DETERMINING THE FLOW CHARACTERISTICS OF SYNTHETIC SLAG AND OPTIMIZING THE SLAG CHARACTERISTICS

A THESIS SUBMITTED IN PARTIAL FULFILLMENT
OF THE REQUIREMENT FOR THE DEGREE OF

Bachelor of Technology
in
Metallurgical and Materials Engineering

By

ANUP AGARWAL (108MM042)
SUDHIR SAHA (108MM057)

Department of Metallurgical and Materials Engineering
National Institute of Technology

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Under the guidance of

PROF. S.SARKAR

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National Institute of Technology
Rourkela

CERTIFICATE

This is to certify that the thesis entitled, " **Determining the flow characteristics of synthetic slag and optimizing the slag characteristics"** submitted by **Anup Agarwal (108MM042) and Sudhir Saha (108MM057**) in partial fulfilments for the requirements for the award of **Bachelor of Technology degree** in **Metallurgical and Materials Engineering** at National Institute of Technology, Rourkela is an authentic work carried out by them under my supervision and guidance.

To the best of my knowledge, the matter embodied in the thesis has not been submitted to any other University/Institute for the award of any Degree or Diploma.

Date:

Prof. Smarajit Sarkar
Dept. of Metallurgical and Materials Engineering
National Institute of Technology
Rourkela-769008

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ANUP AGARWAL

SUDHIR SAHA

ABSTRACT

In the dynamics of blast furnace slag plays an important role in the quality of the hot metal produces and also the efficiency of the blast furnace. The quality of the hot metal depends on the formation and other mineralogical transformation that the slag undergoes during the passage of the burden. The minerals such as SiO_2 and Al_2O_3 increases the viscosity of the slag whereas, CaO decreases the viscosity of the slag.

The cohesive zone determines gas flow pattern. The cohesive zone's thickness is determined by the melting zone of the slag. The ore is compacted due to softening and melting in the cohesive zone. Minimizing the size, lowering the level of the cohesive zone, increases the efficiency of the blast furnace, improves productivity and decreases coke rate. The work is designed at arriving at a slag composition through actual experiments which will ensure the lowering of the cohesive zone of the blast furnace with simultaneous decrease in the difference between the softening temperature (ST) and flow temperature (FT) of the slag.

Synthetic slags were formed by imitation of blast furnace slag using the major oxides (CaO, MgO, SiO_2 and Al_2O_3) and disregarding the minor oxides. The mineralogical compositions of the slag can be varied to obtain different synthetic slag and thus the flow characteristics of the slag can be experimented for different synthetic Slags.

Keywords: cohesive zone, slag, minor oxides, softening temperature, flow temperature.

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CHAPTER-1

INTRODUCTION

1.1. INTRODUCTION

In the dynamics of blast furnace, slag plays an important role in the quality of hot metal produced and also the efficiency of the blast furnace. The quality of the hot metal depends on the formation of the slag and other mineralogical transformation that the slag undergoes during the passage of the burden. The minerals such as SiO_2 and Al_2O_3 increases the viscosity of the slag whereas, CaO decreases the viscosity of the slag. The cohesive zone determines gas flow pattern. The cohesive zone`s thickness is determined by the melting zone of the slag. The ore is compacted due to softening and melting in the cohesive zone. Minimizing the size, lowering the level of cohesive zone, increases the efficiency of the blast furnace, improves productivity and decreases coke rate. [2],[3]

The basic or the most fundamental role of the slag in the process of steel making or iron making is:

- Removal of impurities during the process so that the final product is as pure as possible.
- the slag metal reaction is the most essential and vital part of the process so the slag should enhance this phenomena.
- the slag and the metal should be separated in a better manner. So the slag should disable the entrapment of metal in it as far as possible.

With the descent of burden further into the furnace there are various numerous transformation that the burden undergoes. The quality of the final molten metal hence is determined by these transformations and the formation of slag. The nature of slag is essentially decided by the various c constituent for instance the presence of alumina and silica increases the viscosity while the calcium oxide reduces the viscosity of the slag. Initially in the primary slag in blast furnace large amount of iron oxide is observed but due to the presence of various compositions of flux like CaO and MgO changes the properties of the slag. The cohesive zone in the blast furnace determines the efficiency and the productivity of the blast furnace and the processes involved[19]. As the melting and softening of the ore, the slag and the metal iron phase takes place simultaneously in this region hence, the cohesive zone becomes quite compact and the permeability in this region also decreases. The upward flow of the blast gas and other gases hence takes place through the coke slits. The low fusion temperature of the slag ensures a better slag metal separation. [1],[2],[3]

With the change in composition of the slag the liquidus temperature also changes. Thus, a detailed study of the flow characteristics has to be done to know the different circumstances that are produced during the melting of the slag. There are basically four characteristic temperatures that determine the fusion behaviour of the slag.

(i) Initial deformation temperature (IDT),

(ii) Softening temperature (ST),

(iii) Hemispherical temperature (HT) and

(iv) Flow temperature (FT)

The smelting, the reduction and other processes and the refining processes depend a lot on these four characteristic temperatures. These characteristic temperatures have some significance to the blast furnace processes. The IDT signifies the surface stickiness of the material which is important to determine the slag-state materials. The heat and mass transfer in the cohesive zone is determined by the plastic distortion and the fusion or the liquid temperature which is represented by ST and HT respectively. Wile, FT represents the liquid flow of the material. The cohesive zone in the blast furnace can be lowered by the high fusion temperature of the iron bearing material. This in turn also decreases the distance for the molten metal droplet to travel and hence decreases the chances of picking up silicon during the process.

The characteristic behaviour of slag and the operating conditions is determined by the Composition and various constituents present in the slag. Hence an attempt has been made in lowering of the cohesive zone which in other words means decreasing the difference between the ST and FT of the slag.

The characteristic behaviour of slag and the operating conditions is determined by the Composition and various constituents present in the slag. Hence an attempt has been made in lowering of the cohesive zone which in other words means decreasing the difference between the ST and FT of the slag.

1.2. OBJECTIVE:

- To study the flow characteristics of oxide mixes resembling the composition of the Blast Furnace Slag pertaining to the cohesive zone in the Blast Furnace (Primary Slag).
- To arrive at a composition which would render softening at a relatively high temperature (this would mean lowering of cohesive zone) and a relatively high flow temperature. This would mean narrowing the cohesive zone.
- Such a composition of the slag which would affect the location and extent of the cohesive zone in the Blast Furnace in certain to have an impact on:
  - ❖ Coke Consumption
  - ❖ Quality of Hot Metal
  - ❖ Blast Furnace Operation
  - ❖ Green House Problems

  Thus in a nutshell, the objective of the project is to determine the most desirable composition of the primary slag in the Blast Furnace through preparation of synthetic oxide mixes of varied composition.

CHAPTER-2

LITERATURE SURVEY

2.1. BLAST FURNACE

A blast furnace is a type of metallurgical furnace used for smelting to produce industrial metals, generally iron. In a blast furnace the materials are charged from the top which comprises of the iron ore, fluxes and the coke which meets the preheated air or gases called the blast which is blown from below. As a result due to the prevailing temperature and pressure conditions in the steel stack lined with refractory materials a plethora of reactions takes place throughout the furnace as the material moves downwards. The end products of all these reactions are the molten metal, slag which move towards the hearth of the blast furnace and are tapped from bottom at different positions owing to the difference in their relative densities. While the flue gases which are also an end product exit from the top of the furnace. The hot combustion gas rich in carbon monoxide coming in contact with the ore and the flux moving downwards is a counter current exchange process.

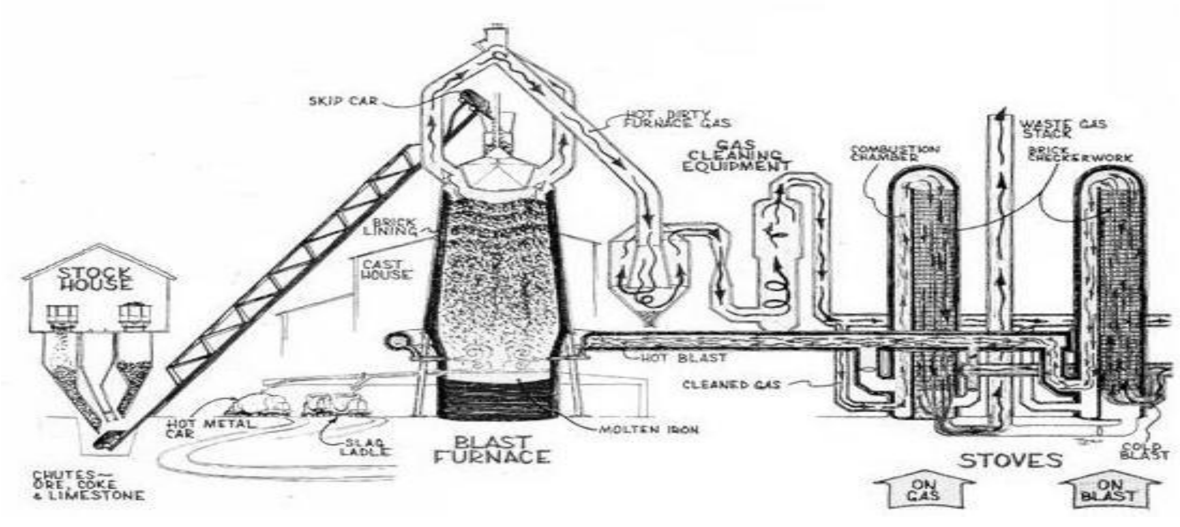


***Figure 1**: Schematic diagram showing Blast Furnace Process*

The materials such as the ore and the flux after numerous reactions in the blast furnace and interacting with all the gases moving upwards gives rise to the final end product of molten metal and the slag in about 8 hours which are tapped at regular intervals. The hot gas after the numerous chemical reactions reaches the top in about 6-8 seconds. The blast furnace operation is a continuous one and once started it is seldom stopped but only for maintenance else it can run continuously for 4 to 10 years. . [1], [3]

2.2. BLAST FURNACE PROCESS

Purification of the raw iron ore is almost an inevitable part if better, efficient as well as economic terms are to be satisfied related to the iron making process. The raw iron is broken down into pieces in the range of .5 to 1.6 inches after getting it from the earth's crust the ore is concentrated specially by removal of gangue particles by crushing the ore in powdered form succeeded by various ore refining techniques such as gravity separation, magnetic separation etc. This refining process is meant to increase the iron content of the ore. The ore can be either or in both forms of magnetite (Fe_3O_4) and haematite (Fe_2O_3) and the iron content in the ore can range from 50 to 70%. The powdered iron rich ore is then rolled into spherical balls called pellets and then they are fired in a furnace to make it ready to be put in the blast furnace.

Sintering is the process of agglomeration of fine particles of raw materials after it has been rolled in to spheres or designed into specific shapes followed by firing the mixed materials raw pellets via gas fires where they get fused into large blocks of sizes .6 to 2.0 inches. The iron from the ore, sinter and pellets gets converted into molten metal and the rest impurity part goes into the slag. The nest important charging material is the coke. The coke generally is prepared by crushing and grinding and then heating coal in absence of air in a furnace, where all the volatile material is removed. The coke after getting cooled is screened for ranges 1 to 4 inches. The coke constitutes of 90 to 93 % carbon, ash and sulphur and the strength of the coke is more than that of coal.

Lastly the limestone constitutes the raw material for the iron making. Explosives are used to from the earth. Then limestone are crushed and screened to a size ranging from 0.5 to 1.5 inches, which becomes the flux for the blast furnace. .[1],[2],[3]

2.3. DIFFERENT ZONES OF BLAST FURNACE

The concept of the different zones of the blast furnace emerged in the quest of understanding and revolutionizing the blast furnace processes. The physical and the chemical phenomena of the blast furnace processes drive the melting and the softening features of the blast furnace process. So the establishment of these fusion characteristics might help a lot in providing the detailed account of physical and chemical dynamics of the operation processes. This fusion behaviour was observed from the collected data from the dissection of numerous quenched blast furnaces in Japan. Thus the zones that can be classified accordingly are:

- **GRANULAR/ISOTHERMAL ZONE:**

It is the zone where the entire raw material charge is in solid form. Here the indirect reduction takes place due to the reducing gas such as carbon monoxide. This is also known as the stack. The iron bearing ore in this zone gets reduced to wustite in the lower end of this zonr due to the indirect reduction.

- **COHESIVE ZONE:**

In this zone the burden starts softening and by the end of this zone the whole of the material melts. This is due the presence of FeO which reduces the melting point. Everything in this region is either semisolid or in molten phase except the coke.

- **ACTIVE COKE ZONE:**

This is the zone just below the cohesive zone. In this zone the coke actively is involved in the direct reduction of the iron bearing ore. The coke interacts with the iron oxide from the trickling slag or from its own reaction with that of carbon dioxide all these takes place mainly in the bosh region.

STAGNANT COKE ZONE:

The coke in this zone or region still remains in solid state. This solid coke is what supports the overlying burden of charges. Here, the Slag and the metal in molten form trickle down through this region. This is the zone where the metal picks up most of its carbon content.

HEARTH:

After all the reduction and trickling down the metal and the slag stand separated into two different layers in this region. Here the slag-metal interface reactions takes place and they try to reach the equilibrium condition as far as possible according to chemistry.

The productivity of the blast furnace, hot metal quality, fuel consumption, stability and lining life depend on the cohesive zone shape and location. At a temperature of about 1000 to 1500°C this cohesive zone was established which is considered as a comprehensive achievement in context of the above studies. The iron bearing material properties determines the pattern of the cohesive zone. Thus the softening and melting properties of the iron bearing materials were considered to be important.

2.4. COHESIVE ZONE

It is the zone where the solid mass is converted into the liquid mass in fact the solid mass just disappears in this region. The material starts softening followed by melting as the burden does not have a fixed melting point; this region is called the cohesive zone. There are several parameters related to the cohesive zone such as the shape, size position and thickness that determines the performance and efficiency of the blast furnace.

The thickness and position of cohesive zone affects the following things

- Gas permeability
- Extent of indirect reduction
- Si content of the pig iron

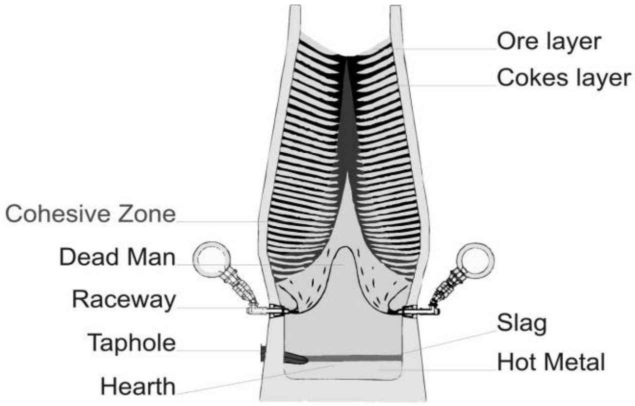


***Figure 2**: Schematic sectional diagram of the internal zones in a blast furnace.*

GAS PERMEABILITY

As far as the permeability of the cohesive zone is concerned it is not much permeable due to the liquid mass that restricts such a feature to be established in the mass in the cohesive zone. Cohesive zone thickness is directly related to gas permeability. The cohesive zone comprises of the semi-fluid alternating layers which resist the flow of the gases. The less the thickness of the cohesive zone the more is the gas that pass through. The wind volume is related to the viscosity, length of the coke slit and the band volume of the melt. .[12],[13]

EXTENT OF INDIRECT REDUCTION

The indirect reduction is the reduction that takes place in the granular zone above the cohesive zone. So with the descent of the cohesive zone further down the blast furnace the granular zone increases; hence the descending materials stay longer in the granular zone. The carbon monoxide gas then gets more of a chance to be better utilized and hence the wustite can be reduced thus indirectly. By lowering of the cohesive zone, the coke consumption for 1 tonne of pig iron gets highly reduced.

Si CONTENT OF PIG IRON

SiO_2 reduction takes place due to the favourable reducing conditions inside the blast furnace. During this reduction the Si gets into the metal. SiO_2 reduces to SiO and finally to Si through a series of reactions and these phenomena takes place in the bosh or the dripping zone. So with the lowering of the position of cohesive zone the chances for picking up silicon also gets reduced as the silicon oxide gets less chance to get reduced. [25]

$SiO_2 + C\ (g) = SiO + CO\ (g)$

$[Fe] + SiO = [Si] + (FeO)$

$(FeO) + CO\ (g) = [Fe] + CO_2\ (g)$

$C + CO_2\ (g) = 2CO\ (g)$

2.5. BLAST FURNACE SLAG

2.5.1 A BRIEF OVER VIEW

There are basically and majorly two products that are formed as a result of the numerous reactions between the raw materials such as the ores, pellets, sinters, flux, coke and the hot gases. The first one being the liquid metal and the other one being the slag; so the impurities that are removed as a result of the reaction between the aluminates, silicates and other gangue materials with that of the fluxes such as lime and magnesia gives rise to a combined form of both the reactants in the form of a product called the slag. Now the fluxes need to be basic in nature in order to bring down the melting temperature of the acidic impurities thus making the slag lighter in weight and thus easily separable from that of the molten metal. Slag-metal reactions are also handled by the basic fluxes which controls the metal quality. The major constituents of the blast furnace slag are CaO, MgO, Al_2O_3 and SiO, apart from these the minor constituents form only 5-10% of the slag such as the FeO, MnO, FeS, CaS, TiO_2 alkali silicates, etc. these minor constituents depend upon the type of the raw materials used and the type of iron smelted. For our experimental purposes a 5% of minor slag is assumed in the slag preparation which is neglected in the final slag volume.

The main objective of the blast furnace operation is to maximize the production of the metal and minimize the volume of the slag, the fuel usage and the metal-sulphur content. This can only be achieved if a slag of desired composition is used and the operating conditions are smoothly running in the furnace. There are various numerous factors that control the formation of a slag for instance the kind of raw materials used, The composition of the slag, flame temperature, distribution of materials at the top, ore reducibility, burden yield, sinters and pellets, softening temperatures of the ferrous charge, coke ash content, furnace lines, etc. The viscosity of the slag and its fusion characteristics are the major parameters that can define the performance and most importantly the efficiency of the blast furnace. A low viscosity slag at operating temperature is always desirable to reduce the coke rate and enable more economic fuel usage. The slag should be able to retain the sulphur more than that of the liquid metal. The slag should also maintain stability in terms of temperature and also the physical and chemical alterations of the burden. The furnace gases and the stock movement should also be smooth which is regulated by the slag. The slag also regulates the metal quality and its homogeneity. The end usage of the slag should be conducive such as use in cement manufacture road ballast etc.

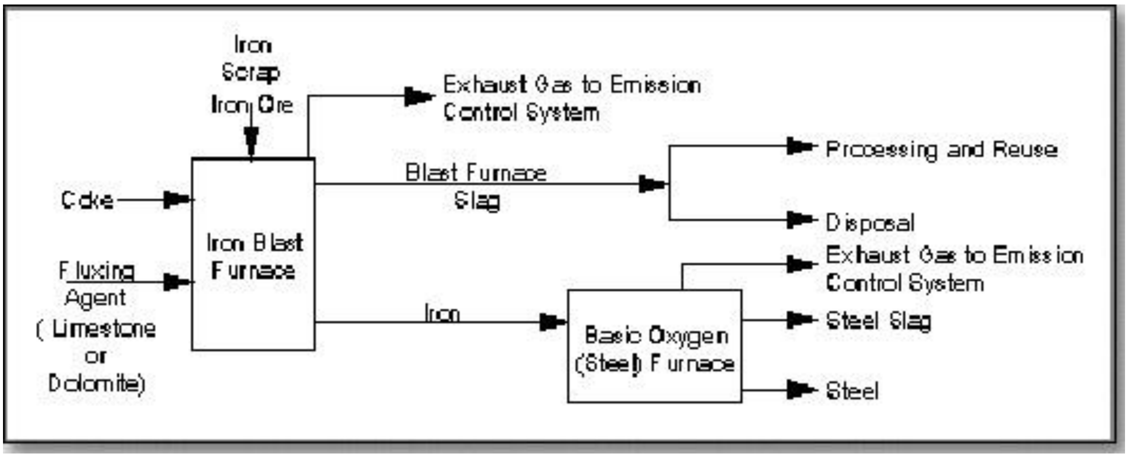


Figure. 3 *shows a schematic of blast furnace operation which represents the blast furnace feed stocks and the production of blast furnace co products (iron and slag)*

For best results in terms of productivity and efficiency of the blast furnace the basicity also plays a very important role. The basicity of the slag which is basically determined by the ratio CaO/SiO_2 or $(CaO + MgO)/SiO_2$, should be maintained at about 1.2 or 1.4 respectively this ensures a smooth running of the blast furnace operations. The content of Alumina in the sag should remain within the range of 12-18%. If the alumina content is too high the slag consequently becomes more viscous which is harmful for the desulphurization. To compensate for high alumina content increasing the viscosity, MgO is added however this results in an increase in slag volume this degrades the furnace productivity and increases the coke rate. A study of the viscosities of blast furnace slags reveals that acceptable viscosities are obtained with either 5% or 10% MgO in the slag, for slags containing up to 20% alumina.

2.5.2 SLAG COMPOSITION

The basicity of the slag depends upon the amount of calcium oxide and magnesium oxide present in the slag. The slag formed id nearly 20% of the total product formed in terms of the Molten metal iron. The basicity ranges from 1.2- 1.55 as a result of the presence of the calcium, magnesium and the Silicon oxide resent in the slag. The slag chemistry of overall components reported as equivalent to Calcium oxide plus magnesium oxide divided by silica is given below:

- CaO - 38%
- SiO_2 - 36%
- MgO - 10%

Minor elements are as follows:

- Iron Oxide (FeO & Fe_2O_3) - <1%
- Sulfur(S) - 1%
- Alumina (Al_2O_3) - 6-12%.

2.5.3 SLAG REGIME

The sequence of slag formation in a blast furnace can be divided into three zones:

(a) Primary slag fusion zone

(b) Bosh slag fusion zone

(c) Final slag or hearth slag zone

The primary slag is formed above the bosh region. The slag here is rich in FeO content due to mostly the unreduced ore. This high content of FeO makes the slag acidic in nature. Furthermore the calcinations and assimilation of the limestone is a slow process and proceeds towards completion at very high temperatures i.e. in the bosh, tuyères and the hearth zone. Hence, along with high content of FeO there's also presence of gangue particles along with alumina, silica and some MnO content. A high content of FeO facilitated by rich iron ores and low slag bulk even if the ore is highly reducible, reduces the slag's fusion temperature at around 1200^{o}C. However a lean and thin ore which is highly reducible has a low FeO content so, the fusion temperature is raised a bit relatively at around 1200-1350^{o}C. As the slag trickles further down the FeO content decreases due to direct reduction and this increases the fusion temperature[19]. The slag however remains molten due to the presence of MnO, lime and magnesia during its passage to hearth.

In the bosh region due to high temperature the direct reduction of FeO increases thus the slag becomes basic in nature. The composition of the bosh slag depends on the individual charged materials such as the iron ore, sinters, fines, limestone and manganese. Iron oxide is usually low (5 percent) but maybe as high as 10-20 percent. Due to greater coke rate, high sulphur content, high metal-silicon content, greater coke ash content and richer ore, the basicity also increases. The lime absorption is initially slow but as the burden goes down to hotter region the absorption increases and is almost completed in the hearth region; same is the case with FeO and its reduction completes above and around the tuyères where the reduction happens at a faster rate due to high temperatures.

The dissolution of lime into the slag takes place in the hearth region along with the incorporation of coke ash released into the slag these incorporations gets completed in the combustion zone. The slag and the metal flows down to the hearth region where each of them get separated into different layers with the molten metal being the heavy one it settles down below the molten slag layer. The molten metal droplets go through the slag metal interfacial reaction occurs basically to attain equilibrium in terms of distribution of Sulphur, manganese and silicon. Thus the composition, nature and the volume of slag plays an important role in determining the quality of the iron, its composition and the productivity and hence, the efficiency of the blast furnace. The sulphur here plays a critical role in controlling the quality of the iron. An optimum slag composition should be maintained to keep a check on the sulphur content in iron along with minimizing the slag volume and the fuel costs.

2.6. SLAG PROPERTIES:

2.6.1 VISCOSITY:

The blast furnace slag behaves as a Newtonian fluid due to the presence of range of shear stresses applicable on the slag. Generally the viscosity of Newtonian fluid does not depend on the presence of shear stress. It’s the iconic and molecular structure that governs the viscosity of the blast furnace slag. Various important phenomena such as the heat transfer, mass transfer and the chemical reactions depend on the flow phenomena of the slag hence on its viscosity[20]. A comprehensive slag-metal separation depends on the free flow nature of the slag at operating temperatures. The gangue particles should go into the slag to ensure a metal of desired quality. The diffusion of ions to and from the slag to the metal influences the reaction rates and that too is very much dependent on the viscosity of the slag. Yet, from the available heat (in the hearth) point of view the blast furnace slag should be neither very viscous nor very fluid Slag viscosity is a transport property that relates to the reaction kinetics and the degree of reduction of the final slag. The viscosity of the slag controls the aerodynamics such as the gas permeability and the heat transfer this in turn affects the efficiency of the blast furnace.

With the increase in basicity the 3-dimensional silicate network chains are broken into discrete anionic groups hence, the viscosity of the slag decreases. Beyond a certain level of basicity the chemical potential of certain solid phases increases and there's also an increase in the viscosity of the slag.

The slag-metal separation efficiency, the metal quality now can be explained and based on the viscous nature of the slag. The ease with which the slag can be tapped depends on its viscosity and hence the energy requirement and the profitability of the process. The slag viscosity is sensitive to its iconic and molecular structure.

2.6.2 LIQUIDUS TEMPERATURE:

The liquidus temperature can be defined as the temperature at which the slag when heated it assumes a hemispherical shape according to the German Industrial Standards 51730. The slag sample observed having a hemispherical form is of a very small mass. This temperature can also be nominated as the temperature at which the first crystal is formed when the melt is cooled down as indicated by Osborn [21] and Snow [22]. While Ohno *et al* [23] indicated that all the crystal disappear when the slag is heated to the temperature of Liquidus temperature. So these are some of the numerous nomenclatures reported by scientists to indicate the liquidus temperature. In our experimental work the liquidus temperature is measured by the Leitz heating microscope.

The liquidus temperature gives us an approximated assumption of the position, width and shape of the cohesive zone. As the cohesive zone geometry affects the gas permeability along with the amount of silicon picked-up by the hot metal and also an idea about the extent of indirect reduction. Thus the liquidus temperature measurement bears a great importance for its measurement.

In a pyrometallurgical process or in industrial melts, the fusion behavior of the non-metallic melts i.e. the combination of oxides which form the slag plays an important part than the actual fusion temperature. The fusion behaviour is described in terms of four characteristic temperatures. These are; the initial deformation temperature (IDT), symbolising the surface stickiness; the softening temperature (ST), symbolising the plastic distortion; the hemispherical temperature (HT), which is also the liquidus temperature, symbolising sluggish Flow; and the flow temperature (FT), symbolising liquid mobility.

2.6.3 FLOW CHARACTERISTICS OF SLAG

The high temperature microscope is used for determining the flow characteristics of slag. It has got four characteristics temperatures:

- Initial deformation temperature (IDT)
- Softening temperature (ST)
- Hemispherical temperature (HT)
- Flow temperature (FT)

The followings are defined as per 51730, German Industrial Standards. .[18]

2.6.3.1 INITIAL DEFORMATION TEMPERATURE (IDT)

It is the temperature at which first changes in the shape of small sample is observed. The curving of the edges too occurs. So these are some of the primary observations of changes occurring at the IDT. The IDT signifies the surface stickiness of the slag.

2.6.3.2 SOFTENING TEMPERATURE (ST)

This is the temperature at which further modification of the slag sample takes place. The slag either shrinks by one division or there’s some swelling observed after one point of temperature. The outline of the sample may even change at this temperature. This temperature signifies the plastic deformation of the slag sample.

2.6.3.3 HEMISPHERICAL TEMPERATURE (HT)

It is the temperature at which the sample assumes a hemispherical shape. Which can be observed by the number of divisions measured in the height is just half of that of the number of divisions in the base. This is also known as the liquidus temperature of the slag. This temperature signifies the sluggish flow of the slag.

2.6.3.4 FLOW TEMPERATURE (FT)

Here the sample starts to flow. This temperature can be nominated as the flow temperature by observing the measured height of the sample being 1/3rd that of the original height. This temperature signifies the liquid flow of the slag.

2.7. STUDY OF EFFECT ON VISCOSITY WITH VARYING COMPOSITIONS AND CONDITIONS

Y.S. Lee et al [4] studied and observed the viscous behaviour of CaO- SiO_2- Al_2O_3-MgO-FeO slag under controlled conditions of C/S = 1.15-1.6, 10-13mass% Al_2O_3, 5-10mass% MgO and 0-20% FeO. The study of such a slag by the scientists leads them to infer that there's depolymerization of silicate network above the C/S ratio of 1.3 and less than the ratio of 1.5 this causes the viscosity of the slag to increase. The slag viscosity otherwise up till the ratio of 1.3 decreases due to the increasing chemical potential of the dicalcium silicate which is a primary solid phase. This good correlation between the viscosity and the slag components was basically due to the thermodynamic approach taken up for the activity of primary solid components. So it was confirmed that slag viscosity in highly basic slags (C/S>1.3) can be estimated by the chemical potential of dicalcium silicate.

. They proposed trough their studies that for a low value of FeO content of about less than 7.5% the slag viscosity showed minimum value with increasing MnO content. While, with the FeO content being more than that of 7.5% there is no particular effect on the slag viscosity with increasing MnO content. They also concluded that the BF slag viscosity decreases with increasing FeO content for a fixed CaO/ SiO_2 ratio. The variation in the slag basicity as well as the Si content in the metal can be minimized by less reduction of SiO_2 into Si. This can be achieved by injection of flux in the blast furnace according to some tests conducted by some Japanese companies.

Y.S.Lee, J.R.Kim, S.H.Yi and D.J.Min: "Viscous behavior of CaO- SiO_2- Al_2O_3- MgO-FeO slag". Proceedings of VIII international conference on molten slag, fluxes and salts, The South African Institute of Mining and Metallurgy, 2004, p.225.**[5]**

- Their studies showed that the heat transfer, mass transfer, SiO_2 and FeO reduction and gas permeability is controlled by the flow characteristics of the slag. This in turn plays an important role in the effect of the viscous nature of slag on the efficiency and productivity of the blast furnace. The viscous behaviour of CaO- SiO_2- Al_2O_3-MgO-FeO slags was studied under the conditions of CaO/ SiO_2 = 1.15-1.6, 10-13 % Al_2O_3, 5-2. % MgO, 5- 20% FeO.
- Slag viscosity decreased with increasing slag basicity up to the CaO/ SiO_2 ratio of 1.3.
- The silicon network repolymerizes and the silicate structure changes into simple chains of discrete anionic groups from the silicate 30 thus a decrease in basicity occurs.
- The FeO content in slag if increases the viscosity of the slag decreases so when the FeO decreases from 10-15% so the viscosity of slag at basicity of CaO/ SiO_2 = 1.5 increases from about 2.5 to 10 dPa.s with increase in FeO content as mentioned above.

The viscous behavior of CaO- SiO_2- Al_2O_3-MgO-FeO slag and measured the viscosity under conditions of C/S 1.35-1.45, 10-18% Alumina, 3.5-10% MgO and 5% FeO. They basically studied the influence of MgO and Al_2O_3 alteration on the viscosities of BF slag. For a fixed MgO content and basicity the viscosity increases with increase in the Alumina content. The slag also showed a minimum value of viscosity at around 7% of MgO at over the temperature of 1723K. The MgO content variation did not significantly change the slag viscosity.

Seong-Ho Seok et al [17] the viscous behavior of CaO- SiO_2-FeO-MgO and CaO- SiO_2-FeO- Al_2O_3-MgO melts were studied which were saturated with dicalcium silicate with a

MgO content of 8% under conditions of high basicity and temperature of around 1873K. Through their studies they inferred that the viscosities of slag depend relatively more on the alumina content as the solid phases present is more in case of alteration in alumina content than that of MgO.

Yasuji Kawai [8] studied on the viscosities of molten slags and on the viscosities of CaO-SiO_2- Al_2O_3-MgO slags. When MgO was added to CaO- SiO_2 slags, the viscosities decreases with increasing amount of MgO up to about 20%, beyond which, however, it increased. The region of low viscosity was greater than that in CaO- SiO_2- Al_2O_3 slag.

Noritaka Saito et al [26] studied the effect of MgO on the viscosity of 40CaO-40 SiO_2-20 Al_2O_3 slags. They suggested through their studies that magnesia acts a network modifier and also that the activation energy for viscous flow also decreases with addition of MgO. And they were able to show through their experiments that the viscosity of the slag decreases with that of addition of MgO.

Amitabh Shankar et al [15] for the CaO- SiO_2-MgO- Al_2O_3 and CaO- SiO_2-MgO- Al_2O_3-TiO_2 system by varying the C/S ratio between 0.72 and 1.23 in the temperature range of 1573-1873 K. Alumina content was varied between 21-28%, Magnesia was varied between 2-8% and Titania was varied between 0-2%. They have shown that viscosity decreases with increase in basicity. It was also shown that the slope of the Viscosity vs. Temperature curve is steeper for low basicity slags. An increase in basicity decreases the slag viscosity, because silicate structure changes from network to discrete anionic groups containing simple chains or rings as basic oxides are increased.

Masashi Nakamoto et al [16] they used the rotating cylinder method to measure the viscous behavior of molten CaO- SiO_2-MgO- Al_2O_3 and compared the result with its model that was created. They actually wanted to study the viscosity of slags that melt at low temperatures to improve the blast furnace operations at lower temperatures i.e. at around 1673K. They showed that slag of the following composition 35% Al_2O_3-43.1% CaO-7.5% MgO-14.4% SiO_2 has a viscosity less than 0.6 Pa.s below 1673 K and it melts at around 1673K and below.

J.-Y. JIA, C.-G. BAI, G.-B. QIU, D.-F. CHEN and Y. XU [6] a calculation model was established based on the studies of the ternary slag system of CaO- SiO_2- TiO_2. Thus, they were able to form a mass action concentration calculation model and viscosity calculation model based upon the existing theories and documented data at different temperatures of the ternary slag system at different compositions. The results obtained from the calculation are consistent with the literature values.

- ❖ With increasing TiO_2 content the mass action concentration also increases. This is also applicable practically.
- ❖ Viscosity of slag decreases with increasing TiO_2 .content in the slag.
- ❖ Temperature is a key to viscosity. If the temperature rises, viscosity decreases, and running quality is good.

2.8. STUDY OF SIMULATION BASED MODEL TO PREDICT THE OPERATION BEHAVIOR OF BLAST FURNACE

Kiichi NARITA, Shin-ichi INABA, Masakata SHIMIZU, Arata YAMAGUCHI, Isao KOBAYASHI and Ken-ichi OKIMOTO [7] the study of gas and burden distribution was done by them with the blast furnace aerodynamics in consideration was done by them. The formation of central coke column has been of particular concern related to the behaviour of charged burden which has been studied aerodynamically by a model furnace. With the permeability of the charged ore and the charging sequence the column volume changed .The formation of central coke column is found in practical blast furnaces. Its presence decreases the pressure drop inside the furnace. This can be concluded with due respect to the analysis of the gas velocity in the central part with respect to permeability and piling profile of the ore.

G. Danloy, J. Mignon, R. Munnix, G. Dauwels, L. Bonte [9] a mathematical model of the blast furnace was designed and developed to optimize the burden distribution. This mathematical model of the blast furnace simulated the main reactions and phenomena involved in a blast furnace in a steady state condition. The theoretical data was calibrated with the experimental data which was obtained by gas tracing or by vertical probing method of the B furnace of Sidmar. The model showed a great correlation and influence of the mathematical model results on the burden distribution pattern on the shape and position of cohesive zone, the gas distribution pattern, top gas profile, the pressure drop, the productivity and the heat losses through the wall. Hence the model may emerge as a very useful and powerful tool by the operator to control all the parameters related to the burden distribution pattern to produce an almost desired effect on the blast furnace functions and its results. It can also be used to predict the changes in the burden distribution changes that would be made by the operator.

2.9. COHESIVE ZONE MODEL OF THE BLAST FURNACE

S.Z. Li, Jian Cheng, and W.Q. Ma's [29] the quality of iron and the efficiency of the blast furnace too much depends on the cohesive zone properties of the blast furnace. Thus they described a method to predict the shape of the cohesive zone of the blast furnace. This model developed can be observed during the operation of the blast furnace. This model is based on the principle of the conservation of the heat and mass transfer which is abided by the chemical reactions between coke, ore and the gas. Following which the blast furnace is divided into a series of homocentric circles and in vertical direction and each equation is resolved on each of the homocentric circles depending upon various parameters. The relationship between the temperature and the height thus can be established. Thus the cohesive zone can now be predicted based on the fusibility character of the ore. Thus this process is applied to real blast furnace and the results related to cohesive zone properties obtained are observed and evaluated.

2.10. EFFECT OF SILICON AND ITS OXIDES ON PROPERTIES OF SLAG AND METALS

B.Ozturk and R.J.Fruehan: "Kinetics of the Reaction of SiO (g) with carbon saturated Iron": Metall.Trans.B. Vol.16B, 1985, p.121**[27]**

Silicon transfer is considered to be very important in the iron blast furnace and this concern is explicitly explored in this paper. The main reaction which takes place in blast furnace for the Silicon transfer in given as follows:-

$(SiO_2) + 2[C] = [Si] + 2CO$ (g)

When coke reacts with its ash in the tuyères zone there's formation of SiO because there's presence of the silicon element in the charged coke. The reaction of silicon with carbon is critical for silicon transfer in iron blast furnace. When carbon saturated iron droplets passes through the furnace, it reacts with the SiO (g) to put Si into the metal.

At the slag-gas interface CO reduced the SiO_2 to SiO (g)

$(SiO_2) + CO$ (g) = CO2 (g) + SiO (g)

At metal-gas interface SiO reacts with dissolved carbon

SiO (g) + [C] = CO (g) + [Si]

CO2 oxidizes carbon to form CO

CO2 + [CO] = 2CO

So, the overall reaction taking place is summarized to,

$(SiO_2) + 2[C] + [Si] + 2$ CO (g)

The reaction of carbon with SiO is the rate controlling mechanism which can be controlled by the following:

- Gas phase mass transfer of SiO (g) to the metal surface.

- Diffusion of the reactant in liquid phase (carbon) to the surface or product
- (Silicon) into the metal.
- Chemical kinetics on the metal surface.
- Transfer of the product CO in gas phase away from the surface.

B.Ozturk and R.J.Fruehan: "The Reaction of SiO (g) with liquid slags": Metall.Trans.B. Vol.17B, 1986, p.397. [**28]**

- The rate of transfer of silicon is too slow which is based on the results obtained from the slag-metal reaction so actual silicon content in the blast furnace is difficult to obtain. But now alternative mechanisms are available to the slag-,etal reaction for which SiO gas is used. This paper thus indulges in the discussion of transfer of Silicon in the blast furnace.
- The carbon saturated iron droplets reacts with the SiO generated as well as with the slag droplets.
- The gas phase mass transfer controls the kinetics of reaction between SiO in gaseous form and carbon dissolved in.
- With decreasing diffusion distance the rate of transfer of silicon increases.

CHAPTER-3

EXPERIMENTAL DETAILS

3.1 EXPERIMENTAL PROCEDURE

Slags from different blast furnace of different plants were analysed to get a base idea of the expected synthetic slag composition and thus an average slag composition was determined. An Average Slag is a slag arrived by taking the average of the maximum and minimum composition that we got from the slags collected from different blast furnaces.

Five different basicity ratio (CaO/SiO_2 ratio) or (c/s ratio) were obtained by some variation in c/s ratio of the average slag that was determined. Also five different MgO and Al_2O_3 variation were included. Thus different combinations of the synthetic slag are possible for these particular combinations.

For our experimentation we first took a particular constant value of MgO and only c/s ratio was varied. Next some slags were prepared by taking the Basicity ratio as constant and varying the MgO compositions. Thus various combinations can be prepared and then analysed to get the best slag. Slag compositions obtained now needs to be prepared from the major oxides such as the CaO, MgO, SiO_2 and Al_2O_3.The major oxides are obtained individually from the commercial market which are about 99% pure.

The following is the detailed sample preparation list.

SAMPLE PREPARATION:

We are making 150 g of slag sample. Minor constituents taken = 3.66 % i.e. nearly 5 g in 150 g of total slag. This includes TiO_2, FeO. We have neglected the minor slags in our experiment. For the sample preparation after obtaining almost 99% pure oxides of CaO, MgO, SiO_2 and Al_2O_3, following processes are involved.

DIFFERENT PROCESS INVOLVED:

A) FURNACE HEATING:

CaO and MgO content are heated at 200 degrees Celsius to remove moisture. Furnace heating at 200 takes usually 1-2 hours of time and is very effective in removing moisture which can increase the weight of the oxides and thus create a problem.

B) WEIGHING

After the oxides are furnace heated, they are then weighed and mixed according to their percentage composition in the digital weighing machine accurately.

C) MIXING:

After taking proper accurate weights of the oxides they need to be thoroughly mixed. The mixing of the major oxides is done in the abrasion tester machine mixer. A fixed 25 grams of total weight (containing weighted percentage composition of all the major oxides) of the combination of major oxides are taken into a plastic container. There are 3 such containers that can be put together, making it 75 grams. Since the mixing should be homogenous and perfectly mixed, each container of 25 g is separately taken weights as per calculations.

This plastic container is then placed in one of the 3 rotating chambers of the mixer. A total of one lakh revolutions are required for appropriate mixing which is completed in 6 hours. 3 such sessions are required for complete mixing of 75 grams. So the total 145 gram of the required synthetic slag sample is prepared in 6 days. The mixing is very homogenous when done by this process and gives us thoroughly mixed oxides.

D) PELLETIZATION:

The total slag then obtained is pelletized in the compression machine under 5 ton load, where the slag is compacted between the dies under pressure. Thus small cylindrical pellets are formed with each pellet having almost the same dimension. The process of Pelletization is done as the platinum crucible used for the firing of the oxides , are very small and cannot contain powdered slag so making into pellets they become compacted and will take less space and so can be easily put in the crucibles for the firing procedure.

The Pelletization process generally takes 3 hours continuously for converting the 150 g of sample powder into form of pellets. After the formation of pellets it must be kept away from moisture and must be used for the firing process as soon as possible else the pellets can break back to powder form in due time.

E) FIRING:

The pellets thus obtained are then sintered at around 1680 degrees Celsius in the sintering furnace to bind the slag material by the process of diffusion. This temperature is selected as it is the temperature that the slag undergoes when comes out of the blast furnace, so firing is done at this temperature. Proper firing can be easily done when homogenous mixing is done. There are two crucible holders where two platinum crucibles are places each containing different slags. Thus at a time 2 slags can be prepared. After attaining the required temperature gradually, the slag is then quenched in water to room temperature with the crucible in different containers.

F) AFTER FIRING

After firing and quenching is done, the slags are taken out from the crucibles and heated to remove the water content. They are kept in the furnace at a temperature of 150 degrees Celsius for 1 hour .The crucibles used are then cleaned using dilute HCl (50% water and50% Conc. HCl). The cleaning process generally takes 2 days after which gel formation takes place for the slags that were stuck on the walls of the crucible. Platinum crucibles are used for the process as very high temperature is reached during firing and platinum can easily sustain that temperature and also is very nonreactive with the slags or the outer ambiance.

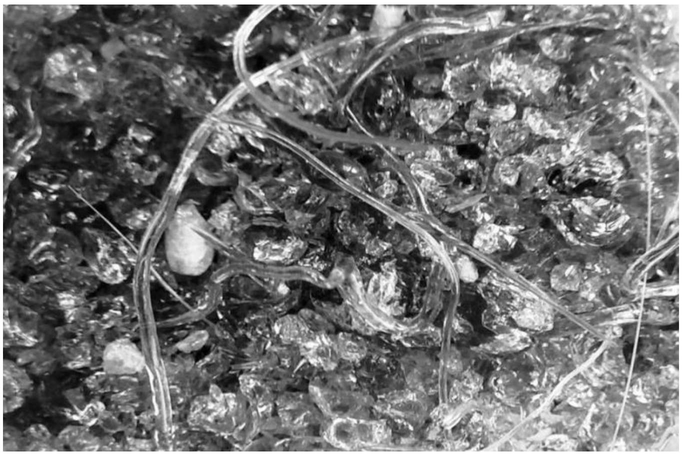


***Figure 4**: Synthetic slag prepared in the laboratory*

G) BALL MILLING:

The sintered slag pellets after furnace heating are then reduced to fine powder by the process of ball milling in the planetary ball mill. This process usually requires about 30 minutes.

300 rpm is used for the milling process. After this the slag is obtained as fine powder from the planetary mill. Thus the mechanical and physical process for the sample preparation concludes with this process.

H) SAMPLE ANALYSIS:

1) SAMPLING:

Sampling is usually done and especially for the case of coning and quartering for the purpose of checking the uniformity and the homogeneity of the sample prepared. For the method of coning and quartering the sample is first powdered and then laid out on a clean surface in the form of a conical heap. The cone is then quarters into four parts, following which only two opposite quarters are considered (like first and third) while the other quarters (second and fourth) are discarded. the samples are taken from each of the two opposite quarters and those small quantity of sample are formed into small cubes .The process is repeated as many times as necessary to obtain the quantity desired for some final use. [14]

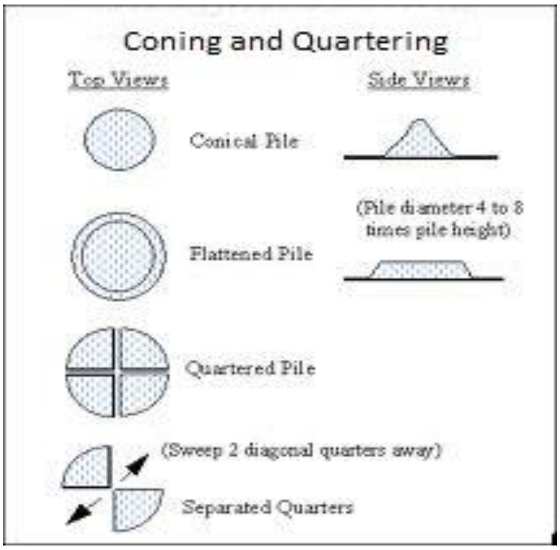
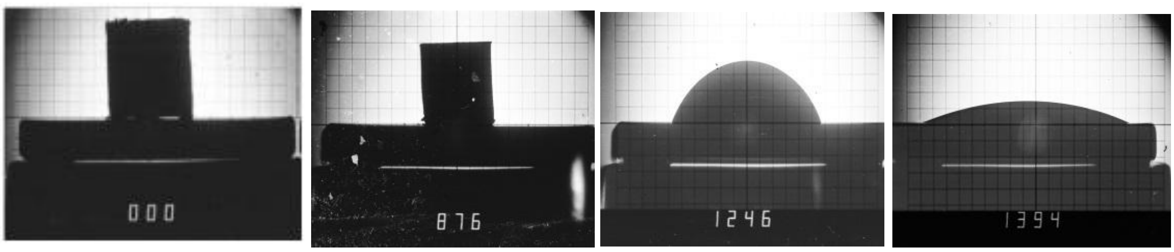


***Figure 5**: Coning and Quartering*

2) ANALYSIS:

Analysis part consists of the high temperature microscopy. Leitz heating microscope is used for this process. The powdered slag is prepared in the form of small cubic shapes for testing. They are mounted in the heating microscope. The sample gets heated gradually and deformation takes place. This deformation defines the flow characteristics of the slag in the form of IDT, ST, HT and FT. There is a control of heating rate, water is used as coolant and there is a camera attached to take photographs of different characteristics temperature of slags when required.



INITIAL **ST** **HT** **FT**

***Figure 6**: View of Different Flow characteristics of the slag prepared in the lab observed through Leitz heating microscope.*

3.2 EXPERIMENTAL APPARATUS

3.2.1 HEATING MICROSCOPE

The heating microscope records the temperature characteristics of the slag sample. This instrument is known as the Leitz heating microscope. A picture of the instrument used for our experimental purposes is shown below in the **Fig. 6.** The instrument works on the principle of heating the sample at a constant rate via a heating coil and the changes in the sample observed are noted and marked by a temperature at which the changes in the sample initiates. The temperature is displayed by a digital display.

A cubic sample of 3 mm dimension is formed and incorporated into the heating component of the instrument.

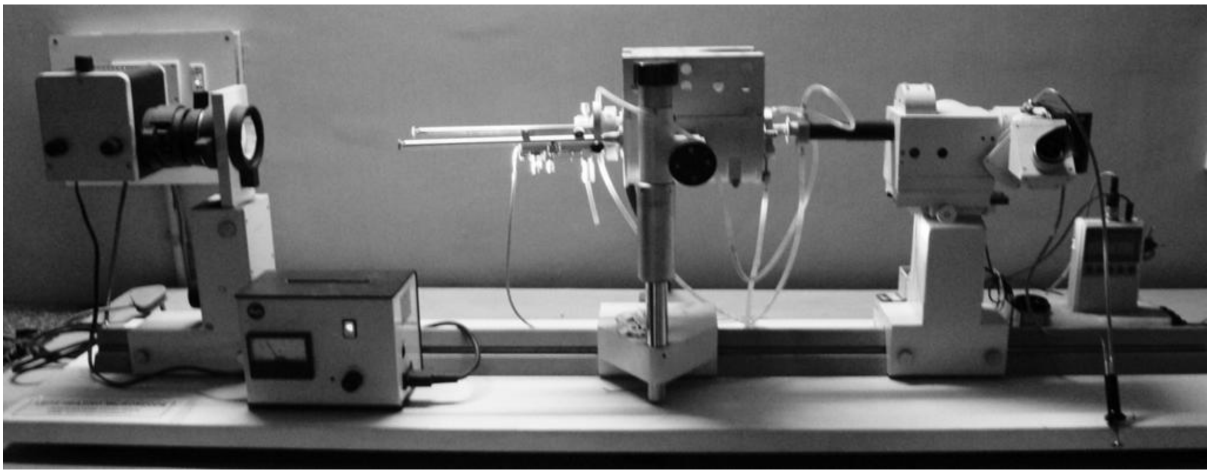


***Figure 7**: Symbolic view of Leitz heating microscope*

The grids are designed for the better observation of the sample which is observed through the eyepiece. The grids are of .5 mm in dimension. The heating rate is maintained as the standard rate which otherwise inflict changes and affect the characteristic temperature. For instance increasing the heating rate also increases the FT and the ST as the high heating rate decreases the action of the charge. Several readings for the same sample are taken in order to justify the correctness of the observational results. If the difference in the two readings for the sample varies by a temperature range of 5°C then the sample is again tested.

3.2.2 PLANETARY BALL MILL

The planetary ball mills are also referred to as the centrifugal mills. This mill is purposed for grinding the sample or mixing the sample. For our experimentation the mill was used to grind the quenched hard samples after the sintering process. The mill can be segregated into various components or parts. The container in which the sample is fed is made up of zirconia and the balls used to grind the sample are of the same material. The container is fixed onto the rotatable platform. The container or the vile rotates in the opposite direction to the rotation of the rotator platform. After the containers are mounted the machine becomes operational and ready to grind by generation of huge grinding energy after the lid has been closed. The material is grinded into colloidal fineness. The machine is run at a speed of 300 rotations per minute and the sample is subjected to the grinding action for 1 hour to obtain the desired fineness for our experimental work. The figure below shows a planetary ball mill of the Gilson Company.

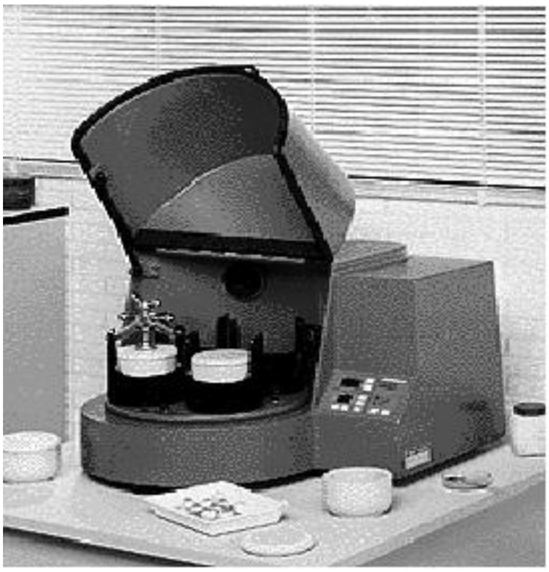


Figure 8- *A four station planetary mill*

As the container and the rotator platform rotate in the opposite direction so the cancellation of these opposite centrifugal forces makes the balls in the container to roll halfway around the container. The balls then fall from the halfway mark and are thrown across to the opposite wall at very high speeds this results in very high impact**.** Thus this kind of a planetary action causes the acceleration to reach around 20g and hence the time is reduced by a factor of 2/3 than the time taken by simple centrifugal mills to grind the sample.

3.2.3. ABRASION TESTING MIXER

The Abrasion Testing mixer is used to mix the slag samples. A fixed 25 grams of total weight (containing weighted percentage composition of all the major oxides) of the combination of major oxides are taken into a plastic container. There are 3 such containers that can be put together, making it 75 grams. Since the mixing should be homogenous and perfectly mixed, each container of 25 g is separately taken weights as per calculations.

***Figure 9**: Abrasion Testing Mixer*

This plastic container is then placed in one of the 3 rotating chambers of the mixer. A total of one lakh revolutions are required for appropriate mixing which is completed in 6 hours. 3 such sessions are required for complete mixing of 75 grams. So the total 145 gram of the required synthetic slag sample is prepared in 6 days. The mixing is very homogenous when done by this process and gives us thoroughly mixed oxides.

3.2.4. SINTERING FURNACE

The pellets obtained are sintered at around 1680 degrees Celsius in the sintering furnace to bind the slag material by the process of diffusion. This temperature is selected as it is the temperature that the slag undergoes when comes out of the blast furnace, so firing is done at this temperature. Proper firing can be easily done when homogenous mixing is done. There are two crucible holders where two platinum crucibles are places each containing different slags. Thus at a time 2 slags can be prepared. After attaining the required temperature gradually, the slag is then quenched in water to room temperature with the crucible in different containers.

Figure-10*: Sintering Furnace*

After firing and quenching is done, the crucibles used are then cleaned using dilute HCl (50% water and50% Conc. HCl). The cleaning process generally takes 2 days after which gel formation takes place for the slags that were stuck on the walls of the crucible. Platinum crucibles are used for the process as very high temperature is reached during firing and platinum can easily sustain that temperature and also is very nonreactive with the slags or the outer ambiance.

3.2.5. PELLETIZER MACHINE

The total slag obtained is pelletized in the compression machine under 5 ton loads, where the slag is compacted between the dies under pressure. Thus small cylindrical pellets are formed with each pellet having almost the same dimension. The process of Pelletization is done as the platinum crucible used for the firing of the oxides , are very small and cannot contain powdered slag so making into pellets they become compacted and will take less space and so can be easily put in the crucibles for the firing procedure.

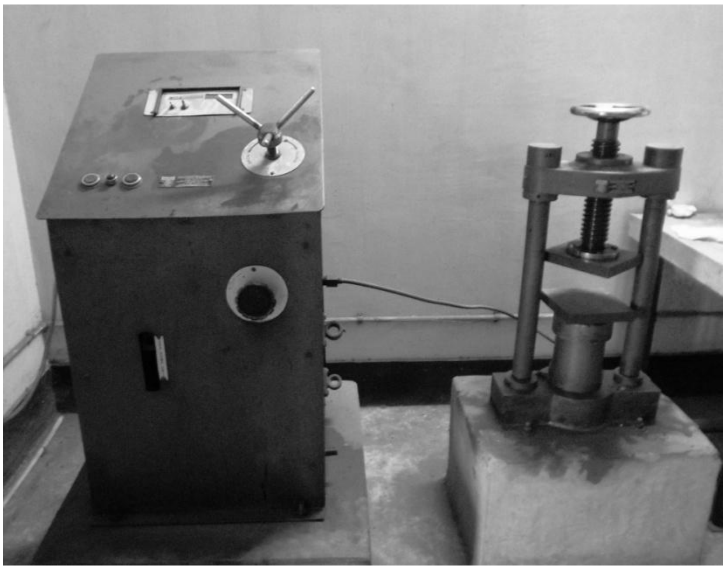


Figure 11: *Pelletizer Machine*

The Pelletization process generally takes 3 hours continuously for converting the 150 g of sample powder into form of pellets. After the formation of pellets it must be kept away from moisture and must be used for the firing process as soon as possible else the pellets can break back to powder form in due time.

3.3 EXPERIMENTAL WORK

1) Different combinations of synthetic slags:

Table 1: Combination of different slags possible for preparation in the lab for varying basicity.

C/S Ratio	**MgO variations**	**Al_2O_3 variations**
1.13	11.9	20.5
1.07	10.2	20.0
1.01	**9.26**	**19.71**
0.96	8.32	19.5
0.907	7.4	18.8

For each value of MgO or Al_2O_3, there can be 25 different slag combinations possible.

Here we see that there can be different combinations of slag that can be synthetically prepared. For our experimental work, first we took MgO and Al_2O_3 compositions as constant at 9.26 and 19.71 respectively. Thus we obtained synthetic slags of five different basicity.

After that next 5 slags were prepared by taking the basicity constant and varying the MgO %.

For this we took the basicity as 1.1 and varied the MgO as 4, 6,8,10 and 12%. Thus 5 different slags were possible in this case too.

2) Synthetic Slags prepared:

Table-2: Slags Prepared with Different C/S ratio and at constant MgO and Al_2O_3 percentage along with its characteristics temperature:

C/S ratio	MgO	CaO	SiO_2	Al_2O_3	IDT	ST	HT	FT
0.907	9.26	32.04	35.33	19.71	813	1232	1248	1424
0.96	9.26	33	34.37	19.71	838	1232	1249	1430
1.01	9.26	33.85	33.52	19.71	836	1242	1250	1432
1.07	9.26	34.82	32.55	19.71	830	1232	1260	1435
1.13	9.26	35.74	31.63	19.71	826	1228	1275	1420

Here we see different slags of varying basicity showing MgO, CaO, SiO_2, Al_2O_3 percentages along with the characteristics temperature of slags.

The MgO is kept constant here as 9.26 % and Al_2O_3 is kept constant as 19.71 %. The minor constituent like FeO, TiO_2 are ignored in this and kept constant as 3.66%.

Here the Slag analysis and heating microscope testing was done several times for certain slags which had certain problems like difference between the opposite corners of the cone was more than 5% , or there was bubble formation in it. Due to these reasons, the samples were tested again until a confirm good reading was determined.

Table-3: Slags Prepared with different MgO variations (theoretical slags) & constant C/S ratio (1.1) along with its characteristics temperature:

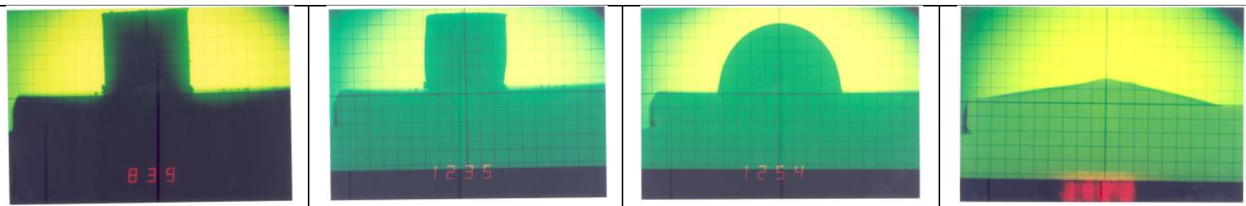
C/S ratio	MgO	CaO	SiO_2	Al_2O_3	IDT	ST	HT	FT	Remark
1.1	4	38.04	34.59	19.71	832	1233	1285	1328	N/A
1.1	6	36	33.63	19.71	838	1270	1285	1365	N/A
1.1	8	35.95	32.68	19.71	838	1218	1260	1316	N/A
1.1	**10**	**34.9**	**31.73**	**19.71**	**817**	**1227**	**1335**	**1440**	Bubble formation started
1.1	12	33.85	30.78	19.71	815	1210	1300	1328	N/A

Here we see different slags of varying MgO % with constant basicity as 1.1 and Al_2O_3 as 19.71%. The minor constituent like FeO, TiO_2 are ignored in this and kept constant as 3.66%. Here we can see at 10% MgO, Bubble formation takes place. Here the Slag analysis and heating microscope testing was done several times for certain slags which had certain problems like difference between the opposite corners of the cone was more than 5% , or there was bubble formation in it. Due to these reasons, the samples were tested again until a confirm good reading was determined.

Table-4: The final table showing all the slags together along with its characteristics temperature:

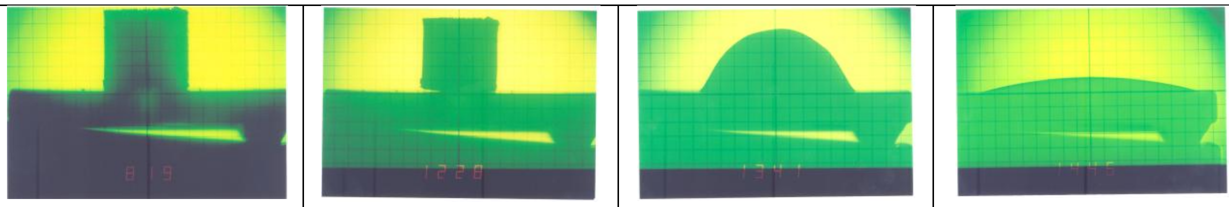
Sample No	C/S ratio	MgO	CaO	SiO_2	Al_2O_3	IDT	ST	HT	FT	FT-ST
1	0.907	9.26	32.04	35.33	19.71	813	1232	1248	1424	192
2	0.96	9.26	33	34.37	19.71	838	1232	1249	1430	198
3	1.01	9.26	33.85	33.52	19.71	836	1242	1250	1432	190
4	1.07	9.26	34.82	32.55	19.71	830	1232	1260	1435	203
5	1.13	9.26	35.74	31.634	19.71	826	1228	1275	1420	192
6	1.1	4	38.04	34.59	19.71	832	1233	1285	1328	95
7	1.1	6	36	33.63	19.71	838	1270	1285	1365	95
8	1.1	8	35.95	32.68	19.71	838	1218	1260	1316	98
9	1.1	10	34.9	31.73	19.71	817	1227	1335	1440	213
10	1.1	12	33.85	30.78	19.71	815	1210	1300	1328	118

This Table shows all the 10 slags with the constituent % and the Characteristics temperature. Here the last column shows the difference between the flow temperature of the slag and the softening temperature of the slag (FT-ST). The data hence got was then plotted accordingly to get some fascinating results.



IDT	ST	HT	FT

Figure-12: *The Flow Characteristics images of the synthetic slag -2 as obtained from the heating microscope. (The temperatures used in the data are the corrected real values from the digital temperature measuring instrument.).*



IDT	ST	HT	FT

Figure-13: *The Flow Characteristics images of the synthetic slag -9 as obtained from the heating microscope. (The temperatures used in the data are the corrected real values from the digital temperature measuring instrument.).*

3.4. EXPERIMENTAL RESULTS AND DISCUSSION

Slags have been prepared synthetically on the basis of average slag estimated on the basis of industrial slag. The variation of major oxides such as SiO_2 and CaO, while keeping the values of MgO and Al_2O_3 constant, provides us with the 5 samples that have been used for our experimental work. The next 5 slags are prepared by taking the basicity ratio as constant and changing the MgO ratio as given.

Here we have considered a constant percentage of minor constituents (TiO_2, FeO, Fe_2O_3, etc) of 3.66% of the total slag weight considered (150 g).

The variation of IDT, ST, HT and FT with basicity of the slag is given in the graphs below.

Also the variation of ST and FT separately has been done with the varying basicity to determine the cohesive zone and hence optimize the best slag.

3.4.1. RESULTS

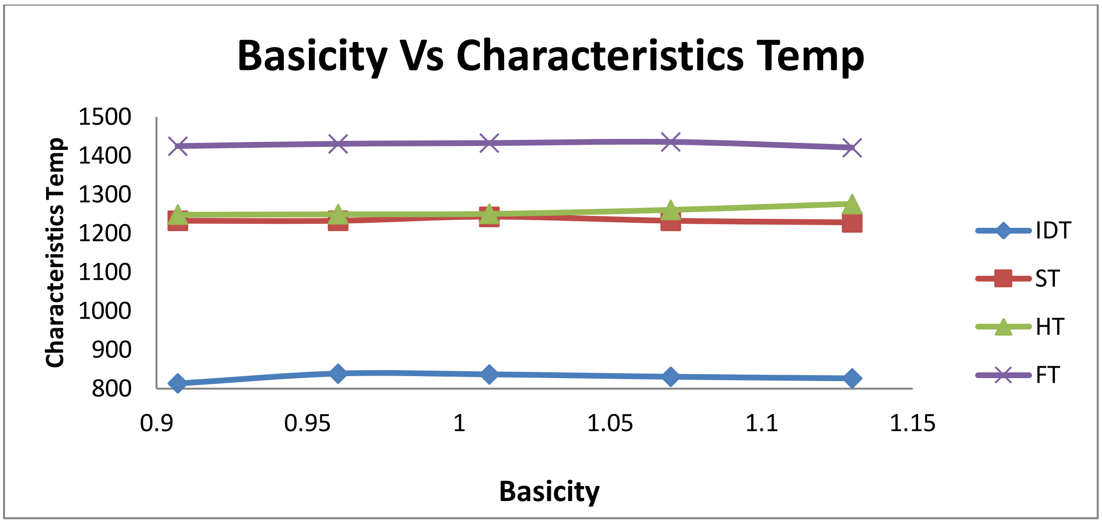


Figure-14: *Variation of Basicity Vs Characteristics Temperature**.** Here the Basicity is varied and MgO and Al_2O_3 are constant.*

This graph shows the variation of basicity and characteristics temperature of the slag. Here the Basicity is varied and MgO and Al_2O_3 are constant at 9.26 and 19.71 %. We can see here that as the basicity increases, the IDT, ST and FT decreases and there is increase in HT as the basicity increases. Here the minor constituent were also neglected so the inclusion of minor constituent can also change the graph accordingly. The variation of the characteristics temperature with varying basicity is in relevant to the theory.

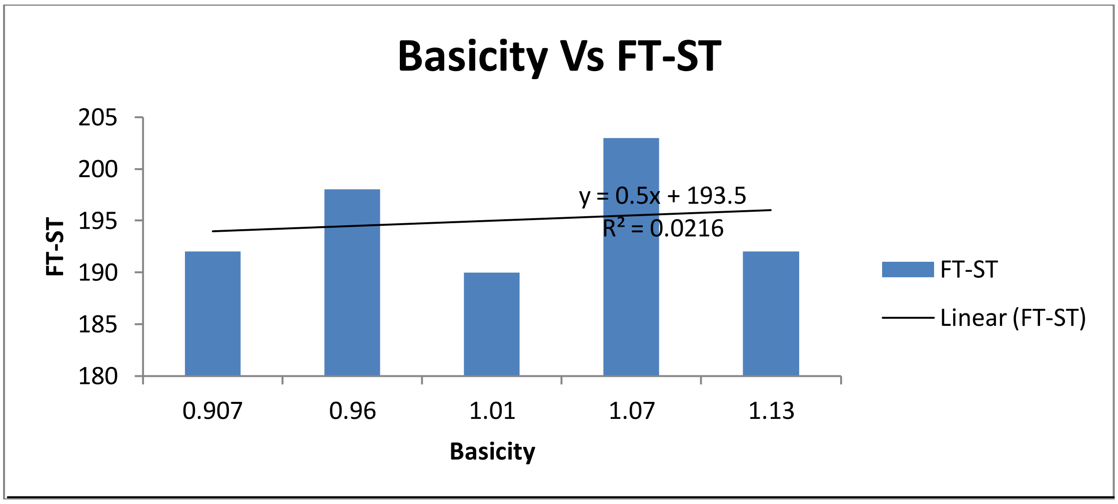


Figure-15: *Variation of Basicity with Difference of Flow Temperature and Softening Temperature. Here the Basicity is varied and MgO and Al_2O_3 are constant.*

This graph shows the variation of basicity with the difference between the flow temperature and the softening temperature (FT-ST). Here the Basicity is varied and MgO and Al_2O_3 are constant at 9.26 and 19.71 %. We can see here that there is a slight increase in the slope of the graph that shows that as basicity increases, the difference between the flow temperature and the softening temperature increases. Here the difference between the flow temperature and softening temperature determines the cohesive zone`s width and thus the cohesive zone width increases as the basicity increases with constant MgO and Al_2O_3. Here the minor constituent were also neglected so the inclusion of minor constituent can also change the graph accordingly.

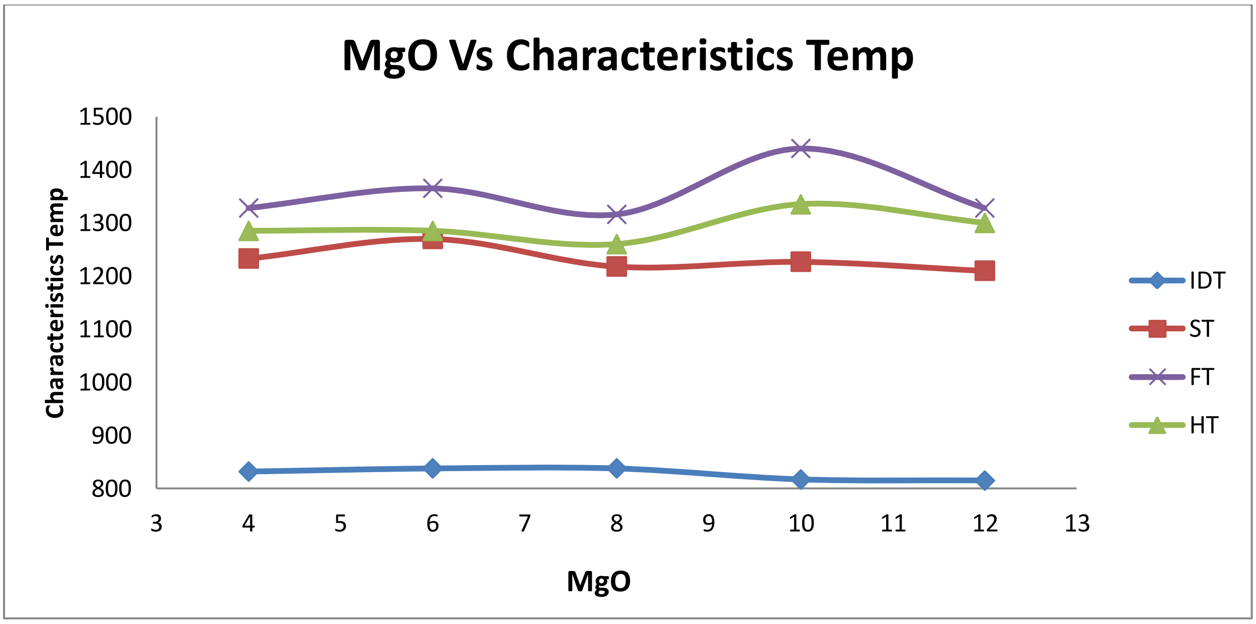


Figure-16*: Variation of MgO content with Characteristics temperature. Here the Slags have constant basicity with varying MgO content.*

This graph shows the variation of MgO and characteristics temperature of the slag. Here the basicity is kept constant at 1.1 and Al_2O_3 constant at 19.71 %. We can see here that as the MgO increases, the IDT, ST and FT decreases and there is increase in HT as the MgO content increases. Here the minor constituent were also neglected so the inclusion of minor constituent can also change the graph accordingly.

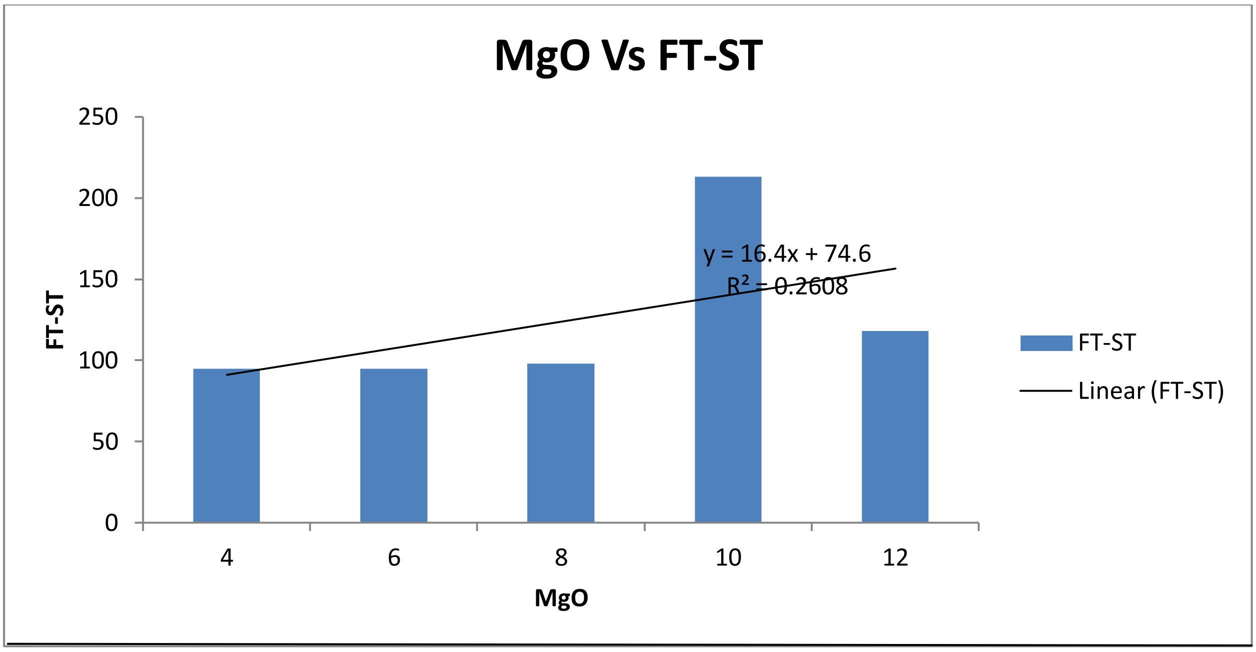


Figure-17*: Variation of MgO content with Difference of Flow Temperature and Softening Temperature. Here the Slags have constant basicity with varying MgO content.*

This graph shows the variation of MgO with the difference between the flow temperature and the softening temperature (FT-ST). Here the Basicity is kept constant at 1.1 and Al_2O_3 constant at 19.71 %. We can see here that there is just a very slight increase in the slope of the graph. We can see here that the trend is not that clear and so significant outcome was not determined. Here the minor constituent were also neglected so the inclusion of minor constituent can also change the graph accordingly. However, with further experimentation of slags with other variations of MgO, the trend can be made clear.

3.4.2. DISCUSSIONS

In Figure-14 the variation of basicity and characteristics temperature of the slag was shown. Here the Basicity is varied and MgO and Al_2O_3 are constant at 9.26 and 19.71 %. We can see here that as the basicity increases, the IDT, ST and FT decreases and there is increase in HT as the basicity increases. The increase in basicity increases the content of the basic oxides such as the CaO which breaks the silicate networks hence the fluidity of the slag increases hence there's a drop in the IDT, FT and the ST temperatures. However the temperature for the sluggish flow or the slow movement of the slag increases so the HT also increases. All the changes in the characteristic temperatures are in accordance with the theories related to the flow characteristic. [12], [13]

In Figure-15 the variation of basicity with the (FT-ST) was shown. Here the basicity is varied and MgO and Al_2O_3 are constant at 9.26 and 19.71 %. We can see here that there is a slight increase in the slope of the graph that shows that as basicity increases, the difference between the flow temperature and the softening temperature increases. This difference determines the cohesive zone`s width and thus the cohesive zone width increases. The ST decreases but the FT decreases mildly with increase in basicity so the observed trend is obtained; Hence, the 'shortness' of the slag decreases with increase in basicity.

The variation of the characteristics temperature with varying basicity is in relevant to the theory, but the second graph does now show much clear trend in accordance to the theory as the minor constituent was discarded and the MgO and Al_2O_3 were constant. With the change in the MgO and Al_2O_3 content and the inclusion of minor constituent, there can be a change in the trend that is observed.

In Figure-16 the variation of MgO and characteristics temperature of the slag is shown. Here the basicity is kept constant at 1.1(This basicity considered because of the observed best behaviour of slag at this composition according to theories and also from our obtained results.) and Al_2O_3 constant at 19.71 %. We can see here that as the MgO increases, the IDT, ST and FT decreases and there is increase in HT as the basicity increases. MgO acts as a network modifier and also the activation energy for the flow decreases on addition of MgO. Hence viscosity decreases with addition of MgO. As shown from the graph the IDT, ST and FT decrease with the addition of MgO.

In Figure-17 the variation of MgO with the difference between the flow temperature and the softening temperature (FT-ST) is shown. Here the Basicity is kept constant at 1.1 and Al_2O_3

constant at 19.71 %. We can see here that there is just a very slight increase in the slope of the graph. We can see here that the trend is not that clear and so significant outcome was not determined. In a generic sense there's not much significance on the shortness of the slag with increasing MgO content.

The variation of the characteristics temperature with varying MgO is in relevant to the theory. But as here the basicity was kept constant which if changed can affect the trend of the graph. Here the minor constituent were also neglected so the inclusion of minor constituent can also change the graph accordingly. With further experimentation of some different slags, the trend can be made clear for the case of the FT-ST with the MgO content.

CHAPTER-4

CONCLUSION

4.0. CONCLUSION

With our result obtained from our work, we deduce that with an appropriate selection of raw materials, desired slag can be obtained which leads to lower coke consumption and gives a greater control on metal composition by control of slag-metal reaction. [12], [13]

The future prospect of the project is to use the data provided and to alter the composition in the slag in order to lower the cohesive zone. This can be done by preparing synthetic slag of different composition and of different weight percentage and then studying their flow characteristics. The characteristics obtained should be compared with the slag from different steel plants of India. From the data obtained a related phase diagram should be deduced and then it should be used in lowering the difference between ST and FT and thus finding out the characteristics for a narrow cohesive zone. On the basis of final slag obtained, burden distribution will be formulated. Finally, we can arrive to a specific slag composition which will have some industrial significance.

Here we have found that the theoretical slags that were prepared synthetically in the laboratory with an idea of the industrials slags showed same behaviour as the industrial slag showed. So the theories studied were quite relevant and correct. From the obtained result and also from the theoretical consideration the slag of Basicity 1.1 with MgO-9.26 and Al_2O_3-19.71 composition is the best slag obtained. This composition is considered to be the best for the desired operation of the blast furnace. This simulation of primary slag is devoid of the iron oxides content to avoid complexity. The influence of the iron oxides in the primary slag on the blast furnace operations and various phenomena can be experimented and studied as a different segment of experimental work altogether. Thus this experimental work is dedicated to determine the flow characteristics of the oxide mix devoid of the real blast furnace conditions such as pressure and the interaction with gases and other materials to find out the optimized slag composition.

5.0. FUTURE PROSPECTS

The experimental work and the data obtained through it can be utilised for knowing the slag composition which is the best for the smooth running of the blast furnace increasing its productivity and also its efficiency. The results can be used for other experimental purposes such as taking the best slag composition to study its effect on the reduction of the iron oxides. This experiment is actually a simulation of the flow characteristics of primary slag of the blast furnace and an attempt at predicting the best slag through optimizing and analysing the result data.

6.0 REFERNCES:

1) Blast furnace Iron making by S. S. Gupta & A. Chatterjee.

2) Principle of Iron making By A.K. Biswas.

3) An introduction to modern Iron Making by Dr. R. H. Tupkary and V. R. Tupkary.

4) LEE, Y.S., KIM, J.R., YI, S.H. and MIN, D.J; "Viscous behaviour of CaO- SiO_2- Al_2O_3-MgO-FeO slag": *VII International Conference on Molten Slags Fluxes and Salts,* The South African Institute of Mining and Metallurgy, 2004.

5) Y.S.Lee, J.R.Kim, S.H.Yi and D.J.Min; "viscous behavior of CaO- SiO_2- Al_2O_3-MgO-FeO slag". Proceedings of VIII international conference on molten slag, fluxes and salts, The South African Institute of Mining and Metallurgy, 2004, p.225.

6) JIA, J.-Y., BAI, C.-G., QIU, G.-B., CHEN, D.-F., and XU, Y; "Calculation models on the viscosity of Cao- SiO_2- TiO_2 slag system", VII International Conference on Molten Slags Fluxes and Salts, The South African Institute of Mining and Metallurgy, 2004. 52

7) Kiichi NARITA, Shin-ichi INABA, Masakata SHIMIZU, Arata YAMAGUCHI, Isao KOBAYASHI and Ken-ichi OKIMOTO; "Burden and Gas Distribution Considering Blast Furnace Aerodynamics", ISIJ Journal, Vol.21 , No.6(1981)pp.405-413.

8) Yasuji kawai; “Viscosities of CaO- SiO_2-Al3O3-MgO Slags”, http://ir.library.tohoku.ac.jp/re/bitstream/10097/26544/1/KJ00004195839.pdf, retrieved on 04:05:10.

9) G. Danloy , J. Mignon , R. Munnix , G. Dauwels , L. Bonte; “A Blast Furnace Model to Optimize the Burden Distribution”, http://www.crm-eur.com/FPUBLICATIONS/media/BF_MODEL.pdf, retrieved on 04:05:10.

10) Paulo Nogueira, Richard Fruehen; “Blast Furnace Burden Softening and Melting Phenomena”- Part I Pellet Bulk Interaction Observation, Metallurgical and Materials Transactions B. Vol 35B, 2004, pp.829. 54

11) P.F.Noguira and R.J Fruehen; “Blast Furnace Softening and Melting Phenomenon” – Melting Onset in Acid and Basic Pellet:, IUSS-AIME Iron making Conference, 2002, pp.585.

12) U. K. Mohanty: Ph. Dr. Dissertation, R. E. College, Rourkela, (2000).

13) U.K. Mohanty, R.C. Behera: ISIJ Int., Vol. 43 (2003), No. 12.

14) IUPAC Compendium of Chemical Terminology, 2nd Edition, 1997

15) Noritaka Saito, Naoto Hori, Kunihiko Nakashima and Katsumi Mori, Metallurgical and Materials Transactions, Volume 34B, October 2003

16) Nakamoto Masashi, Tanaka Toshihiro, Lee Joonho and Usui Tateo, ISIJ International, Vol. 44, No. 12, 2004, pp. 2115-2119

17) Seok Seong-Ho, Jung Sung-Mo, Lee Young-Seok and Min Dong-Joon, ISIJ International, Vol. 47, No. 8, 2007, pp. 1090-1096

18) German Industrial Standard 51730

19) Taskanen P.A., Huttunen S.M., Mannila P.H. and Harkki J.J., *Ironmaking & Steelmaking*, 29, 2002, pp. 281-286

20) Muller M. Erwee, Southern African Pyrometallurgy, 2011

21) Osborn E. F. et al.,Process Blast Furnace, Coke Oven and Raw Materials Conference,1953

22) Snow R. B., Proc., AIME, 1962

23) Ohno A. and Ross H. U., Can. Metall. Q., 2, 1963, p 243.

24) Muller J. And Erwee M., Southern African Pyrometallurgy, 2011

25) Clixby G., Softening & Melting of super fluxed sinters and acid pellets, BSC, Ironmaking Session, Tesside Laboratories, International Report,1979

26) Shankar Amitabh, Gornerup Marten, Lahiri A.K, Seetharaman S., Experimental Investigation of the Viscosities in CaO- SiO_2-MgO-Al_2O_3 and CaO-SiO_2-MgO-Al_2O_3-TiO_2 Slags, Metallurgical and Materials Transactions B, 38 (6), pp. 911-915

27) B.Ozturk and R.J.Fruehan: "Kinetics of the Reaction of SiO (g) with carbon saturated Iron": Metall.Trans.B. Vol.16B, 1985, p.121

28) B.Ozturk and R.J.Fruehan: "The Reaction of SiO (g) with liquid slags": Metall.Trans.B. Vol.17B, 1986, p.397.

29) S.Z. Li, Jian Cheng, W.Q. Ma: 'a method to forcast the cohesive zone of the blast furnace' . Materials Science Forum, 2004, 471-472, 358