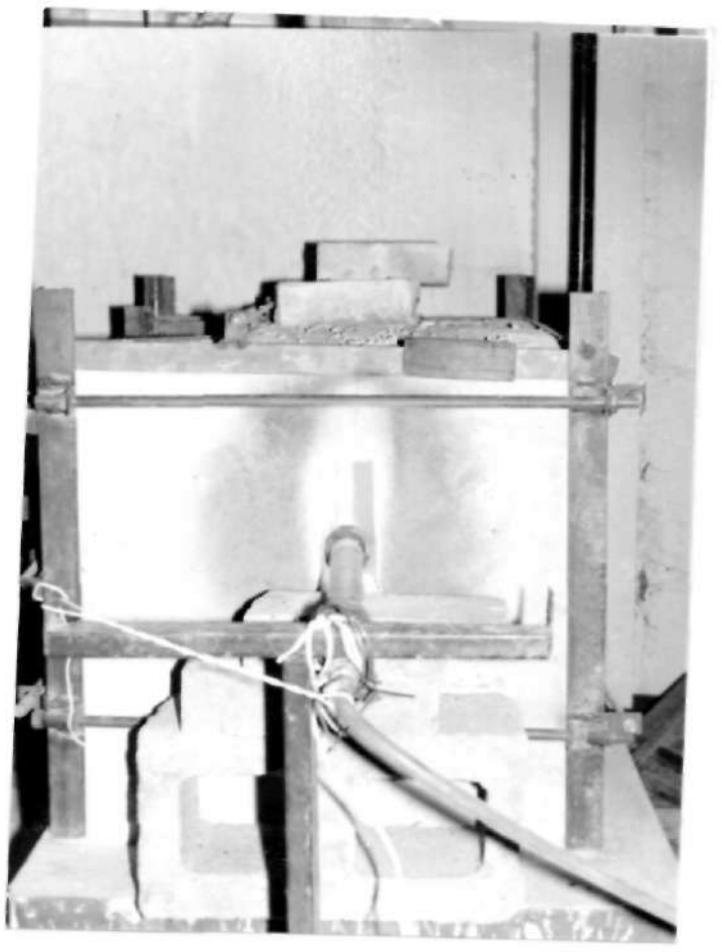


Plate XIII: Yellow Flame produced within the first 6 hours of Preheating, essentially under a Reducing Atmosphere.

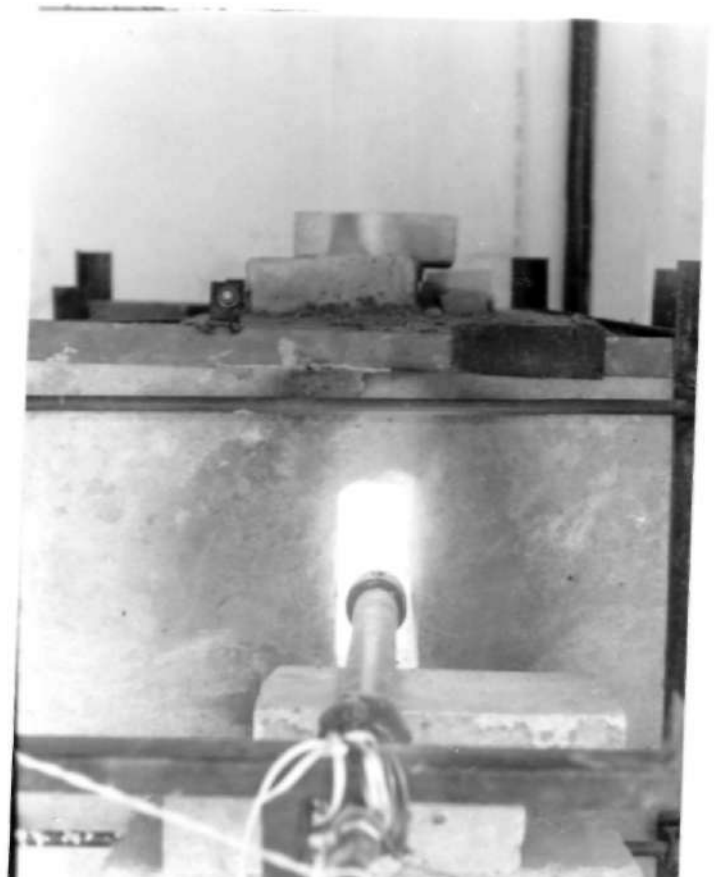


Plate XIV: Beginning of White-Yellowish Flame after 8 hours of True Firing under an Oxidizing Atmosphere.

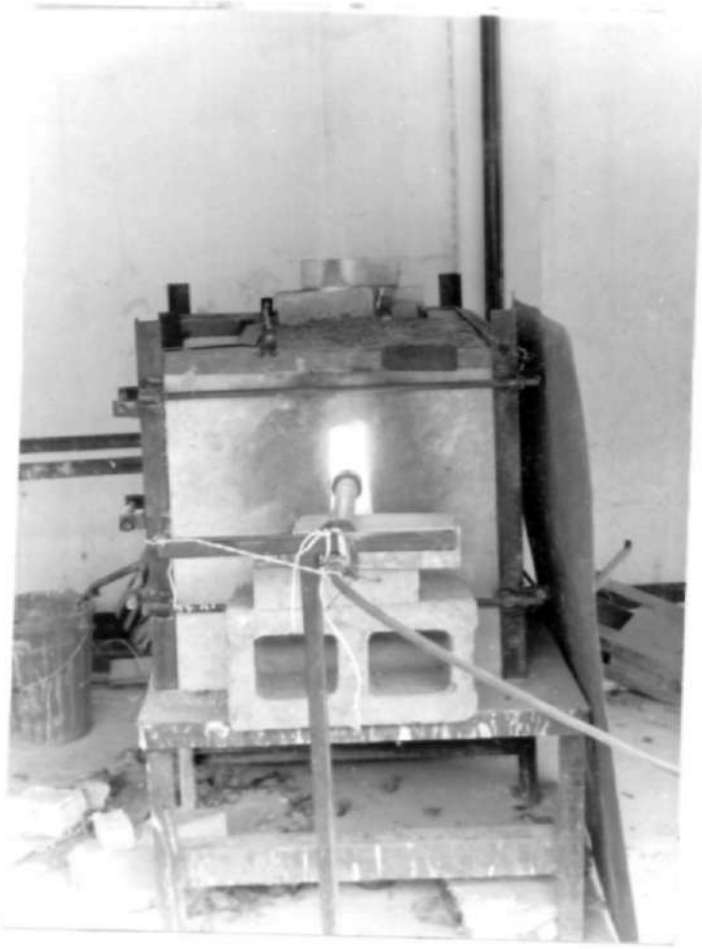


Plate XV: Glare-White Flame produced after 15½ hours of True Firing under an Oxidizing Atmosphere.

4.6 First Experimental Test-Melting of Glass

With successive alteration of the air/gas ratio mixture in an upward direction at hourly interval, the furnace temperature was noticed to increase substantially. This procedure was carried out unabatedly and white heat was established after 8 hours of firing, indicating that the temperature of about 1300^{o}C was attained.

Throughout the melting operation, the port served as an inspection hole for observing the melting process as well as flame intensity. The glass could be seen bubbling in

both chambers. From time to time, the samples of the two melts were brought out with a gathering rod to observe progress in both melting and fining.

Two 50kg of LPG cylinders were connected, but they were used in succession.

A loss in pressure of the operating cylinder caused a freezing effect in about 12 hours of firing, including the preheating period. The flame intensity began to reduce noticeably. As a corrective measure, a hot plate was put on under the operating cylinder to heat it up. No sooner than later, the pressure rose instantaneously, with the flame temperature returning to normalcy almost at the same rate. Positive pressure was maintained throughout the melting process to keep rise in temperature.

At about 15 hours of firing, the level of the gas went down to a very low level that the pressure again reduced drastically. At this juncture, the second cylinder was switched on and the first one closed up.

4.6.1 Result

After about 23 hours of true firing, the blue coloured glass in chamber one was completely melted and refined. The flint glass in chamber two however did not melt properly as

The melting period, though within the 24 hours duration was considered as rather protracted. This could be attributed to two factors; first, the furnace was new, and secondly, no cullet was included in the batches.

The inability of the flint glass to go into absolute melt was due to the fact that quartz was used rather than sand, and besides, it contained larger grains than the sand used for the blue glass. It will be recalled that sieve 22 was used. Because quartz is of higher purity, it actually must require a higher melting temperature than an ordinary sand as the impurities reduce the SiO_2 content and aid in the melting process by forming temperature eutectics. The large difference in the viscosities of the two glasses goes to uphold this assertion.

Cracks noticed in flint articles of CII after annealing points to the different expansion coefficient that existed between the vitreous glass and the unmelted constituents. This could have possibly come as a result of the fact that the annealing temperature was below the upper annealing point for the flint glass being a harder glass than the blue glass, hence the stresses set up during forming process was not relieved.

unmelted constituents were apparently visible. Fining of course proceeded to completion.

Cones 04 (1020^{o}C), 10 (1300^{o}C), 11 (1320^{o}C) and 12 (1350^{o}C) were arranged on the base of the door of each chamber. When the doors were opened for glass working, cones 04 and 10 bent while cones 11 and 12 did not squat. This indicates that the temperature attained in both chambers was uniform (1300^{o}C), about.

During offhand working of the glass, the blue coloured glass was discovered to be very soft and even proved difficult to gather due to low viscosity. The flint glass on the other hand was rather stiff and difficult to gather due to high viscosity.

The good melt of chamber one was however adversely affected by kaolin that found its way into the melt through the chimney opening.

The glass articles produced from the two melts were annealed in the annealing oven that was operated at a temperature between 550^{o}C and 600^{o}C. When the articles were eventually brought out the following day, some of the flint ones cracked while the blue ones did not.

The unmelted constituents observed at the bottom of some corners of both chambers during glass working must have come about as a result of the fact that these corners were shielded from the flame and also due to segregation occuring during charging.

Cracks developed on the backing insulation of the furnace were continually mended with wet mixture of kaolin and saw dust.

4.7 Second Experimental Test-Melting

Preventive measures were adopted to curtail some of the problems encountered during the first test-melting.

Accordingly, batch one composition used in the first test-melting was revisited for the pair of batches of the second melting test (quartz was discarded in favour of sand for both batches). In addition, 15 per cent inplant cullet was included in both batches.

Prior to charging, some of the cullet was introduced at the corners of the two chambers to inhibit the problem of unwanted unmelted constituents in these areas of the tank.

As a first step, the chimney portion, especially the hole leading to the key-brick was cleaned free of loose

particles of kaolin and saw dust to prevent them from being introduced into the chamber.

Again, the furnace was taken up gradually for the first three hours after which the true firing commenced. The same procedure was adopted in the firing operation as in the previous one.

4.7.1 Result

After 14 hours of hard firing, white heat was established. Intensive convective agitation was seen going on in the two chambers. Two hours later, batch-free time was reached, characterized by absolute batch disappearance and glass was properly refined. At about the eighteenth hour of firing, the mirro glass was ready for working.

When the two chambers were opened for glass working, it became evident that the temperature attained in both chambers ranged between 1020^{o}C to 1300^{o}C as cones 04 and 10 bent. Cones 11 and 12 again did not squat to indicate that the temperature was below 1320^{o}C and 1350^{o}C respectively.

During working, the glass of both chambers was found to be very soft and of equal viscosity. The long glass produced enabled working with the doors of both chambers open for as long as desired without becoming too stiff as to hinder the smooth working process.

The unmelted constituents, mainly kaolin, observed in the product of chamber one were traces from the previous melt. Their sparse distribution in the glass volume compared to the dense distribution of the first melt testified to this assertion. Obviously, it would take a number of successive melting operations to completely rid the chamber of these foreign bodies.

When the glass articles were annealed, none of them cracked to show that they had the same chemical composition, and hence the same annealing schedule. Again, this was an indication that no differential coefficient of expansion existed.

In terms of fuel consumption, the second melt was more economical as the two 50kg gas cylinders were not completely exhausted during the whole melting and working operation. In the first melting test, a third cylinder was used.

4.8 Third Experimental Test-Melting

While the first two melting tests consisted of soda-lime-silica batches, the third one was made up of tableware lead crystal glass batch composition.

During the firing operation, a strongly oxidizing atmosphere was maintained. This was crucial to hinder

chemical reduction of the lead oxide which formed a large proportion of the batch to the metallic state which would have resulted in producing a black glass.

4.8.1 Result

Being a low-melting glass, it started melting and bubbling within the first eight hours of firing, and was completely melted and plained after 14 hours of firing.

The same cone numbers like in the first two melting tests bent. This denotes that the furnace temperature also got to about 1300^{0}C. For squating temperature of cones and temperature estimate by flame vision (see Appendix I). Note that all the coloured products show dichroism.

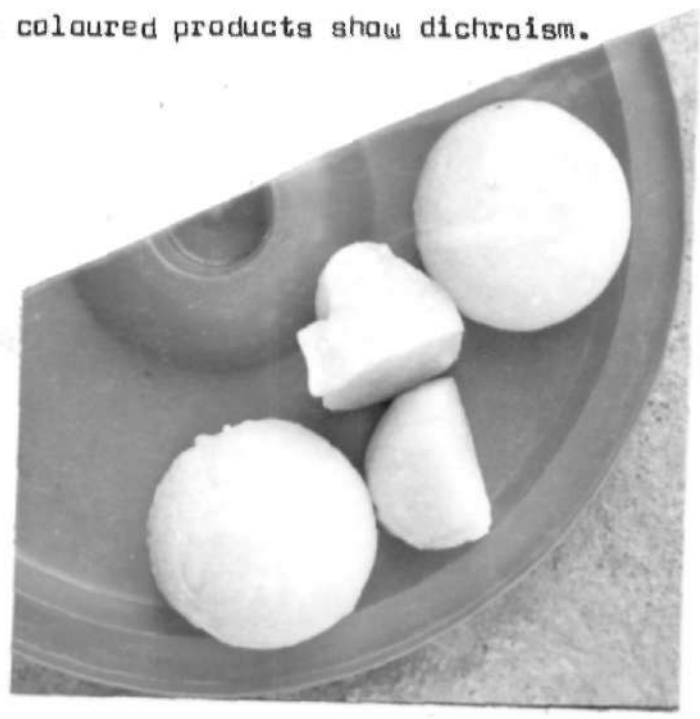


Plate XVI(a): The Partially Melted Products of the First Melting Test, with some Cracked Pieces After Annealing.

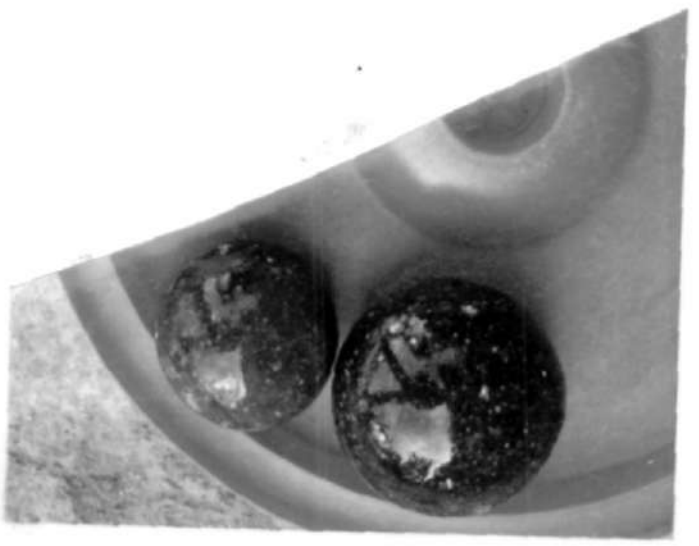


Plate XVI(b): The Well Melted Blue Coloured Products, but Adversely Contaminated with Foreign Bodies, Mainly Kaolin.



Plate XVII(a): The Flint Products of the Second Test Melting, Properly Melted, Refined and Homogenized after Rectifying the Faults of the First Test Melting.



Plate XVII(b): The Positive Effect of the Corrective Measures Adopted on the Coloured Products of the Second Test Melting.



Plate XVIII: Some Products of the Third Melting Test.

Chapter 5

SUMMARY OF FINDINGS, CONCLUSION AND RECOMMENDATIONS

5.1 Findings

During the course of the study, the following findings emerged:

1. The two-chamber furnace was capable of simultaneous melting of both flint and coloured glass using a single burner; it could melt both lead crystal and soda-lime-silica glass. Except in the first experimental test-melting, both pair of glasses in the two chambers in the three separate firing operations melted at the same time, and on each occasion, were found to have the same viscosity, surface tension, and therefore could be shaped at the same operating temperature. The inability of batch two in the first firing operation to completely melt was due to the high purity of quartz relative to the ordinary glass making sand, with the former demanding a higher melting temperature. The glass produced in both chambers were soft and very suitable for hand production. Where a low-melting glass was used, it became necessary to lower the melting temperature to the working temperature to make the viscosity suitable for gathering and shaping.

2. The furnace provided an ample working space for two glass workers at a time. In the single compartment unit, only one person could conveniently work without obstruction.

3. Judging from the quality of the glass produced, indications were that it was properly melted, refined and homogenized as it was characterized by freedom from stones, cords, striae and bubble. The unmelted constituents observed were foreign in origin, mainly from kaolin and not from the melt itself.

4. The furnace was found economical in terms of fuel consumption and constructional materials. This is particularly so since one burner was capable of simultaneously firing the 21kg of glass of the two chambers, thereby effecting saving in both time and material. Since there was no device for measuring fuel flow, it was difficult to quantify the exact amount of fuel consumed. The average fuel consumption was however roughly put at two 50kg gas cylinders to melt and work soda-lime-silica glass, and one and a half for lead crystal glass. The single-compartment unit which was capable of melting 25kg of glass was also found to consume the same amount of fuel. With respect to constructional materials, the furnace was also economical as it was neither regenerative nor recuperative (for cost of materials, refer to Appendix J).

The furnace therefore offered flexibility and relative economy of construction and operation for small quantities of glass, particularly where frequent changes of colour and compositions are considered desirable. It reduced drastically the undue change-over time often demanded by single-melting units which is wasteful, both in time and material, leading to high cost of production.

Although the single compartment unit could melt 25kg of glass (3kg higher than that of the two-chamber unit), the shortcoming of the latter was attributed to the unsuitable size of the refractories. Given the right sizes of the refractory bricks, especially the crown bricks, the capacity of the two-chamber furnace could be doubled and yet consuming the same quantity of fuel. The original plan of the furnace was designed to melt 50kg of glass (25kg per each chamber), but this was unavoidably abandoned due to lack of refractory bricks cutting machine at disposal. With such a constructional design, it would have been possible to melt twice the amount of glass melted in the single compartment structure. Since one burner was to be used in firing the two chambers, it means that the fuel consumption would have remained the same.

5. The bending of the same cone numbers - cones 04 and 10 in each chamber in each of the melting operations carried out was an indication of uniformity of temperature distribution in both chambers, and that the maximum temperature attained was about 1300°C.

6. The longitudinal method of firing ensured better and more efficient utilization of the furnace space as more surface area was made available for flame propagation. This was further aided by adequate and proper insulation which helped to a great extent in conserving the heat generated.

7. With the two-chamber construction, it was possible to have a clear and easy view of the melt and melting conditions through the port without necessarily having to open the doors which would have led to heat loss during the course of firing. Through the same opening (the port), glass could be brought out for closer examination of the degree of melting and fining attained.

8. The reduced height of the two-chamber furnace and the strategic location of the port made consistent with providing only enough space necessary for combustion in that the flame was confined nearer the glass surface for quicker heat

transfer. Suffice to mention here that heat transfer in a tank furnace takes place almost entirely by radiation, aided by convection currents set up in the melt, and to a lesser extent, by conduction. This fact is attested to by Datschefski (1975), Scholes (ibid), Gunther (ibid) and Doyle (ibid). Theoretically, the crown of the furnace becomes heated by the flame and returns the heat so produced to the bath by reflection. This explains why a tank furnace is termed a "reverberatory furnace", carrying the idea of reflection of heat from the crown upon the charge. The reduced height of the furnace therefore satisfied this fundamental prerequisite.

9. The provision of the chimney key-brick adjunct the L-shaped brick ensured better control of atmospheric conditions prevailing in the furnace chambers as this made feasible proper regulation of the draught.

10. The nooks provided by the two-chamber construction, the location of its port and the longitudinal flame made it possible for temperature determination by arranging pyrometric cones. This situation had not been possible with the cross-firing of the single compartment unit in existence, where the cones would have lied directly in the path of the flame as to give a false reading.

5.2 Shortcomings Of The Furnace

The findings of the two-chamber periodic tank furnace will not be complete if its disadvantages are not mentioned.

Included among these was the non-attainment of founding temperature exceeding 1300^{0}C, despite the fact that the furnace was properly backed-up with insulation materials. The implication here was that hard borosilcate and aluminosilicate glasses requiring higher melting temperatures could not be melted, except where a means of stepping-up the melting temperature was found. As evidenced with the first test-melting, it became apparent that two widely varied glass compositions could not undergo simultaneous melting operation without material cost and on the score of time factor. Obviously, only pairs of glasses of the same or near similar compositions, melting under the same atmospheric conditions could be melted simultaneously.

However, the reasons advanced for the non-attainment of higher melting temperature might not be much inherent in the furnace itself, but rather, in the heat yield of the combustion equipment used, the C.V. of the fuel and the absence of device for preheating incoming combustion air which would have raised substantially the melting

temperature. The combustion equipment lacked mixing regulator for approaching stoichiometric air/fuel ratio for optimum temperature attainment. The manual adjustment of the fuel/ air mixture could have been far from being precise.

The use of loose binding materials for insulation (wet mixture of kaolin and saw dust) resulted in the introduction of defects in the glass through the chimney. This problem can be remedied by application of stronger binding material at the joints of insulation bricks; especially at the furnace crown; better still, composite glass fibre wool should be used in this area of the furnace, especially around the chimney. The use of strong binding materials will also assist in reducing cases of cracks developing along joints during firing schedules.

5.3 Conclusion

The primary objective of the study has been achieved - that of simultaneous dual melting of glass in the same furnace space using a common burner. From the advantages and the disadvantages of the furnace highlighted above, it would be seen that the former outweigh the latter, a basis on which the study could be judged a glaring success. This is particularly so when viewed against the fact that the

furnace was not accompanied by any marked problems that could not be remedied, coupled with its portability, simplicity of construction, operation and parts replacement.

5.4 Recommended Applications

Based on its operational performance, the following recommendations are put forward:

1. The proto-type two-chamber periodic tank furnace is recommended as suitable for adoption for simultaneous dual melting of both flint and coloured glasses melting under equal atmospheric conditions. It is however, not recommended for melting hard borosilicate and aluminosilicates, unless a machinery is set in motion, geared towards achieving higher melting temperatures than presently obtained. It is as well recommended for the production of flashed glass.

2. The furnace in question is found very suitable for studio glass practice in institutions of higher learning and for enterprising small-scale glass practitioners/industrialists for the production of a variety of glass articles.

In institutions of higher learning, such a furnace design will maximize students participation in studio glass practice and hence their production capacity by providing ample working space for the growing students enrolment, especially in the area of science and technology. This will also cope with the increased population under the course credit system that encourages students' mobility, both within and outside a department.

5.5 Recommended Areas For Improvements And Modifications For Further Research Undertakings

In order to optimize its performance, effort has been geared towards identifying areas of deficiencies that deserve improvements and modifications to serve as a basis for future research work. The areas requiring improvements and modifications are found to lie generally in the structure itself, the non-inclusion of auxiliary component parts, the combustion equipment and the fuel used.

It will be discovered that the recommendations for further research are made based on the problems encountered in the course of conducting the research, and also, on projection of future trends as envisaged. Hence, the followings are recommended:

1. Experimentation with horse-shoe flame firing with a view to raising the founding temperature. This mode of firing was contained in the original design, but was abandoned due to lack of suitably sized refractory bricks for the furnace lining, particularly the crown bricks.

2. In order to catch up with the problems associated with unsuitably-sized refractory bricks, it is recommended that an intensive independent research be carried out on local refractory brick making so as to de-emphasize reliance on importation of these items. This, however, is going to be capital intensive that it may not succeed without government funding.

3. Making the two chambers fully separated, which will allow for individual firing and temperature control. Also, this design will make possible differential melting conditions and wide variations in glass compositions. Under this dispensation, as many chambers as desired can be constructed, and as a further step, a waste heat utilizing annealing lehr can be included. This means that more than one coloured glass can undergo simultaneous melting operation along

with the flint glass. To achieve this objective, it is recommended that cross-firing be adopted to ensure coefficient of coverage.

4. Waste-heat recovering device be researched into as a means of recycling part of the heat lost through the flue gas for other useful purposes such as preheating incoming combustion air or for annealing process as mentioned under "3" above. This is in recognition of the fact that not less than twenty-five percent of the total heat generated in the furnace is lost through the waste gases. Due to the extended surface area of the furnace walls, the heat lost through these areas is by radiation and convection, and can only be utilized with great difficulty. Apart from heating the factory buildings during cold weathers, there is yet to be a very useful way of utilizing the heat loss through the walls of the furnace. In some plants, heat lost through the crown of the furnace is used for providing hot water in tubular coils, but not without the risks of the tubes breaking as well as the cooling effect upon the furnace crown if not installed at a reasonable distance.

5. It is recommended that a research be conducted in the area of gas/liquid fuel burners to carter for the requirements of varying sizes of the furnace designs. On the score of its short, intense flame, oil is a favourite fuel for day tank furnaces of this nature. Therefore, an intensive research work in this direction is considered appropriate.

6. Finally, in order to curb the problem of fluctuation in prices and supply of fuels in Nigeria and the world over, it is recommended that dual fuel furnace designs for firing both gas and liquid fuel, either simultaneously or on an interruptible supply basis be brought forward.

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APPENDIX A

Some Tank Furnaces for Container Glass Articles

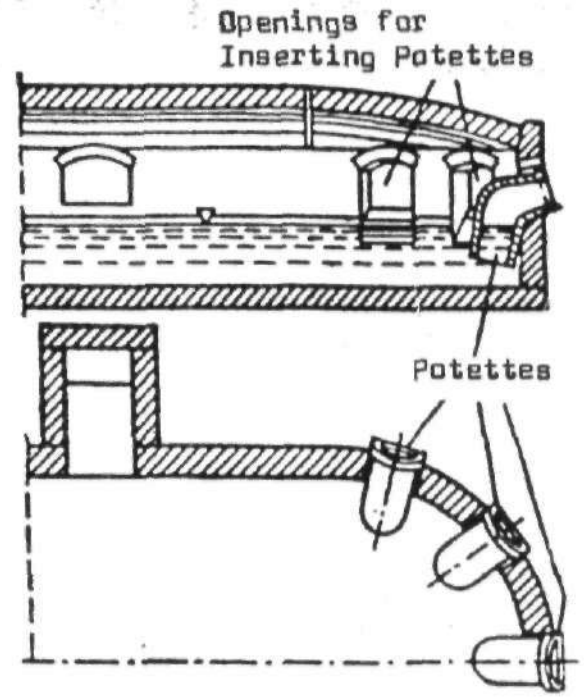


Figure 2.1 Schematic of the Potette Tank

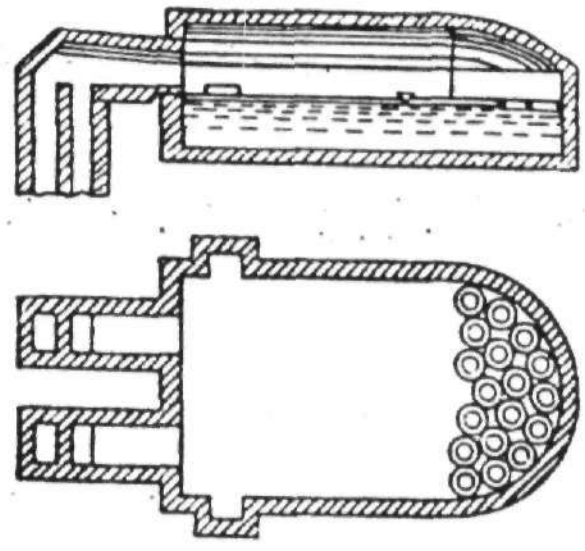


Figure 2.2 Bottle-Glass Tank with Partition of Working Zone by Ring Floaters.

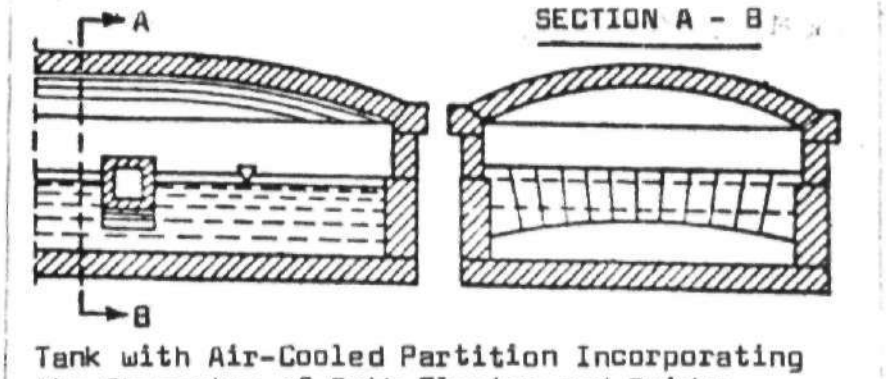


Figure 2.3 Tank with Air-Cooled Partition Incorporating the Character of Both Floater and Bridge.

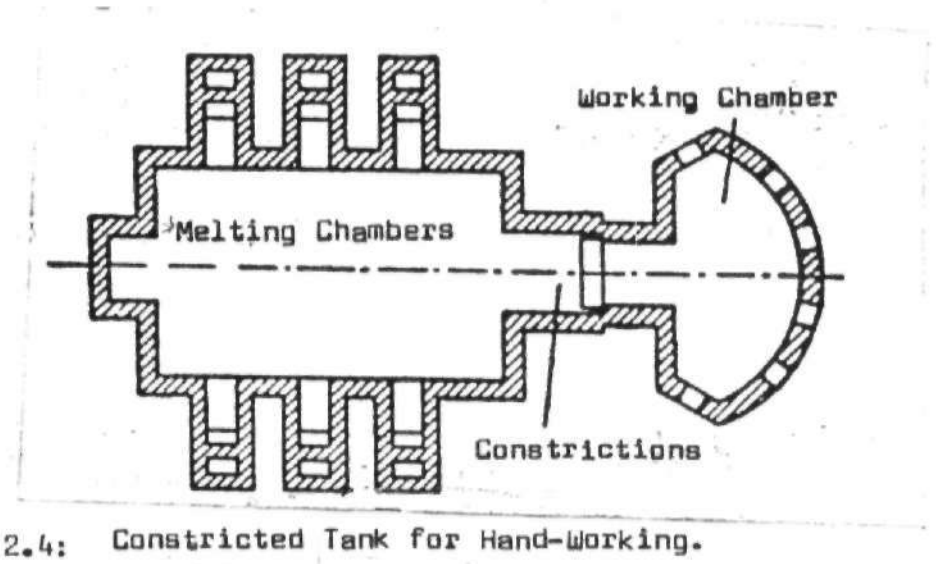


Figure 2.4: Constricted Tank for Hand-Working.

Adapted from Gunther (1958) Glass-Melting Tank Furnaces.

APPENDIX B

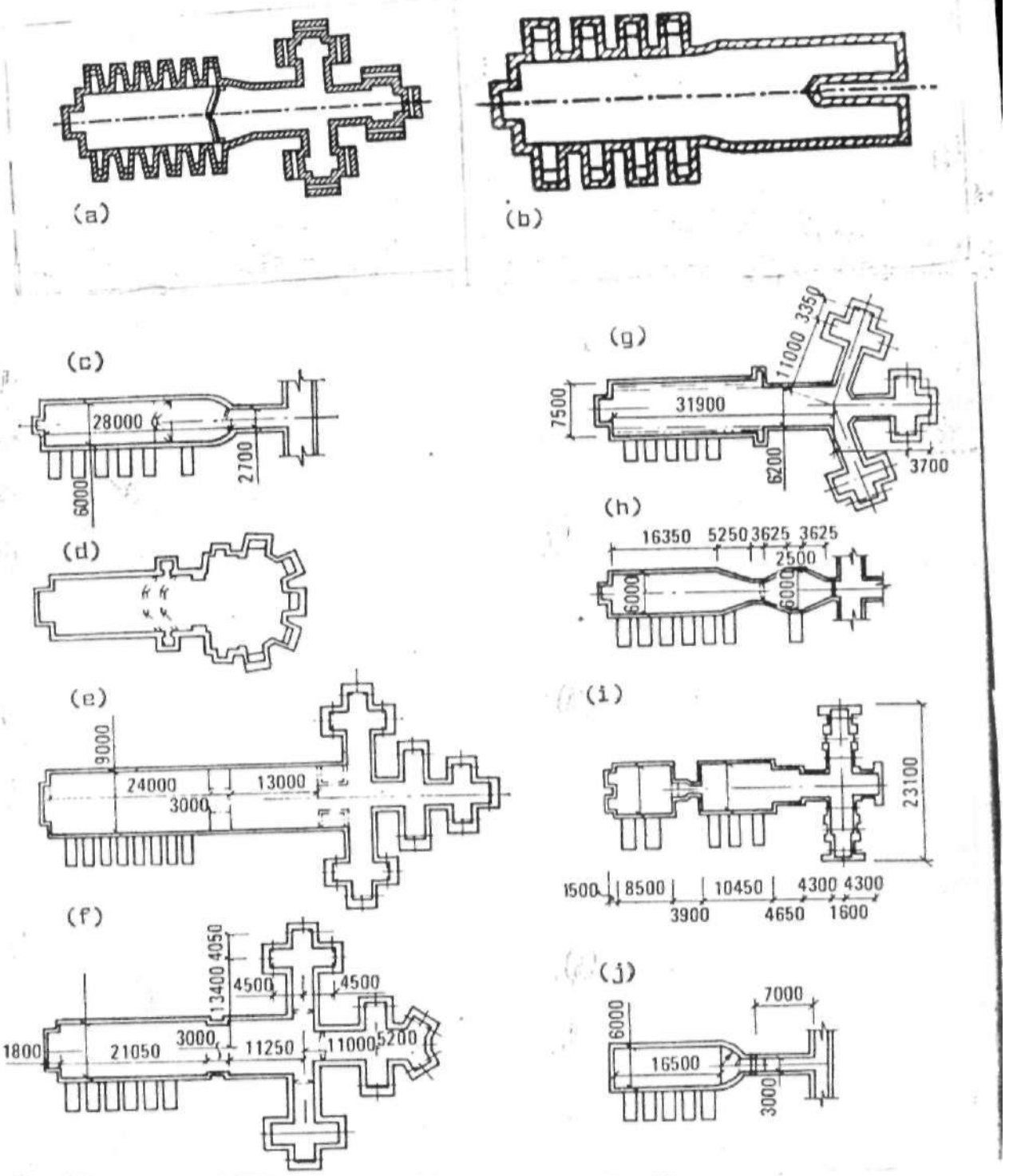


Figure 2.5: Schematic Diagrams of Tank Furnaces for Sheet Glass Manufacture: (c) with a common tank; (d) with boats; (a, b, e, f, g) without separation of tanks; (h, i, j) with separated tanks.

Sources: Bulavin et al (1986) Heat Processes in Glass and Silicate Technology, and Gunther (1958) Glass Melting Tank Furnaces.

APPENDIX C

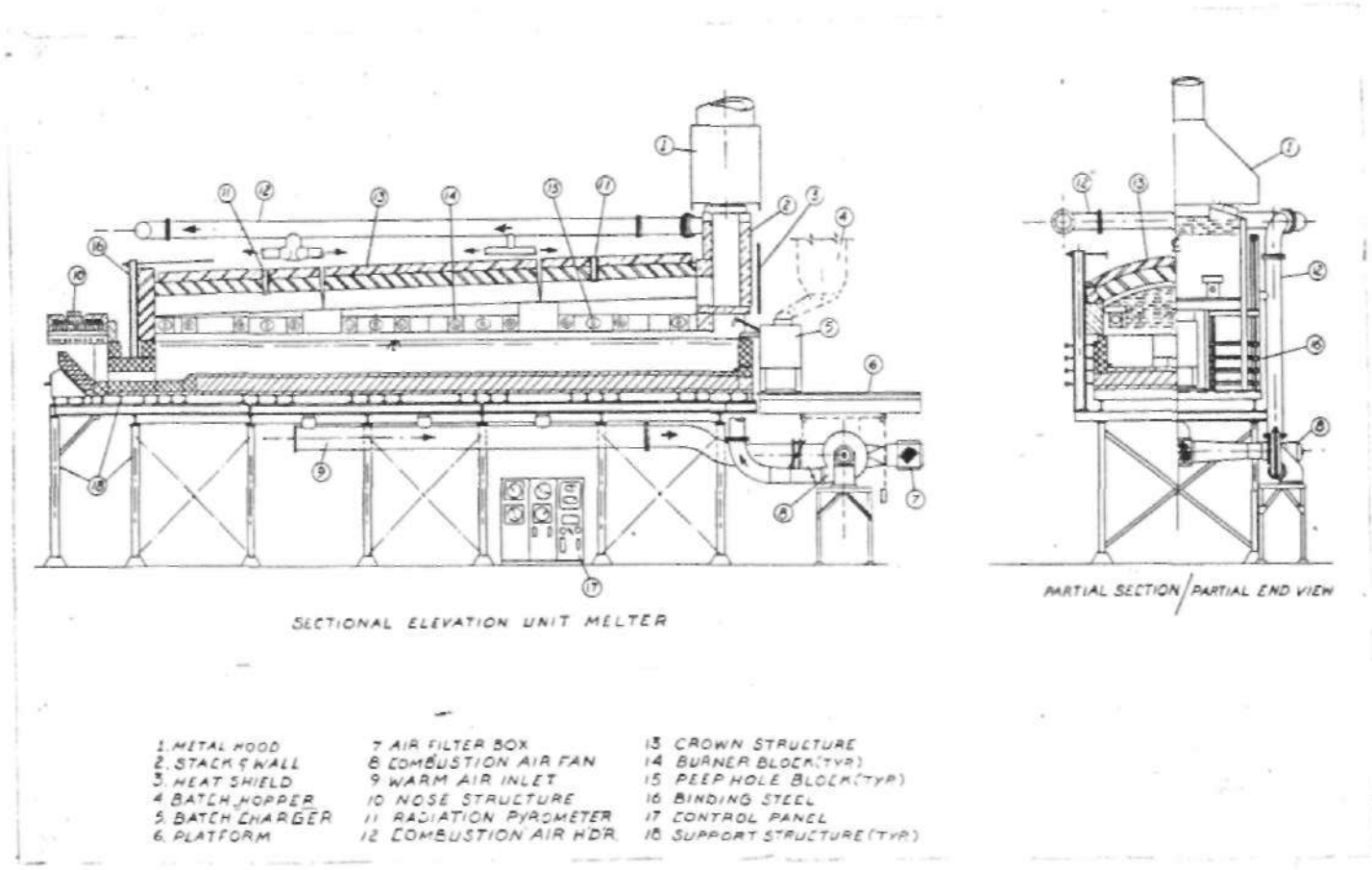


Figure 2.6: Schematic of the Hartford Unit Melter

Adapted from Samuel R. Scholes (1974) Modern Glass Practice.

APPENDIX D

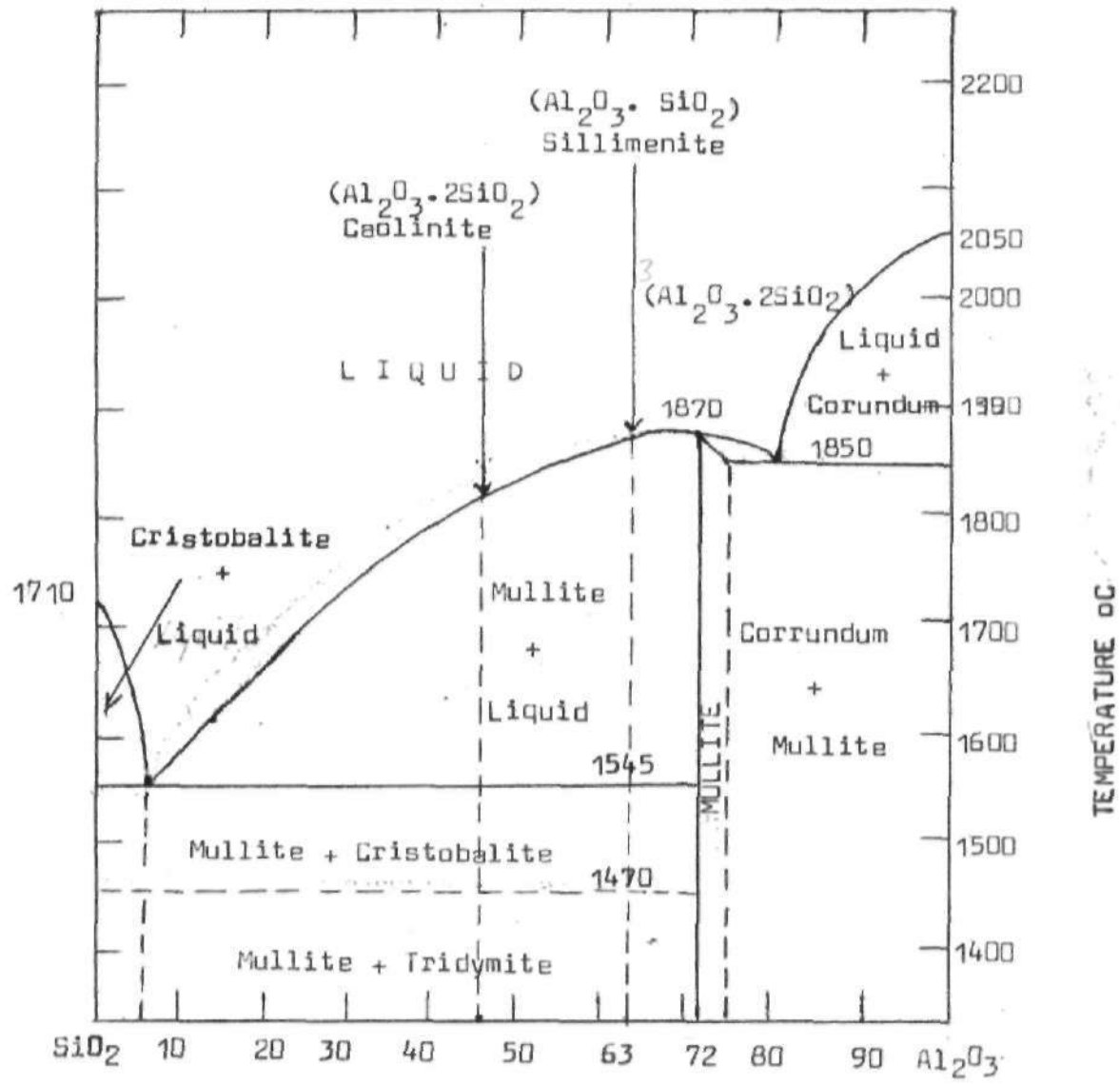
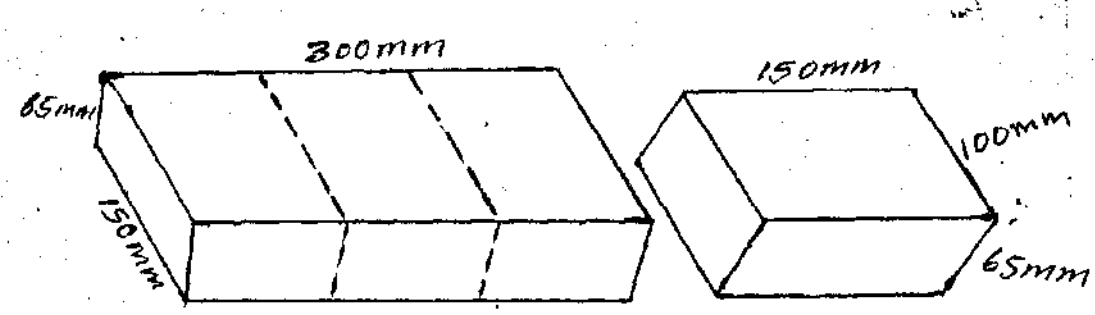


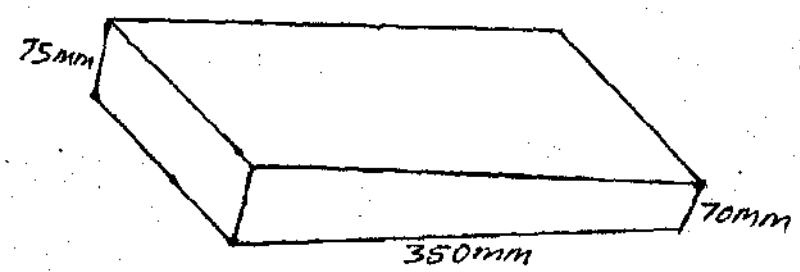
Figure 3.1: Silica-Alumina Phase Diagram

Adapted and Modified from Chesters (1973), Originally from Bowen and Greig based on more recent data of Muan.

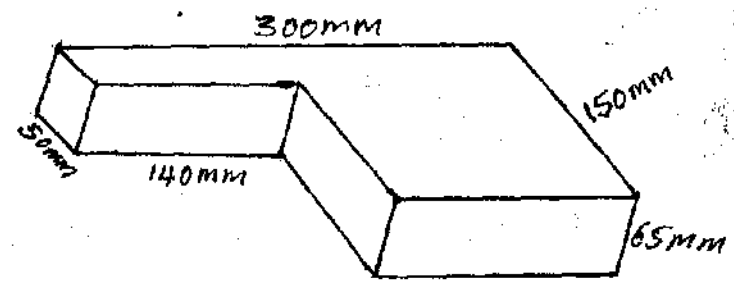
APPENDIX E



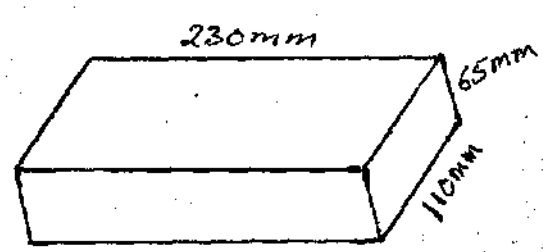
Stein 45D Bricks (Full length and the basic Construction Unit cut out along the dotted line.



SGT 75 - 70 x 350W Silica Arch Brick for the Furnace Crown



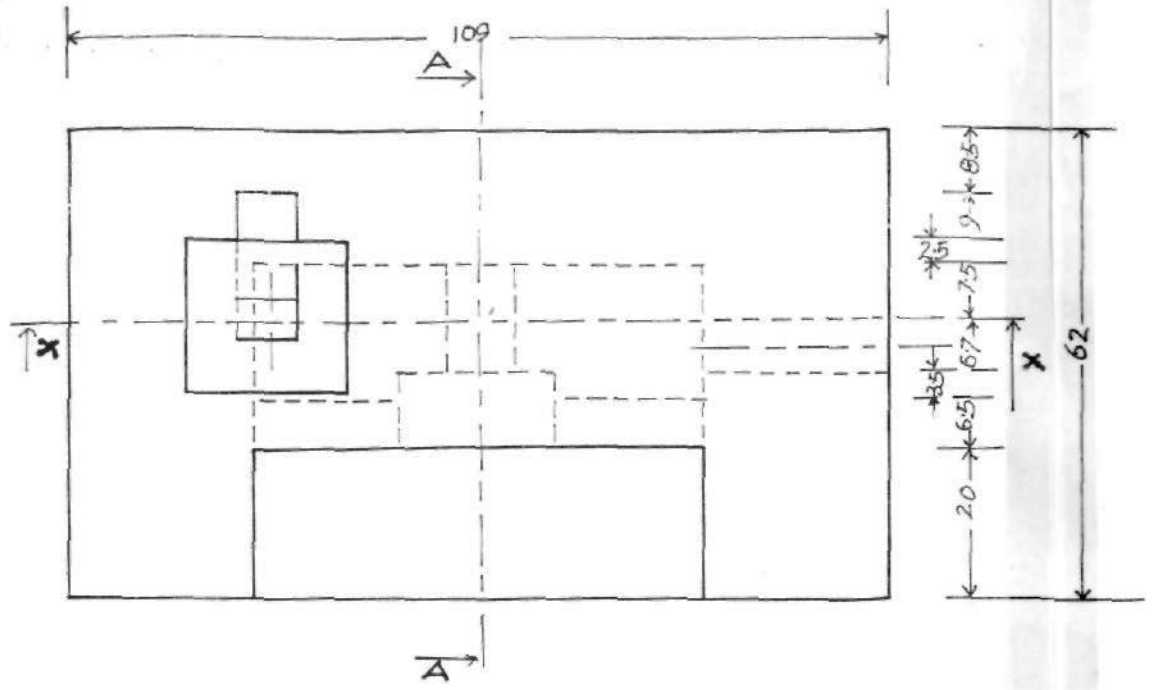
The Chimney L-Shaped Brick, cut out of the full length of the Stein 45D Brick.



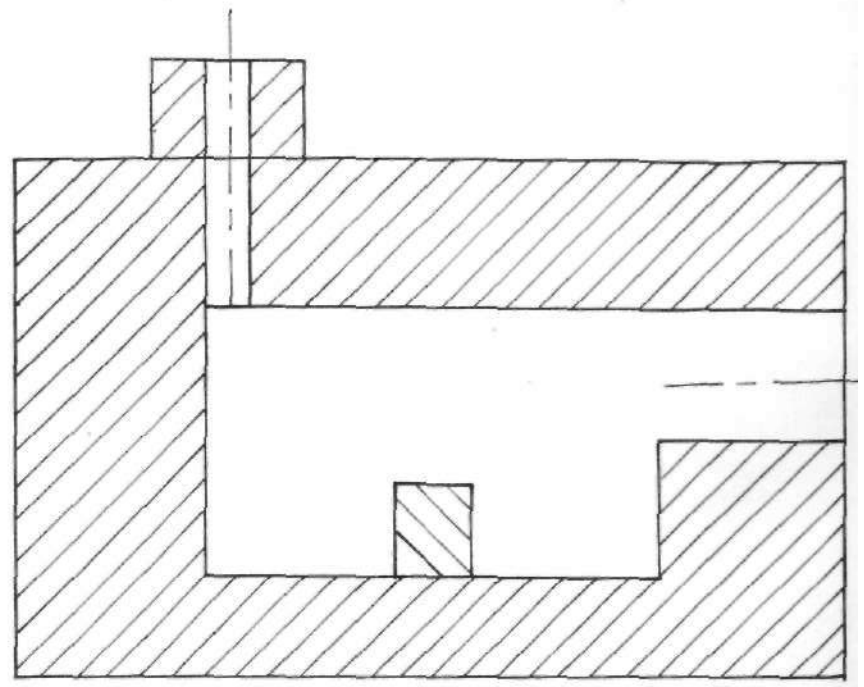
Insulating Brick.

Figure 3.2: Sketchy Diagrams of the Refractory Bricks used in the Furnace Construction.

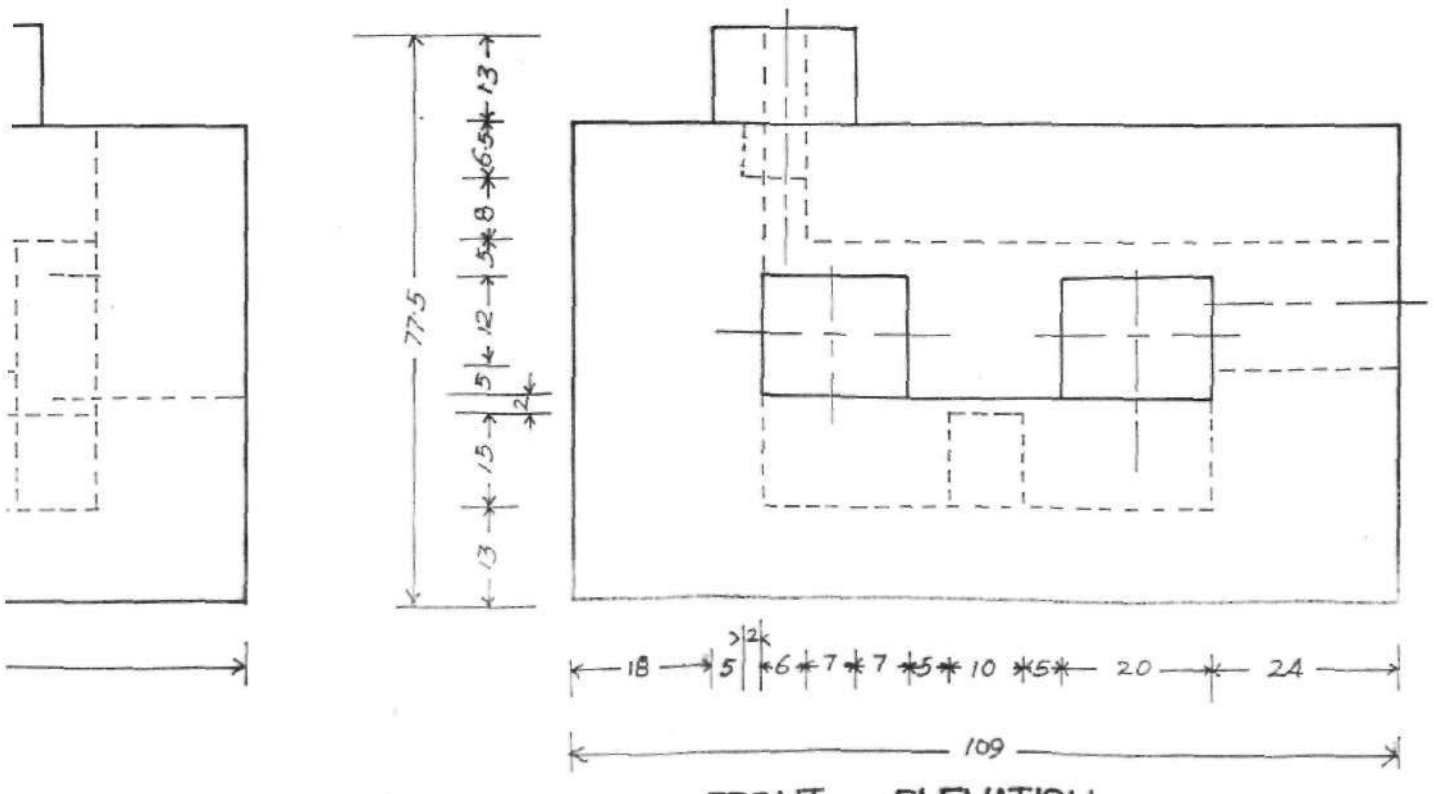
IX F: PLAN OF THE TWO-CHAMBER PERIODIC TANK FURNACE



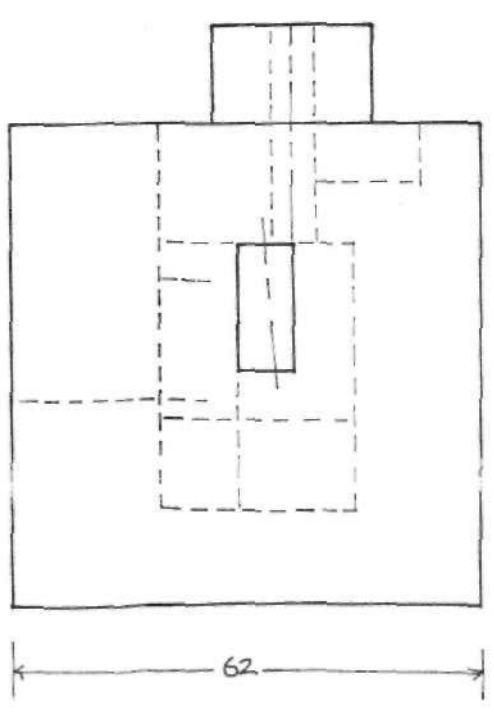
PLAN VIEW



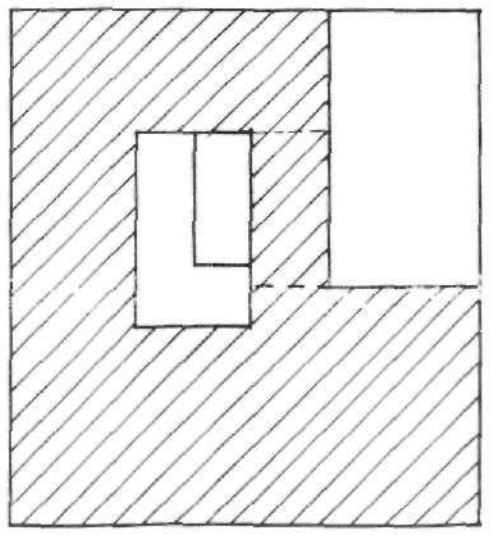
SECTION XX



FRONT ELEVATION



END VIEW



SECTION AA

APPENDIX G

Table 3.1: Some Properties of Typical Refractories

Materials	Main Constituents	Thermal Conduction B. Units	Thermal Exp. x 10 - 6	Maximum Working Temp.	Resistance to Slag	
					Acid	Basic
Semi-silica	88% SiO_2	11	15	1480	V.G	V.G.
Silica	96% SiO_2	13	15	1650	V.G	V.G.
Firebrick	37% Al_2O_3	10	6.5	1350	G	G
Firebrick	42% Al_2O_3	9	5.5	1600	G	G
Sillimenite	58% Al_2O_3	11.5	4.5	1500	G	F.G
High alumina	87% Al_2O_3	14	5	1550+	G	F.G
Magnesite	89% MgO	24	13.5	1600	V.B	V.G
Chrome Magnesite	20% Cr_2O_3.40% MgO	12	13.5	1600	G	G
Dolomite	55% CaO.37% MgO	14.5	--	1500	G	F.G
Zircon	67% $2rO_2$.33% SiO_2	10	--	1850	F.G	B
Carbon	98% C	50	--	1700	G	G

APPENDIX G (Con'd)

Materials	Main Constituents	Thermal Conduction B. Units	Thermal Exp. x 10 - 6	Maximum Working Temp.	Resistance to Slag	
					Acid	Basic
Silicon Carbide	95% Sic	120	4.5	1600	G.	F.G.
Fused alumina	95% Al_2O_3	30	4.5	1600	V.G.	F.G.
Fused zirconia	33% $2rO_2$.52% Al_2O_3	30	3.6	1650+	F.G.	F.B.
Refr. Ins.	42% Al_2O_3	2.5	-	1400	G.	B.
Refr. Ins.	80% Al_2O_3	7	-	1800	B.	G.
Ins. concrete	40% Al_2O_3	2.5	-	1300	G.	F.G.
Plastic refr.	39 - 80% Al_2O_3	6	-	1300	G.	F.G.
Ramming refr.	35 - 80% Al_2O_3	6	-	to	to	
Gunning refr.	30 - 50% Al_2O_3	6	-	1800	G.	F.G.
Fibrous refr.	50% Al_2O_3	1	-	1260	G.	B.

K E Y: V.G. = Very good, F.B. = Fairly bad

Adapted from H. Kay (1977), Heat Compatible Materials In: "Industrial Fuels."

APPENDIX H

Table 4.1: Theoretical Compositions of Glass-Making Raw Materials Indicative of Oxides Remaining in Glass After Melting Processes

Material	Alternative Name	Theoretical Formula	Oxides Supplied	Fraction	Reciprocal
Felspar	Microline	$Al_2O_3.K_2O.6SiO_2$	Al_2O_3	.180	5.556
			$(K,Na)_2O$	.130	-
			SiO_2	.680	-
Kaolin	China Clay	$Al_2O_3.2SiO_2.2H_2O$	Al_2O_3	.395	2.57
			SiO_2	.465	-
Antimony Oxide	--	Sb_2O_3	Sb_2O_3	1.000	1.000
Arsenious Oxide	White arsenic	As_2O_3	As_2O_5	1.160	.860
Boric Acid	Boracic acid	H_3BO_3	B_2O_3	.563	1.776
Limestone	Calcium carbonate	$CaCO_3$	CaO	.560	1.786
Dolomite	Raw Limestone (dolomitic)	$CaMg(CO_3)_2$	CaO	.304	3.290
			MgO	.216	4.580
Red lead	Minium	Pb_3O_4	PbO	.997	1.024
Potassium nitrate	Saltpeter	KNO_3	K_2O	.465	2.151
Potassium carbonate	Calcined carbonate of potash	K_2CO_3	K_2O	.681	1.469
Sand quartz	Glass sand	SiO_2	SiO_2	1.000	1.000
Soda ash	Sodium carbonate	Na_2CO_3	Na_2O	.585	1.709
Sodium nitrate	Chile Saltpeter	$NaNO_3$	Na_2O	.365	2.741

Extracted and adapted from Samuel R. Scholes (1974) Modern Glass Practice.

APPENDIX H (Con'd)

Table 4.2: Felspar Compositions (Weight Percent)

Sample	1	2	3	4	5	6	7
SiO_2	64.8	68.7	43.2	69.5	70.1	68.1	65.6
Al_2O_3	18.3	19.4	36.7	16.2	17.3	18.3	20.3
K_2O_3	16.9	-	-	9.0	9.1	10.2	6.1
Na_2O	-	11.9	-	3.0	3.1	2.9	5.7
CaO	-	-	20.2	0.4	0.1	-	2.2
Fe_2O_3	-	-	-	0.07	0.04	0.08	0.04
Ign. Loss	-	-	-	1.4	0.5	-	0.2

Sample 1, Potash Felspar (microline, orthoclase); 2, soda felspar (albite); 3, lime felspar (anorthite); 4, Maine felspar; 5, North Carolina felspar; 6, North Carolina felspar; 7, Plagioclase-ptash felspar.

Note: Sample 3 was used in the soda-lime-silica batch compositions for the melting tests.

Adapted from Samuel R. Scholes (1974) Modern Glass Practice.

APPENDIX I

Table 4.6: Temperature Equivalents of Pyrometric Cones

Cone Number	Bending Pt. ^{o}C	Cone Number	Bending Pt. ^{o}C
022	600	7	1230
021	650	9	1280
018	710	10	1300
016	750	11	1320
014	815	12	1350
012	855	13	1380
010	900	14	1435
08	940	17	1480
06	980	19	1520
04	1020	27	1610
02	1060	32	1710
1A	1100	36	1790
3A	1140	40	1920
5A	1180	42	2000

Adapted from Green, David (1963) Understanding Pottery Glazes.

APPENDIX I (Con'd)

Table 4.7: Conversion of Temperatures for Celcius, Fahrenheit, and Kelvin

^{o}C	=	$\frac{(^{o}F - 32) \times 5}{9}$
^{o}C	=	$^{o}K - 273$
^{o}F	=	$\frac{^{o}C \times 9}{5} + 32$
^{o}F	=	$\frac{9\ (^{o}K - 273)}{5} + 32$
^{o}K	=	$^{o}C + 273$
^{o}K	=	$\frac{5\ (^{o}F - 32)}{9} + 273$

Adapted from Brodie, R. C. (1962)
The Energy Efficient Potter.

APPENDIX I (Con'd)

Table 4.8: Temperature Estimate by Flame Vision

Starting-red heat	-	$500^{o}C \pm 100^{o}C$
Dark-red heat	-	$600^{o}C \pm 100^{o}C$
Cherry-red heat	-	$700^{o}C \pm 100^{o}C$
Bright-red heat	-	$850^{o}C \pm 100^{o}C$
Yellow-red heat	-	$1000^{o}C \pm 100^{o}C$
Starting-white red heat	-	$1150^{o}C \pm 100^{o}C$
Glare-white heat	-	$1350^{o}C \pm 1650^{o}C$

Adapted from Ezike, Raymond Nnamdi (1990) Design and Production of Pyrometric Cones in Nigeria, Using Locally Sourced Raw Materials.

APPENDIX J

Table 5.1: Cost of Materials

1.	Stein 45D (Fix dense aluminous firebricks) 30cm x 15cm x 6.5cm	50	₦3000.00
2.	SGT 75 - 70 x 350W Silica arch bricks	4	₦220.00
3.	High-duty silica insulating bricks, 23cm x 11cm x 6.5cm	30	₦1500.00
4.	Amberite insulating bricks, 23cm x 11cm x 6.5cm	40	₦1800.00
5.	Firebrick insulating bricks, 23cm x 11cm x 6.5cm	28	₦840.00
6.	75 - 70 x 350W large-size fire brick insulating bricks	15	₦375.00
7.	Composite glass fibre wool, 840cm x 460cm	1	₦25.00
8.	7.5cm x 7.5cm Angle irons	3	₦1050.00
9.	5cm x 5cm Angle iron	2	₦360.00
10.	4cm x 4cm Angle iron	2	₦150.00
11.	Iron rods	2	₦120.00
12.	Nuts	28	₦140.00
13.	Metal sheet (0.2cm thick), 141cm x 86cm	1	₦150.00
14.	Packets of welding electrodes	1	₦35.00
15.	Bags of kaolin	3	₦750.00
16.	Bags of saw dust	3	₦15.00
	Total		₦7830.00