UNIVERSITEIT VAN PRETORIA
UNIVERSITY OF PRETORIA
YUNIBESITHI YA PRETORIA

AD DESTINATUM PERSEQUOR

OPTIMISATION OF THE GRAIN SIZE DISTRIBUTION OF THE RAW MATERIAL MIXTURE IN THE PRODUCTION OF IRON SINTER

By

ELIE LWAMBA

Submitted in partial fulfilment of the requirements for the degree

MEng (Metallurgical Engineering)

in the Department of Materials Science and Metallurgical Engineering,
Faculty of Engineering, Built Environment and Information Technology,
University of Pretoria, Pretoria

August 2007

ACKNOWLEDGEMENTS

Thanks to Lord Jesus Christ for helping me, giving me strength to face all adversity and to get to where I am.

To Professor Andrie, thank you for your guidance, patience and support.
To professor Chris Pistorius, thank you for advice and support.

To Mientjie, André for help and support in the pilot plant, thank you.
To my parents, thank you for your support throughout my studies.
To Julie my wife, all my children, Maryam, Glodi, Benedict and Renau, and all my brothers and sisters Renau, Venant, thank for your support.

OPTIMISATION OF THE GRAIN SIZE DISTRIBUTION OF THE RAW MATERIAL MIXTURE IN THE PRODUCTION OF IRON SINTER.

Candidate: Elie Lwamba
Supervisor: Prof: A.M. Garbers-Craig
Department: Department of Materials Sciences and Metallurgical Engineering.

ABSTRACT

The main purpose of this study was to optimise the grain size distribution of the raw material mixture for the production of iron sinter. It well known that the constitution of the sinter mix is based on the knowledge of chemical composition and grain size distribution. Although Mittal Vanderbijlpark has fixed specifications on the physical and chemical properties of the sinter for optimal blast furnace performance, the particle size distribution of the sinter mix has not yet been optimized. This was achieved by using the granulation characteristics of the sinter mix and the green bed permeability tests. The influence of the moisture content of the feed, granulation time, and mean granule diameter on permeability was investigated on Thabazimbi and Sishen iron ore, as well as on their mixture with fluxes and without fluxes. The iron ore results indicated that the mixture containing 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes where the coke, lime and return fines were sized by removing the – 0.5 mm size fraction of the return fines and coke, and the 1 mm size fraction of lime has the highest permeability of all the studied mixtures.

ABSTRACT

The sintering properties of the mixtures of optimised grain size distributions were also investigated and the results were very similar for all the mixtures and better than the base case mixture, which was not optimised with respect to grain size distribution.

Keywords: Thabazimbi iron ore; Sishen iron ore; sieve analysis; Granulation, Permeability, Sintering.

CHAPTER I. INTRODUCTION.

In the majority of production processes, particle size distribution of the raw materials has an influence on the properties of the product. This also pertains to iron sinter, which is constituted of a mixture of raw materials, namely iron ore, fluxes, coke breeze, limestone, lime, dolomite, and return sinter fines, all having various size distributions.

Currently Mittal Vanderbijlpark uses Thabazimbi and Sishen iron ore in the production of sinter. During the crushing of iron ores a great percentage of fine particles are produced. Due to their detrimental influence on the permeability and flow distribution within the blast furnace and their losses in the off-gas, fine ores are not used directly in the blast furnace, but they undergo initial agglomeration through pelletising or sintering, before they are charged into the blast furnace [1].

Due to its better metallurgical and physical properties than pellets and lump ore, iron sinter is today the major source of iron in the burden to the modern blast furnace [2,3]. The raw materials are blended and subjected to granulation, which consists of homogenisation in a rotary drum for a few minutes with the addition of water. The resulting granules are layered in a bed on a moving strand and ignited for sintering. A number of physical phenomena take place during sintering. These include heat exchange between gases and solids, drying and condensation of moisture, combustion of coke, calcination of limestone, and melting, reaction and solidification of feed constituents. The process continues until the whole bed is converted into a porous sintered mass called sinter, which is crushed to obtain the burden of required size distribution for the blast furnace. The undersize sinter fines are recycled back to the granulation drum [2,4,5].

The sinter productivity and quality are strongly dependent on the green permeability of the bed, which is determined by the particle size distribution of the raw materials, the optimum moisture content, the granulation effectiveness, and by the sintering process itself [3,5,6].

A large amount of research has been done on the optimization of the particle size distribution of fluxes, especially the coke breeze and limestone to improve the quality and productivity of sinter [7]. It was concluded that the sintering process is improved when coarse particles of coke and limestone with low proportions of coke breeze fines are used. The combined use of 5-1 mm limestone and 5-0.5 mm coke breeze improves the granulating ability of raw mix components and enhances the productivity of the sintering machine [8].

Although Mittal Vanderbijlpark has fixed specifications on the physical and chemical properties of the produced sinter for optimal blast furnace performance, the particle size distribution of the sinter mix has not yet been optimized. Therefore, the main purpose of this study was to optimize the particle size distribution of the iron ore in the raw material mixture in order to produce a desired sinter.

CHAPTER II. LITERATURE REVIEW.

II.1 Particle size analysis.

II.1.1 Introduction.

Particle size analysis is a process in which the proportion of material of each grain size range present in a given material is determined. The aim of particle size analysis is to determine the particle size distribution of a given material and the optimum size of the feed to the process for maximum efficiency. In mineral processing the quality of grinding is determined through a particle size analysis [9,].

II.1.2 Particle size.

The particle size distribution is very important in many industries and must be controlled from the raw material source to the finished product. The properties of many materials depend on its particle size distribution. It well known that, only the size of regular geometric shapes can be measured such us a cube and a sphere. The exact size of an irregular particle cannot be measured, as the majority of particles are quite irregular.

It is necessary to adopt an approximate description to define the size of the irregular particle [10]. Many researchers assume irregular particles to be spherical in most calculations. Because the sphere can be described by its diameter, therefore the irregular particle can be defined in converting the volume or the weight of the particle into the volume or weight of an equivalent sphere by the formula below [11]:

- Volume = $4/3\ \pi\ (D/2)^3$.
- Weight = $4/3\ \pi\ (D/2)^3\ \rho$.

Where, D is the diameter of the equivalent sphere. The diameter of an irregular particle can be defined either in terms of the geometry of individual particles or in terms of their physical properties.

In the first case, dimensions of a large number of particles are measured. Diameters obtained by microscopy or sieving are of this type, and in the second case, sedimentation methods are used to determine the diameters of the particles. The most typical equivalent diameters are listed in Table I.

Table 1 Most typical spherical equivalence diameters (d) [11].

Symbol	Name	Definition	Formula
d_v	Volume diameter	Diameter of sphere having the same volume as the particle	$V = (\pi/6)d_v^3$
d_s	Surface diameter	Diameter of sphere having the same surface as the particle	$V = \pi d_s^3$
d_{sv}	Surface volume diameter	Diameter of sphere having the same external surface to volume ratio as a sphere.	$d_{sv} = d_v^3/d_s^2$
d_f	Free- falling diameter	Diameter of sphere having the same density and the same Free-falling speed as the particle In a fluid of the same density and viscosity.	
d_{st}	Stokes' diameter	The free-falling diameter of a particle in the laminar flow region (Re<0.2)	$d_{st}^2 = d_v^3/d_d$
d_A	Sieve diameter	The width of the minimum square aperature through which the particle will pass	
d_a	Project area diameter	Diameter of circle having the same area as the projected area of the particle resting in a stable position.	$A = (\pi/4)d_a^2$

II.1.3 Average particle size.

The particle size measurement results are reported in the form of a particle size distribution. The purpose of an average is to represent a group of individual values in a simple manner in order to obtain an understanding of the group. It is important, therefore, that the average should be representative of the group. All average diameters are measures of central tendency which is unaffected by the relatively few extreme values in the tails of the distribution [11]. The most common type of diameter used in the sintering process is the mean diameter, which is calculated by averaging the mean or equivalent diameters of a number of particles. The following mean diameters are defined [11]:

-Arithmetical mean	$D_A = (d_1 + d_2)/2$
-Geometrical mean	$D_G = \sqrt{d_1 d_2}$
- Laschinger's mean	$D_E = (d_1 - d_2)/(\ln d_1 - \ln d_2)$
- Mellor's mean	$D_M = \sqrt{(d_1 + d_2)(d_1^2 + d_2^2)/4}$
- Mean of form	$D_F = 4(d_1^5 - d_2^5)/5(d_1^4 - d_2^4)$
-Von Reytt's mean	$D_R = 0.435(d_1 + d_2)$
- Number mean	$D_N = \Sigma nd/\Sigma n$
- Length mean	$D_L = \Sigma nd^2/\Sigma nd$
- Surface mean	$D_S = \Sigma nd^3/\Sigma nd^2$
- Volume mean	$D_V = \Sigma nd^4/\Sigma nd^3$
- Harmonic mean	$D_H = \Sigma n/[\Sigma(n/d)]$

Where D is the mean diameter, d_1 and d_2 are the maximum and minimum mean particle diameters, respectively; d represents the successive mean particle diameters in a sizing operation, and n the numerical frequency of the corresponding d.

II.1.4 Particles size measurement techniques.

Various techniques are used to analyse particle size. These techniques depend of the size of the particle and the information needed from the particle. Some of the more common techniques for measuring the particle size distribution together with their effective size ranges are given in the table below. [10]

Techniques	Approximate useful range (microns)
Sieving	100.000 → 10
Elutriation	40 → 5
Microscopy (optical)	50 → 0.25
Sedimentation (gravity)	40 → 1
Sedimentation (centrifugal)	5 → 0.05
Electro microscopy	1 → 0.005

II.1.4.1 Sieving.[10,12,13,14,]

Sieve analysis is the most fundamental and widely used method for determining the size of particles. This method consists of separating a given sample into different size fractions. It involves passing the material being sized through openings of a particular standard size in a screen. It classifies material according to their physical size by using a series of woven wire or punch plate sieves arranged in decreasing order of aperture size. In other words, the ratio between successive sieves is kept as a constant such as $\sqrt{2}$ and hence the sieve varies in geometric progression. The material to be tested is placed in the uppermost, coarsest sieve, and the nest is then placed in a sieve shaker, which vibrates the material for a fixed time.

During the shaking, the undersized material falls through successive sieves until it is retained on a sieve having apertures, which are slightly smaller than the diameter of the particles. In this way the sample is separated into size fractions. The amount of material present in each sieve is then weighed and the values are converted into percentage of the total sample and than tabulated along with their corresponding sieve opening.

II.1.4.2 Sedimentation and Elutriation. [10,12,14]

Sedimentation and elutriation are used to analyse fine particles by the method called hydrometer analysis. This method of analysis is based on Stokes' law, which relates the terminal velocity of a sphere falling freely through a fluid to the diameter. The relation is expressed according to the equation [11]:

$$v = [(\rho_s - \rho_f)/1800\eta] \times D^2$$

Where: v = terminal velocity of sphere, cm per second.

ρ_s = density of sphere, g per cm^3

ρ_f = density of fluid, g per cm^3

η = viscosity of fluid, g-sec per cm^2

D = diameter of sphere, mm

The hydrometer method of analysis is used to determine the percentage of dispersed particles remaining in suspension at a given time. The maximum grain size equivalent to a spherical particle is computed for each hydrometer reading using Stokes' law.

It is assumed that Stoke' law can be applied to a mass of dispersed particles of a given material having various shapes and sizes.

II.1.4.3 Optical microscopy. [10,14]

Optical microscopy is an old technique for particle sizing that is still being used to a considerable extent, in spite of the fact that, unless automatic or semi-automatic methods are used, the procedure may be very tedious. This method measures the particle size by interaction of the particle with light. The particles shapes can be observed, often leading to particle identification. The amount of sample required is small.

II.1.4.4 Electro microscopy. [10, 14]

In this technique, we find the Scanning Electron Microscopy (SEM) and Transmission Electron Microscopy (TEM). Scanning Electron Microscopy (SEM) analysis provides highly detailed information about not only particle size, but also particle shape, surface texture and chemical composition, and at resolutions not approachable by other techniques. Transmission electron microscopy (TEM), which measures the transmitted electron beam after it passes through the sample, is applicable for particle sizing in the extreme lower size limit, below 0.2 µm, although much of the three dimensional information is lost in this case.

II.1.5 Presentation of results. [10]

Generally the results of sieves analysis and hydrometer analysis are presented in the form of a table or as a plot of quantity of particle retained or passing in percentage versus particle size, as respectively shown in Table 2 and Figure 1.

Table 2 shows:

1) The sieve range used in the test.
2) The weight of material in each size range.
3) The weight of material in each size range expressed as a percentage of a total weight
4) The nominal aperture sizes of the sieves used in the test.

5) The cumulative percentage of material passing through the sieves.
6) The cumulative percentage of material retained on the sieves.

Table 2. Results of a typical sieve test. [10]

1 Sieve size Range (μm)	2 Sieve fractions wt (g)	3 %wt	4 Nominal aperture size (μm)	5 Cumulative % undersize	6 Cumulative % oversize
+250	0.02	0.1	250	99.9	0.1
-250 +180	1.32	2.9	180	97.0	3.0
-180 +125	4.23	9.5	125	87.5	12.5
-125 +90	9.44	21.2	90	66.3	33.7
-90 +63	13.10	29.4	63	36.9	63.1
-63 +45	11.56	26.0	45	10.9	89.1
-45	4.87	0.9			

A graphic method gives a better interpretation of sieve data. Graphs can be presented in the form of either a histogram where the percentage of the sample in each class can be shown graphically or in a cumulative curve, which consists of a plot of cumulative undersize (or oversize) against particle size. Data are conventionally presented by plotting particle size horizontally (x-axis) and the measured quantity vertically (y-axis). Also the statistical method has been developed for the interpretation of the sieve data. In this method, the simplest is the measurement of the central tendency of which there are three commonly used parameters: The median particle size is that which separates 50% of the sample from the rest; the median is the 50% percentile. The mode is the largest class interval. The mean is defined in different ways, but the most common formula is the average of the 25 and 75 percentiles. In the cumulative curve method, data of the particle size analysis can be plotted on either arithmetic graph paper, or semi-logarithmic or logarithmic paper.

Although arithmetic graph paper can be used, it suffers from the disadvantage that points in the region of the finer aperture sizes tend to become congested. A semi-logarithmic plot avoids this, with a linear ordinate for percentage oversize or undersize and logarithmic abscissa for particle size. Figure 1 shows graphically the results of the sieve test tabulated in Table 2.

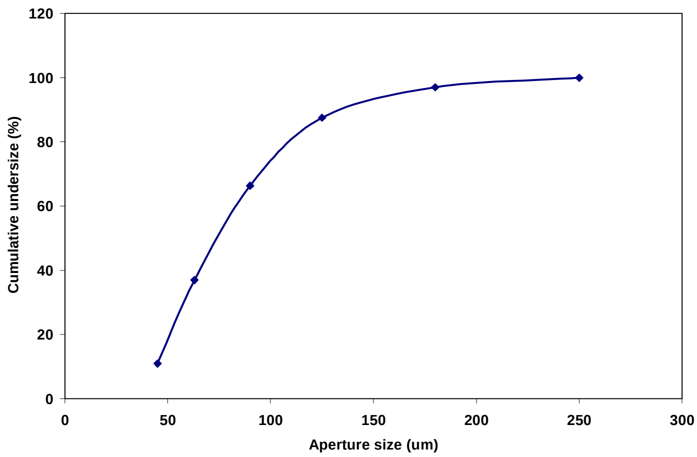


Figure 1. Cumulative Arithmetic Graph

Different functions have been presented to describe the size distribution of particles in the aim to obtain a linear distribution curve. Table 3 shows the common functions used for linearization of particle size distributions. Symbols n, s, and S are constants and d, d* are diameters.

Table 3. Functions used for linearization of particle size distributions.

Name	Σλ (%)=%passing a given d	Meaning of d*
Rosin-Rammeler	$1-\exp[-(d/d^*)^s]$	d value at Σλ = 0.632
Gates-Gaudin-Schumann	$[d/d^*]^n$	Maximum d value
Harris	$1-[1-(d/d^*)^S]^n$	Maximum d value.

II.2 Sintering process.

II.2.1 Introduction.

Sintering is an agglomeration process that involves the heating of a mixture of iron ore fines and fluxes. The heating and sintering process are promoted by coke combustion.

The sintering process can be classified in two parts:

- Cold or wet processing stage, (blending and granulation), and
- Thermal or sintering stage.

The two stages are linked by the fact that the sinter productivity and quality are strongly dependent on the permeability of the bed during sintering, which is determined, in the first instance, by the structure of the bed before its ignition [2].

II.2.2 Cold or wet processing stage.

III.2.2.1 Granulation

In the sintering process granulation is an important step because it determines bed permeability, which in turn determines sinter productivity [3]. The main purpose of granulation is therefore to improve the permeability of the bed, which will enhance the flow characteristics of the combustion air through the sinter bed. A sinter feed consists of iron ores, fluxes, coke breeze, and other raw materials such as plant dusts. The size of these materials may range from very fine particles [> 0.075 mm] to coarse particles

[(1 - 12.5) mm]. The sinter feed components are mixed together and water is added to the mixture in the drum and then granulated into pseudo-particles in a rotary mixer for a few minutes. The addition of water to the drum provides the driving force for granulation. The objective is to layer the fine particles onto coarse particles, which act as nuclei. [6]

In this way granulation is defined as the process where by fine particles (<0.25mm) adhere onto the surface of large particles (>0.75mm), and quasiparticles form [6]. Particles of > 0.75 mm act as nuclei while particles of < 0.25 mm act as adhering fines [6]. Intermediate particles are difficult to granulate and do not have a well defined role. When the water content added to the ore mixture during granulation is increased, the intermediate particles adhere to the coarser nuclei but become detached during drying. [15] The amount of intermediate particles needs to be minimal since it affects the permeability in two ways [15,16]

- As nuclei these particles reduce the size of the quasiparticles, and thus lower the permeability of the bed, and
- As adhering fines, they are poorly bonded and easily separated from the dry particles.

The three factors that control the growth of the adhered fines layer on a nucleus are the structure of the nucleus (surface area, porosity), the moisture content, and the amount of fines present. [15]

The moisture content in the ore is a very important parameter in the granulation stage in sintering. The process of adhering fine particles to nuclei, to form quasiparticles, is very strongly influenced by the moisture available for granulation, the granulation time, and the properties of the raw material mixture. Kumba pilot plant uses the following parameters to judge the granulation effectiveness [9]:

- Granulation index (G.I.) expressed by the following formula:

$$\frac{\{\%\text{Mass } [0.25\text{mm(true particle size)}] - \%\text{Mass } [0.25\text{mm(quasi-particle size)}]\}}{\{\%\text{Mass } [0.25\text{mm(true particle size)}]}$$

The granulation index is considered acceptable if it converges towards 200.

- Granulation diameter (G.D.) expressed by the following formula:

$$\frac{\text{Dp (true particle size)}}{\text{Dp (quasi-particle size)}}$$

The granulation diameter must be less than 1.

- Diameter of particle dry mix (D_p-dry mix) expressed by the following formula:

$$\sum D_p \text{ (lin)[true particle size]}$$

- Diameter of particle wet mix (D_p-wet mix) expressed by the following formula:

$$\sum D_p \text{ (lin)[quasi-particle size]}$$

- Percentage of Moisture: expressed by the following formula:

$$\frac{(\text{Wet mass} - \text{Dry mass})}{\text{Wet mass}} \times 100$$

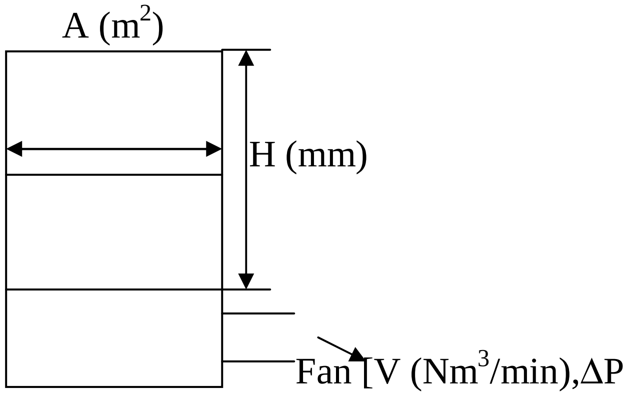
Kumba considers a quasi-particle size to be the size of the particles in the granulated sample after granulation and a true particle size as the quasi-particle dried in the oven at 110^{o}C for 2 hours.

III.2.2.2 Permeability.

The term permeability is widely used in engineering to denote the ease of fluid flow through a particulate bed. The permeability of a sinter bed plays a vital role in controlling sinter properties and productivity, since it governs the bed- temperature profile by determining the gas flow rate through the bed.
Green bed permeability can be characterized by the relation [2,3,17,18]:

$$\mathbf{P = v\,(H/\Delta P)^{0.6} \qquad v = V/A}$$

Where P is the bed permeability, V is the air flow rate, A is the area, H is the height of the bed, v is the superficial velocity i.e. the average linear velocity that the air would have in the column if no packing were present, and ΔP is suction applied across the bed.



(mmH_2O)]

Figure 2. Schematic diagram of the permeability test.

P is traditionally expressed in British Permeability Units (BPU), but there is a tendency to use the Japanese Permeability Unit (JPU) in more recent literature[4]. Permeability is controlled through the control of the following parameters.

- Bed height.
- Airflow rate
- Moisture.
- Granule size.

Table 4. Units of green bed permeability [17]

Units	BPU	JPU
v	ft/min or mm/s	m/min
H/ ΔP	inches bed/inches water gauge	mm bed/mm water gauge

II.2.3 Thermal or sintering stage.

After granulation the granules formed are loaded onto a grid layer of coarse sinter (-40 +20) mm in sinter cars on the sinter machine. The height of the packed bed varies from process to process and can be up to 600 mm in height [6]. The bed immediately passes under an ignition hood where the fine coke in the surface layer is ignited by gas flames. As the sinter cars move forward, combustion is promoted by air drawn through the sinter bed in a series of wind boxes under the sinter bed. The pressure drop over the sinter bed can be up to 2000 mmH_2O [6]. During the sintering process the temperature of the granulated sinter mixture is raised to temperatures between 1050 and 1400^{o}C in order to achieve partial melting and produce a semi molten material.

This material is subsequently cooled and cristallises into several mineral phases of different chemical and morphological compositions: mainly hematite, magnetite, silicoferrite of calcium and aluminum (SFCA) and calcium silicates. The sinter is either cooled on the sinter strand (on strand cooling) or outside the sintering machine (off strand cooling). The sinter is crushed and screened to a size of - 40 + 10 mm for use in the blast furnace, and the size fraction of – 10 mm is recycled back to granulation [6]. The process energy is supplied by the combustion of the coke.

The factors that affect sintering and the quality of the sinter product are:

- The size and composition of the granules.
- The size and composition and relative properties of the mixture components (iron ores, fluxes and coke)
- The mineralogical structure of the ore mixture components and
- The thermal profile of the process.

II.2.4 Sinter properties.

Sinter properties refer to its physical and metallurgical properties. The most important characteristics of a sinter are defined as a combination of the following properties:

- The cold strength
- The Reducibility of the sinter (RI)
- The reduction disintegration index (RDI).
- The high temperature properties using the REAS test.

II.2.4.1 Cold strength. [19,20,21]

Cold strength determines to what extent sinter will maintain its size during different handling operations from the sinter plant to the blast furnace.
The cold strength of the sinter is controlled by:

- The micro cracks: These are either present in the original ore particles or formed in
  the bonding phases during cooling of the sinter.
- The individual mineral components
- The open porosity
- The strength of the individual bonding phases,
- The amount of glass formed as bonding phase.
- Ultrafine particles.

Test procedure.

According to ISO 3271, a test portion of 15 kg of – 40 + 10 mm size fraction is tumbled in circular drum having 1000 mm as internal diameter and 500 mm as internal length at 25 rpm for 200 revolutions, followed by sieving on test sieves of 6.3 mm and 0.5 mm.

The tumble Index (TI) and the Abrasion Index (AI) are calculated as follows:

- **$TI = (m_1/m_O)$ x100** (% + 6,3 mm material after tumbling)

The tumble index (T.I) is a relative measure of the resistance of sinter to breakage by impact and abrasion.

The tumble index is expressed as the percentage of the +6.30 mm fraction remaining after the tumble test. A tumble test greater than 70% is considered to be an acceptable index for iron sinter.

- **$AI = [m_O - (m_1 + m_2)/m_O]$ x100** (% - 0.5 mm material after tumbling)

The abrasion index (A.I) is a relative measure of the size degradation of the sinter by means of abrasion. The abrasion index is expressed as the percentage of the - 0.5 mm fraction present after the tumbler test. An abrasion index smaller than 5% is considered to be an acceptable index for iron sinter.

Where:

m_O = mass of the test portion, in kg, weighed and placed in the tumble drum.

m_1 = mass of + 6.30 mm fraction of the tumbled test portion in kg.

m_2 = mass of - 6.30 mm +0.5 mm fraction of the tumbled test portion in kg.

II.2.4.2 Reduction disintegration index.

The reduction disintegration index (R.D.I) is defined as a quantitative measure of the degree of disintegration, which could occur in the sinter in the upper part of the blast furnace after some reduction.

The reduction degradation index of a sinter is controlled by [20]:

- The amount of relict hematite, as well as rhombohedral hematite found in a sinter.
- The amount of MgO and magnetite.
- Porosity.

Test procedure

According to the ISO 4696-1 test procedure, a test portion of 500 g of –12.5 + 10 mm is subjected to static reduction at a temperature of 500°C for one hour using a reducing gas consisting of:

CO: 20%(V/V) ± 0.5%(V/V).
CO_2: 20%(V/V) ± 0.5%(V/V).
H_2: 2.0%(V/V) ± 0.5%(V/V).
N_2: 58%(V/V) ± 0.5%(V/V).

The test portion is cooled to a temperature below 100°C and tumbled in a circular drum at 30 rpm for 300 revolutions. The test portion is then sieved with test sieves, which have square mesh apertures of 6.30 mm, 3.15 mm, and 0.5 mm.
The reduction degradation index (RDI) is calculated as follows:

- **$RDI\text{-}1_{+6.3} = m_{+6.3}/m_0 \times 100$**
- **$RDI\text{-}1\text{-}_{3.15} = \{[m_0 - (m_{+6.3} + m_{+3.15})]/m_0\} \times 100$**
- **$RDI\text{-}1\text{-}_{0.5} = \{[m_0 - (m_{+6.3} + m_{+3.15} + m_{+0.5})]/m_0\} \times 100$**

Where: - m_0 = mass in grams of the test portion after reduction and before tumbling.
- $m_{1,\,2,\,3}$ = mass in grams of the oversize fraction retained on the 6.30, 3.15, 0.5 mm sieves respectively. Kumba Iron Ore requires that the reduction disintegration index $RDI\text{-}1_{-0.5}$ should be below 5% and $RDI\text{-}1_{+3.15}$ above 70%.

II.2.4.3 Reducibility.

The reducibility index (R.I) is used to evaluate the behaviour of sinter under specific conditions such as: isothermal reduction, reduction in a fixed bed and reduction by means of carbon monoxide.

It is the ease with which oxygen combined with iron can be removed from natural or processed ores.

It depends on the gas accessibility, sinter basicity (CaO: SiO2) [20]. It is done according to the ISO 4695:1995(E) test procedure. In a fixed bed at 950^{o}C, using a reducing gas composition consisting of 40% v/v of CO and 60 % v/v of N_2, a test portion of –12.5 + 10 mm is reduced isothermally. The test portion is weighed at specific time intervals, from which the weight loss is determined.

The reducibility is calculated as follows:

- Degree of reduction. [22]

$$Rt = 0.111w_1/0.430w_2 + [(m_t – m_0) x 100]/0.430m_0w_2$$

Where:

- m_0 = mass of sample before reduction.
- mt = mass of test sample after reduction time t
- w_1 = Iron (II) oxide as % by mass of test sample before test.
- w_2 = total iron content as % by mass of the test sample before test.

- Reducibility Index

$$[dR (O/Fe – 0.9)]/dt = 33.6/(t_{60} – t_{30})$$

Where:

- T_{30} = time to attain 30% degree of reduction.
- t_{60} = time to attain 60% degree of reduction.

The reducibility index should be evaluated along with the results of other tests like the reduction degradation index. The reducibility index is directly related to sinter basicity and increases with increasing basicity. For a basicity of between 1.6 and 2.4, the reducibility index of between 0.95 and 1.2 are expected [22].

II.2.4.4 High temperature properties.

High temperature properties of sinter are evaluated using the REAS test where, a high temperature reduction simulates the blast furnace process from stock line to melting. It is mainly influenced by the melting temperature of gangues minerals and the amount of FeO produced during reduction [21].

The REAS test provides [23]

- An insight into the reactions occurring during the softening and melting processes.
- A range of indices with which to judge the blast furnace performance.

Test procedure.

- A test portion is subjected to blast furnace conditions by increasing its temperature from room temperature to 1600 ^oC in 8 hours.
- Simulation of ideal gas composition and temperature.

Several indices are used to characterise the high temperature properties of a blast furnace charge. Among them are: [23, 24]

- The cohesive and softening zone

The cohesive zone is defined as the area between the melting and softening temperatures (MT-ST) while the softening zone is defined as the area between the dripping and softening temperatures. The cohesive zone should be small but at a high temperature.

- Maximum pressure drop over the sample bed. (ΔP_{MAX})

The gas pressure drop across the bed increases as the sample softens. The temperature where the maximum pressure drop occurs is recorded as well as the value of the pressure drop.

- Softening temperature (ST)

The temperature where a pressure drop of 100 mmH_2O is recorded is taken as the softening temperature (Figure 3).

- Melting temperature (MT)

The Melting temperature is defined as the temperature where the pressure drop recovers to 100 mmH_20 and lowers after dripping has occurred (Figure 3).

- Dripping temperature. (DT)

There are three different temperatures at which this index can be determined:
First mass recorded on scale.
Endothermic drop i.e. a drop in the sample temperature occurs.
Pressure drop decreases to below 100 mmH_20.

- Relative dripping mass.

The relative dripping mass is a function of the total mass of the sample and is calculated after the test has been completed**.**
%Rel Drip Mass = [(Total Drip Mass/(Sample mass – Removable O_2)]x100

- Compaction.

The percentage compaction is the compaction at a certain time relative to the total compaction at the end of the test and is calculated as follows:
% Compaction = (X/Total compaction) x100
Where: X = Compacting at any stage during the test.
Total compaction = compaction at the end of the test expressed in mm.

- Viscosity

The area under the pressure drop versus temperature curve between the softening and the melting temperatures (Figure 3) gives the measure of viscosity [23].

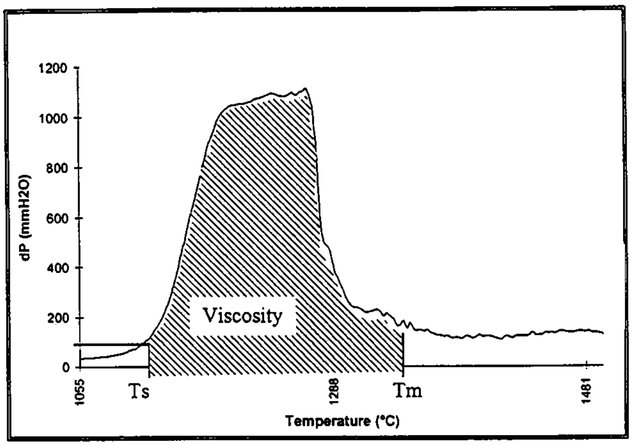


Figure 3. Determination of the viscosity between the softening (Ts) and melting temperatures (Tm)

II.2.5 Aim of the study

The iron ore constitute the big part of raw material mixture for the production of iron sinter. Many study have been investigated the influence of particle size distribution of fluxes, especially the coke breeze and the limestone and the influence of very fine particles of iron ore to the sinter quality. It was been observed that the varying in size distribution in size distribution of coke breeze and limestone has an influence on sinter properties, in improving the granulating ability of raw materials mixture, shortens the sintering time and enhances the productivity of the sintering machine. The majority of results Converge to the conclusion that, the use of coarse particle breeze will not burn out until passing the sintering zone and the use of fine particles will burn prematurely and lead to excessive CO formation in off gas. But size between 0.5-4 mm is considered as optimum for coke breeze, while + 1 mm fraction of limestone is considered optimum [8]. The use of very fine particles of iron ore has an influence on sinter strength [19]. It will be assumed that the size distribution of raw material mixture can influence the sinter properties. Therefore the aim of this study was to optimise, the particle size distribution of the iron ore in the raw material mixture.

CHAPTER III. EXPERIMENTAL

III.1 Materials.

The raw materials used in the sintering experiments were Thabazimbi, Sishen, and Phoenix iron ore, Return fines, Coke, Lime, Silica, water and ferric chloride. Representative samples of raw materials were prepared for sieves analysis, determination of very fine particles, granulation, and for the sinter pot test.

III. 2 Unit operations.

III.2.1 Sieve analysis.

Particle size distribution was determined by sieves analysis. The amount of sample to be sieved depended on the operation. The sample weight used for the sieve analysis was 4 kg for the determination of very fine particles and 10 kg for granulation. With the aim of obtaining a representative sample for sieves analysis, the sample was emptied from the 18 kg sample bag into one of the riffle pans. The material was then poured through the sample splitter by slowly tilting the pan so that the material flowed in an even stream over the width of the pan. One of the samples produced was then weighed. If the desired weight was not reached the operation was repeated by taking either the weighed sample and splitting it again if it was too heavy or by adding two of the produced samples together if the weight was too low. The particle size distribution of the representative sample was determined by using a series of standard sieves with openings ranging from 12.5 to 0.045 mm, including a cover plate and a bottom pan. The screens of the sieves were cleaned with a soft wire brush before they were placed on the sieve-shaking machine. The sample was poured onto the top sieve and then shaken for 10 minutes. After the operation each sieve fraction was weighed.

Another apparatus used in the sieves analysis was an oven for the drying of wet samples from sieves analysis under wet conditions and sieves analysis of granules frozen with liquid nitrogen. The sieve analyses of all the raw materials used in this study are given in Appendix I.

III.2.2 Blending.

The raw materials for this study that were used for the measurement of size distribution and granulation characteristics were mixed in a rotary drum for 20 seconds.

III.2.3 Granulation and Permeability.

Granulation characteristics and permeability tests were very important in this study, because the optimisation of the grain size distribution of the raw materials mixtures were based on these tests results. Granulation tests were carried out in a drum, which has a diameter of 51.5 cm and is 50 cm in height, at a constant rotational speed of 26 rotations per minute. The granulation characteristics of Thabazimbi iron ore, Sishen iron ore, their mixture without fluxes, and finally the optimised mixture without fluxes blended with fluxes were examined. The composition of the optimised mixture with fluxes was calculated taking into account the sinter specifications target of CaO= 9.52 mass %, SiO_2 = 5.00 mass % and MgO = 3 mass %.

The influence of moisture content and granulation time on the permeability and mean granule diameter was investigated. These experiments were conducted by using 10 samples of 10 kg (dry basis) of each raw material mixture under study. The procedure involved varying the moisture content of the mixture while keeping the time constant (5 samples), and then the effect of granulation time on permeability at optimum moisture content (5 samples). The aim of this part of the study was to find the optimum moisture content and the optimum granulation time for each raw material mixture, which yields the maximum pre-ignition permeability.

After granulation part of the granulated sample, approximately 4 kg was used for a permeability test. A pot of 0.595m in height and 0.142 m inside diameter was used to measure the permeability. Figure 4 shows the schematic view of the pot test apparatus. The permeability was calculated in terms of the Japanese Permeability Unit (JPU) by taking the average of 3 measurements of pressure drop for different flow rates at the venturi, at the top and at the bottom. For each moisture content tested (H) there was a related permeability value (P). The highest value of permeability is the maximum permeability, and the associated moisture is the optimum moisture content. The same applies to the maximum time that is associated with the maximum permeability.

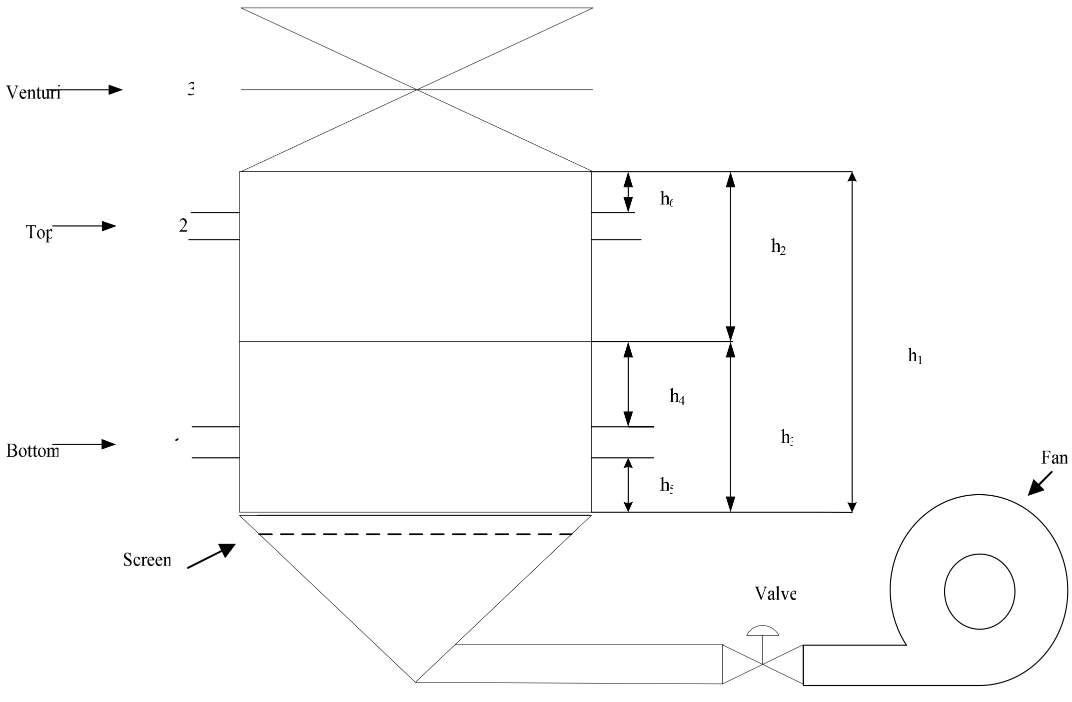


Figure 4. Schematic view of the experimental apparatus in which the permeability was tested.

On the schematic view of the experimental apparatus, 1,2,3 represent respectively the measuring points of suction pressure at the bottom, top, and the venturi.

Table 5. Specifications of the permeability apparatus

Height (m)	Values (m)	Meaning
h_1	0.595	Total available height from the top to the screen.
h_2	± 0.450	Depth of charge after filling.
h_3	$h_1 - h_2$ ± 0.145	Bed height.
h_4	h_3- h_5 ± 0.130	Effective bed height, from top of bed to bottom measuring point.
h_5	0.015	Height difference between screen to lower measuring point.
h_6	0.06	Height difference between Venturi to top measuring point.

Although the total available height of the permeability pot was 0.595m(h_1) the height of the sample to be tested after filling was ± 0.145 (h_3). The bed height used in the formula of permeability (JPU) is the effective bed height (h_4), which is the height from the top of the bed of the sample to measuring point 1 at the bottom (Figure 4). The effective bed height was approximately 0.130 m. At the bottom of the apparatus of the permeability test, a screen of 1 mm was placed, to allow suction through the sample bed, but to avoid the sample to be sucked by the airflow through the pipe to the exhaust. The diameter of the venturi was 0.0444 m and the diameter of the pipe was 0.140 m in the first test done on Sishen iron ore and Thabazimbi iron ore. In the rest of the tests a venturi having a diameter of 0.025 m and a pipe of 0.142 m were used.

A portion of granulated sample was frozen with liquid nitrogen, in order to perform a sieve analysis on the granules, whereby the material transfer between granulometric classes was studied by comparing the size distribution before and after granulation. This was done by placing 500- 700g of granulated mixture on a metallic tray. And then, the liquid nitrogen (-200^{O}C) was poured on the granulated sample and on the screen.

The granule size distribution was determined by weighing separately the cooled fractions retained onto different screens after 5 minutes of screening. The granulated sample was cooled together with the screen in order to avoid deterioration of the granules during sieving. This test characterised the granulation potential of a given iron ore by comparing the size distribution of the raw materials, before and after granulation.

III.2.4 Sintering.

Sintering tests were carried out at Kumba pilot plant in a sinter pot with a cross sectional grate area of 0.16 m^2 (Figure 5).

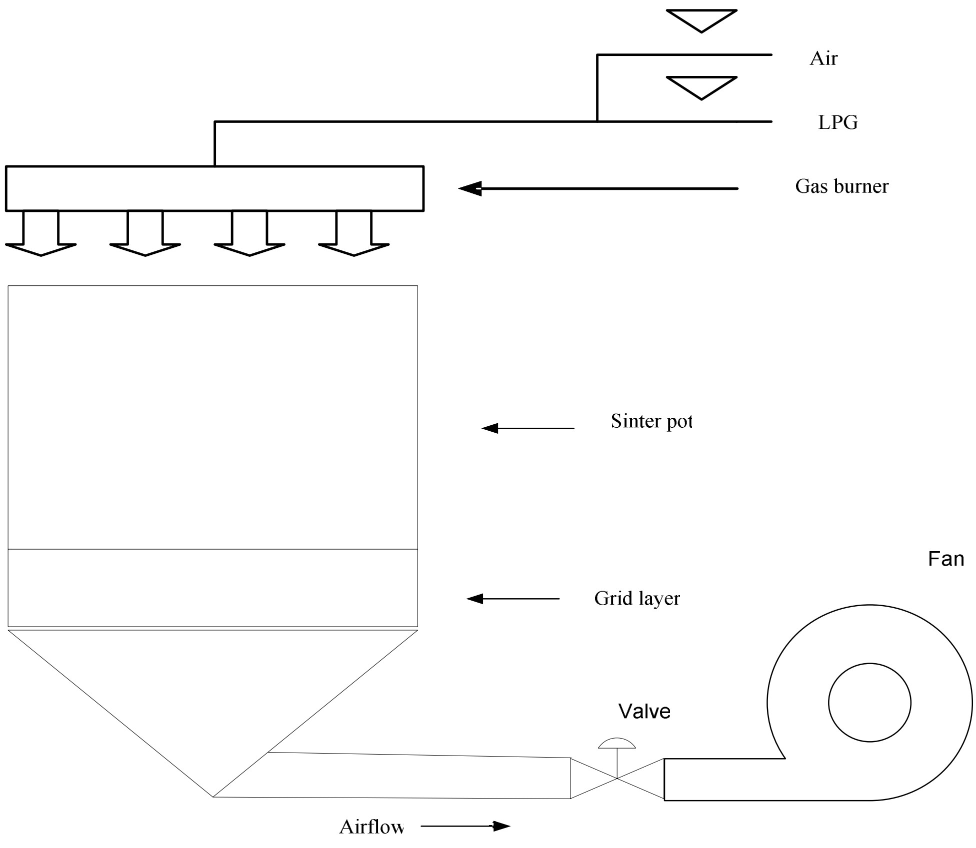


Figure 5. Sinter pot test equipment.

Four sinter mixes retained as the optimised mixture after granulation were investigated. Their compositions are shown in Tables 6 and 7. Mixture I contained 50% of Thabazimbi iron ore and 50% of Sishen iron ore, and Mixture II contained 20% Thabazimbi iron ore and 80% Sishen iron ore. In mixtures I and II, the coke, lime and return fines were sized. Mixture III contained 20% of Thabazimbi iron ore and 80% of Sishen iron ore; Mixture IV contained 50% of Thabazimbi iron ore and 50% of Sishen iron ore. In mixtures III and IV, only the coke and lime were sized.

Table 6 Composition of ore mixture, wt-%

	Mixture I						
Raw material	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Thabazimbi	50	50	50	50	50	50	50
Sishen	50	50	50	50	50	50	50
Return fines	26	24	25	26	28	27	28
Coke breeze	4.50	4.75	4.75	4.60	4.50	4.40	4.40
Lime	5.67	5.83	5.8	5.71	5.56	5.65	5.57
Dolomite	8.03	8.25	8.12	8.01	7.77	7.91	7.78
Silica	0.00	0.00	0.00	0.00	0.00	0.00	0.00
Water	5.50	5.50	5.50	5.50	5.50	5.50	5.50
Ferric chloride	0.417	0.430	0.423	0.417	0.405	0.411	0.405

Table 7 Composition of ore mixture, wt-%

	Mixture II	Mixture III		Mixture IV		
Raw material	**8**	**9**	**10**	**11**	**12**	**13**
Thabazimbi	20	20	20	50	50	50
Sishen	80	80	80	50	50	50
Return fines	28	28	27	28	27	26
Coke breeze	4.40	4.45	4.50	4.40	4.50	4.60
Lime	5.50	5.50	5.57	5.67	5.80	5.80
Dolomite	8.05	8.05	8.17	7.76	7.87	7.98
Silica	0.10	0.10	0.10	0.00	0.00	0.00
Water	4.50	4.50	5.50	4.50	5.50	5.50
Ferric chloride	0.437	0.437	0.444	0.413	0.419	0.429

Table 8. Particle size distributions of limestone, coke breeze, wt-%.

	- 5 + 3.35 mm	- 3.35 + 1 mm	- 1 + 0.5 mm
Coke breeze	20	40	40
Lime	20	80	-

Table 8 shows the particle size distribution of limestone and coke breeze used in the mixtures (I, II, III, and IV). The sizing of the coke breeze implied removal of the –0.5 mm size fraction and of the lime the –1 mm size fraction. In mixture I and II the return fines were sized by removal of the – 0.5 mm size fraction.

Raw materials were fed from the mixing drum (1000 mm in height and 500 mm in diameter), which Kumba pilot plant uses for the granulation, into the sinter pot with a conveyer system. The dry sinter mix was about 140 Kg. The surface of the mixture was ignited with a gas flame under pressure drop of 500 mm H_2O over the bed. After an ignition time of 1.5 minutes, the gas flame was stopped. The temperature reached 1050^oC after the flame front burnt through the sinter pot. The sinter cake was cooled in the sinter pot. It was then crushed and screened to a size fraction between -50 mm +5 mm for analysis. The - 5 mm size fraction was kept and used as return fines. The goal of the sinter test was to determine the effect of particle size distribution of the raw materials mixture on the rate of sintering, the productivity, the ratio of fines, the amount of FeO (%), the sintering time, the fuel consumption, the coke rate (kg/t.sinter), the yield (%), the Tumble Index (TI), the Reduction Degradation Index (RDI), the Reducibility Index (RI) and the moisture content.

In the sintering process, some parameters have been kept constant in accordance with the Kumba pilot plant practice, such as:

- Basicity index (CaO/SiO_2): 1.9
- FeO: 7.0- 9.0 %
- MgO: 3.00 %
- Ignition time: 1.5 minutes.
- Ignition temperature: 1050 ^{0}C
- Bed height: 516 mm
- Grid layer height (mm): 50
- Pressure drop (mm H_2O): 500 ^{o}C for ignition time, 1200 ^{o}C for sintering, and 1500 ^{o}C for cooling.

CHAPTER IV. RESULTS AND DISCUSSION

IV.1. Raw materials without fluxes.

In this section the granulation characteristics of Thabazimbi iron ore and Sishen iron ore and their mixture without fluxes were investigated.

IV.1.1 Pure iron ores: Thabazimbi and Sishen iron ore.

The particle size distributions of Thabazimbi iron ore and Sishen iron ore are respectively shown in Figures 6 and 7. Fives samples were studied for each iron ore.

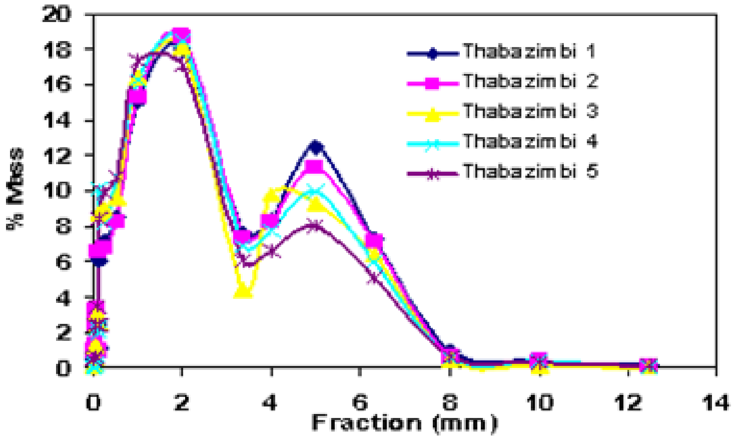


Figure 6. Size distribution of Thabazimbi iron ore.

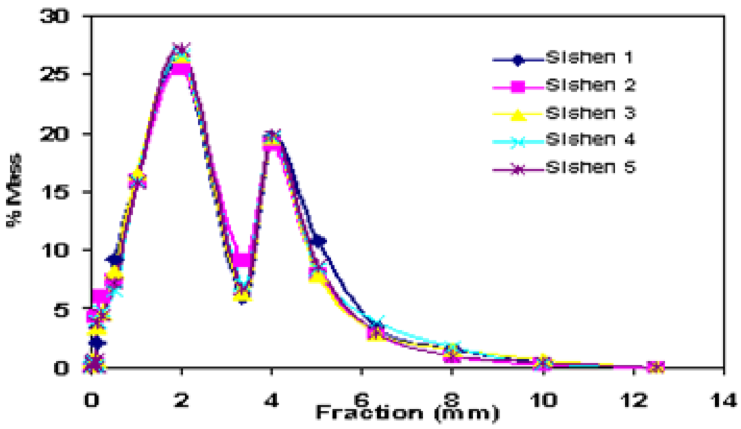


Figure 7. Size distribution of Sishen iron ore.

It can be seen from Figures 6 and 7 that the particle size distributions for the different samples of Thabazimbi iron ore as well as Sishen iron ore are very similar.
In comparing the size distributions of the Thabazimbi and Sishen iron ores, the Sishen iron ore has a higher proportion of particles in the (+2 –3.35) mm, (+ 4 – 5) mm size fractions and lower proportion of particles in the of - 0.25 mm, (+1 – 2) mm size fractions than the Thabazimbi iron ore.

IV.1.1.1 Determination of very fine particles.

After crushing, iron ore contains a large amount of fine particles. It is assumed that improved granulation will be achieved when appropriate amounts of very fine particles are present in the sinter mix. Past studies have shown that the very fine particles have a great effect on sinter quality especially with respect to sinter strength, better reactivity, and better fusibility as they adhere naturally to coarse particles [20]. The aim of this part of the study was to determine the amount of very fine particles that are present in the Sishen and Thabazimbi iron ores. The very fine particles were determined by comparing the size distributions of Thabazimbi and Sishen iron ores calculated after wet and dry screening. The results are shown in Table 9. Two parameters AC and Δ were calculated: [27]

- $AC = (\%<75\ \mu m)_W$
- $\Delta = (\%<75\ \mu m)_W - (\%<75\ \mu m)_D$

Where: $(\%<75\ \mu m)_W$ represents the weight fraction of the grains < 75 µm in the ore, sieved under water

$(\%<75\ \mu m)_D$ represents the weight fraction of the grains < 75 µm in the ore, sieved dry.

The procedure first consisted of sieving a sample of 4 kg through a 75 µm sieve for 5 minutes, and weighing the retained (+75 µm) and the passing (-75 µm) fractions. This is the sieve analysis under dry conditions.

$(\%<75\ \mu m)_D$ is the weight of the fraction that passed the 75 µm sieve. Secondly the retained fraction (+75 µm) is placed on the 75 µm sieve and washed under running water, making sure that all the water is passing through the sieve and none over its edges.

The process is stopped when the water passing through the sieves is clear. The retained fraction is dried in the oven at 120 ^{o}C for 2 hours to remove water. The weight of the fraction passing the 75µm sieve under wet conditions $(\%<75\ \mu m)_W$ will be equal to the sum of the weight of the -75µm fraction when sieved under dry conditions and the difference between the retained +75µm fraction under dry and wet conditions.

Table 9 Determination of AC and Δ

Sample	AC (%)	**Δ (%)**	Sample	AC (%)	**Δ (%)**
Thabazimbi 1	**10.53**	**3.30**	Sishen 1	**6.35**	**2.05**
Thabazimbi 2	**10.00**	**3.60**	Sishen 2	**7.30**	**2.10**
Thabazimbi 3	**9.75**	**3.75**	Sishen 3	**7.40**	**2.10**
Average	**10.09**	**3.55**	Average	**7.02**	**2.08**
Standard deviation.	**0.40**	**0.23**	Standard deviation.	**0.58**	**0.03**

Table 9 gives the results of sieve analyses done under dry and wet conditions, using a 75µm sieve. It shows that the parameters AC and Δ for Thabazimbi iron ore are bigger than for Sishen iron ore. It can therefore be concluded that Thabazimbi iron ore has more fine particles than Sishen iron ore.

IV.1.1.2. Influence of moisture on permeability and mean granule diameter.

The influence of moisture content on the permeability and mean granule diameter was studied in the range of 1-5% moisture for Sishen iron ore and 2-8% moisture for Thabazimbi iron ore at 6 minutes of granulation.

Figure 8 shows that Sishen iron ore is more permeable than Thabazimbi iron ore at moisture levels of 2 to 3%. The maximum permeability of 65.18 JPU was obtained at 2% moisture for Sishen iron ore, while for Thabazimbi iron ore a permeability of 43.1 JPU was obtained at 4% moisture. Sishen iron ore requires less water for granulation to reach the maximum permeability than Thabazimbi iron ore. When water addition is increased beyond the optimum value, bed permeability decreases. It was not possible to test the permeability of Sishen iron ore at more than 5% moisture content, because a further increase in water content resulted in the formation of a slurry during granulation.

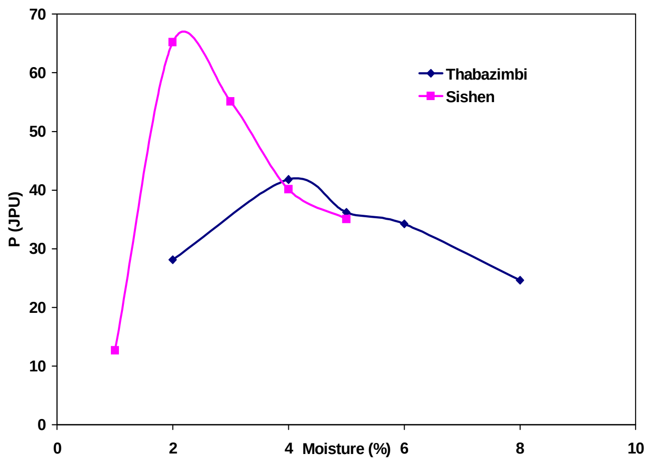


Figure 8. Influence of moisture content on permeability at 6 minutes of granulation

Figure 9 shows the influence of moisture content on the mean granule diameter. The average particle size of the Sishen iron ore increases slightly from 3.1 mm before granulation to a maximum value of 3.5 mm after granulation, while for Thabazimbi iron ore it increases from 2.6 mm to 3.5 mm (Table 10). The difference between the diameter before and after granulation of Thabazimbi is higher than for Sishen, presumably because Thabazimbi iron ore has more fines than Sishen iron ore. Thabazimbi iron ore granules also grow bigger than Sishen ore granules, also presumably due to the higher fines (< 75μm) content of the Thabazimbi iron ore.

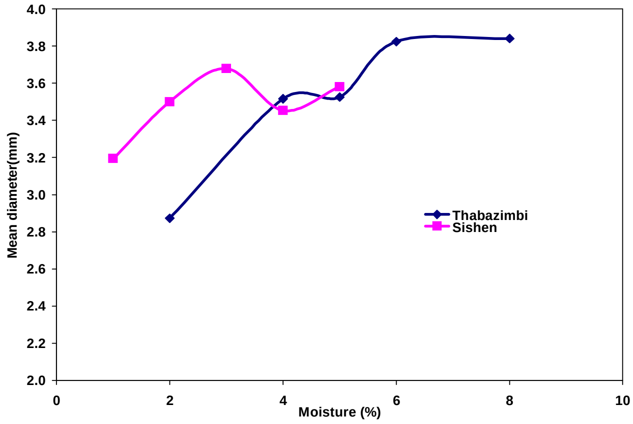


Figure 9. Influence of moisture content on mean granule diameter of pure iron ore

Table 10. Mean granule diameter of pure Thabazimbi iron ore and Sishen iron ore

	Thabazimbi iron ore.				Sishen iron ore			
	H (%)	P (JPU)	D(mm) B.G	D(mm) A.G	H (%)	P (JPU)	D(mm) B.G	D(mm) A.G
Sample 1	2	12	2.85	2.90	1	12	3.12	3.20
Sample 2	4	43	2.74	3.51	2	65	2.91	3.50
Sample 3	5	36	2.52	3.53	3	55	2.97	3.68
Sample 4	6	34	2.57	3.82	4	40	3.06	3.45
Sample 5	8	24	2.32	3.84	5	35	2.98	3.58
Average			2.60	3.52			3.01	3.48

IV.1.1.3 Influence of granulation time on permeability and mean granule diameter.

The influence of granulation time on permeability and mean granule diameter was investigated in the range 2-10 minutes at optimum moisture content of 2% for Sishen iron ore and 4% for Thabazimbi iron ore.

The highest permeability was obtained at 10 minutes for Thabazimbi iron ore, and 2 minutes for Sishen iron ore (Figure 10). Thabazimbi iron ore therefore requires more time to be optimally granulated than Sishen iron ore; presumably to the higher fines content of Thabazimbi iron ore.

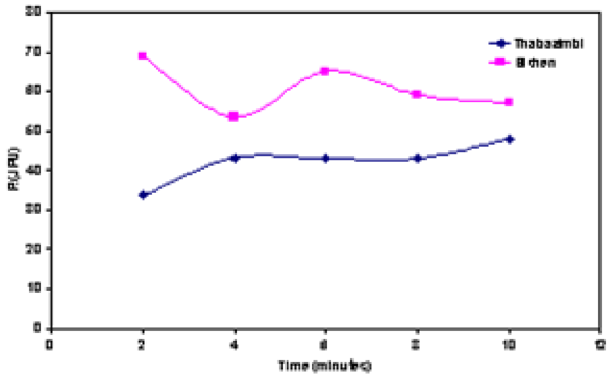


Figure 10. Influence of granulation time on permeability of pure iron ore.

At their optimum moisture contents the permeability of Sishen iron ore is higher than for Thabazimbi iron is.

Figure 11 shows the influence of granulation time on mean granule diameter. It reveals that the mean granule diameter is a function of granulation time. As the time increases, the mean granule diameter of the Sishen iron ore increases up to a certain value after which it starts to decrease. With a further increase in time the mean granule diameter starts to increase again in size. The same trend can be observed on Figures 9 and 10, which represent respectively the influence of moisture content on the mean granule diameter and the influence of granulation time on permeability. These curves are sinusoidal.

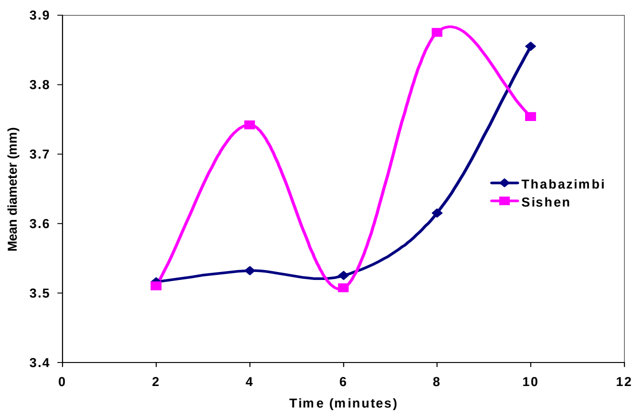


Figure 11. Influence of granulation time on mean granule diameter of pure iron ore

The form of the mean diameter vs. time curve for Thabazimbi iron ore differs from that of the curve for Sishen iron ore. The mean granule diameter of Sishen iron ore grow more rapidly as a function of time than the mean granule diameter of Thabazimbi iron ore. This explains why, Thabazimbi iron ore requires more time to reach its highest permeability than Sishen iron ore.

IV.1.2. Mixture of Thabazimbi and Sishen iron ore only

In this part of the study the influence of moisture and granulation time on permeability of a mixture of Thabazimbi and Sishen iron ore without fluxes were investigated at 6 minutes of granulation. The mass ratio of Thabazimbi iron ore: Sishen iron ore in the mixture was varied as follows: 20-80; 40-60; 50-50; 60-40; 80-20.

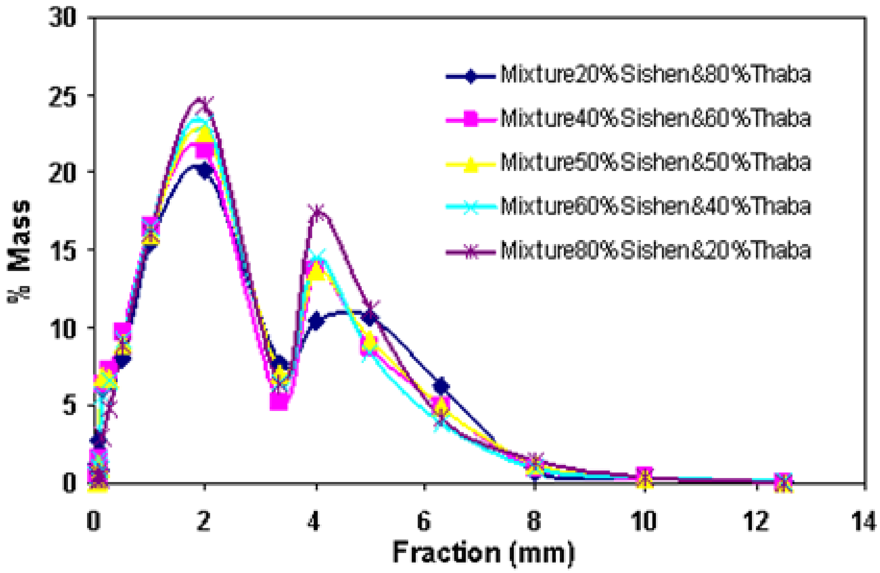


Figure 12. Size distribution of the mixture Thabazimbi iron ore and Sishen iron ore without fluxes.

By increasing the amount of Sishen iron ore in the Thabazimbi: Sishen iron ore mixture without fluxes the mass percentage of the (-3.35 +2) mm and (-5 +4) mm size fractions increased, while the mass percentages of the (– 4+3.35) mm and + 6 mm size fractions decreased.

IV.1.2.1. Influence of moisture on permeability.

The influence of moisture on permeability was studied in the range of 2-6% of moisture content. It can be observed from Figure 13 that the mixture of 80% Sishen iron ore and 20% Thabazimbi iron ore without fluxes is more permeable than any of the other mixtures examined from 2 to 4% moisture content. A permeability of 44.24 J.P.U was obtained after 6 minutes of granulation at 3% of moisture. The permeability increases with an increase in Sishen ore content in the mixture. At a 5% of moisture content, the permeability of the mixture 20%Sishen iron ore and 80% Thabazimbi iron ore peaks, and is higher than for any of the other mixtures.

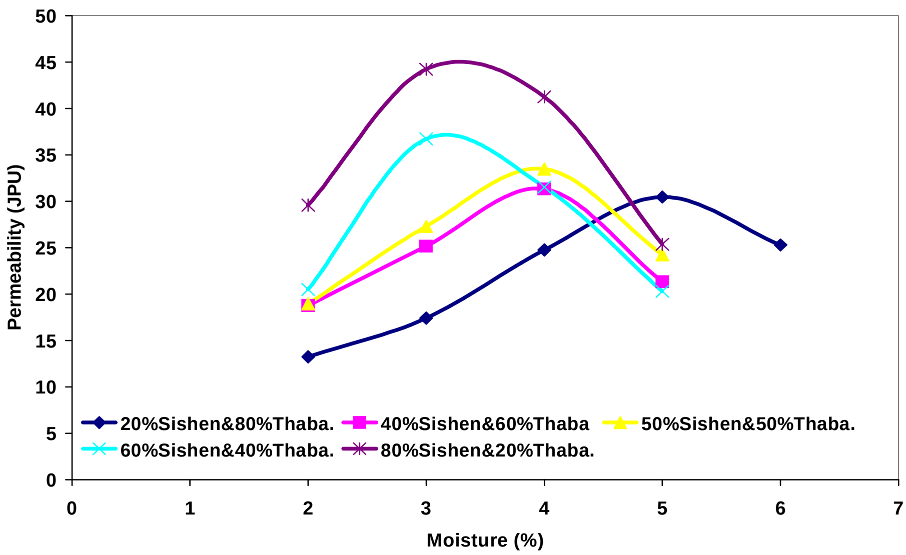


Figure 13. Influence of moisture on the permeability of the mixture Thabazimbi iron ore: Sishen iron ore without fluxes.

The mixture 20% Sishen iron ore and 80% Thabazimbi iron ore requires more water due to the high Thabazimbi iron ore content in the mixture, with associated higher fines content.

It is not possible to compare the exact permeability values of the Sishen iron ore and Thabazimbi iron ore mixtures to pure Thabazimbi iron ore or Sishen iron ore, because the permeability test setup was different. This due to the fact that the venturi of the permeability test used in Kumba Iron Ore pilot plant was changed after the permeability tests on the pure Thabazimbi iron ore and Sishen iron ore samples. The pressure drop (ΔP) was consequently different, and therefore also the permeability values. However, the trends of permeability vs. moisture content of pure Thabazimbi iron ore and Sishen iron ore (Figure 8) can be compared to the trends of permeability vs. moisture of Thabazimbi iron ore and Sishen iron ore mixtures (Figure 13). It can be seen from these figures that the difference of permeabilities at optimum moisture and at low moisture as well as at high moisture content of pure Sishen iron ore and the mixture containing more Sishen iron ore than Thabazimbi iron ore is higher than of pure Thabazimbi iron ore and the mixture containing more Thabazimbi iron ore.

IV.1.2.2 Influence of granulation time on permeability.

The influence of granulation time on permeability was investigated at an optimum moisture content of 3%. Figure 14 shows that the permeability of the mixture 20% Thabazimbi and 80% Sishen is the highest for any granulation time from 2 to 10 minutes. A permeability of 46.45 J.P.U was obtained after 2 minutes of granulation at 3% of moisture content. The mixture 20% Thabazimbi, 80% Sishen without fluxes is the optimum mixture.

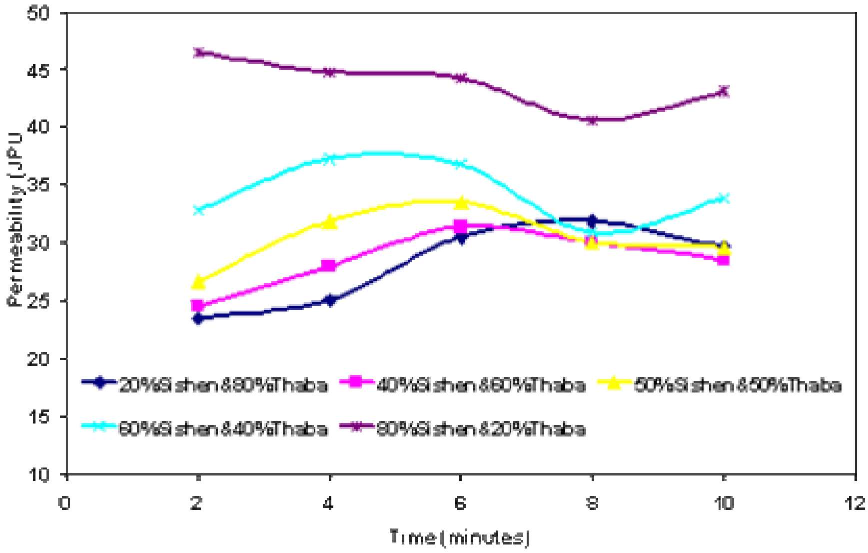


Figure 14. Influence of granulation time on permeability at optimum moisture content (3%) for Thabazimbi iron ore: Sishen iron ore mixtures without fluxes.

IV.2. Raw materials with fluxes

IV.2.1 Sishen and Thabazimbi iron ores with fluxes.

Figure 15 shows the size distribution of the mixture Sishen iron ore and Thabazimbi iron ore with fluxes both sized and unsized. All the mixtures have high proportions of material in the (-3,35 +2) size fraction. The mixture 20% Thabazimbi iron ore and 80% Sishen iron ore without fluxes has the highest proportion of material in the (-3.35, +2) mm size fraction, while the mixture 80% Sishen iron ore and 20% Thabazimbi iron ore with sized coke, lime, and return fines has the highest proportion of material in the (-6, +5) mm size fraction.

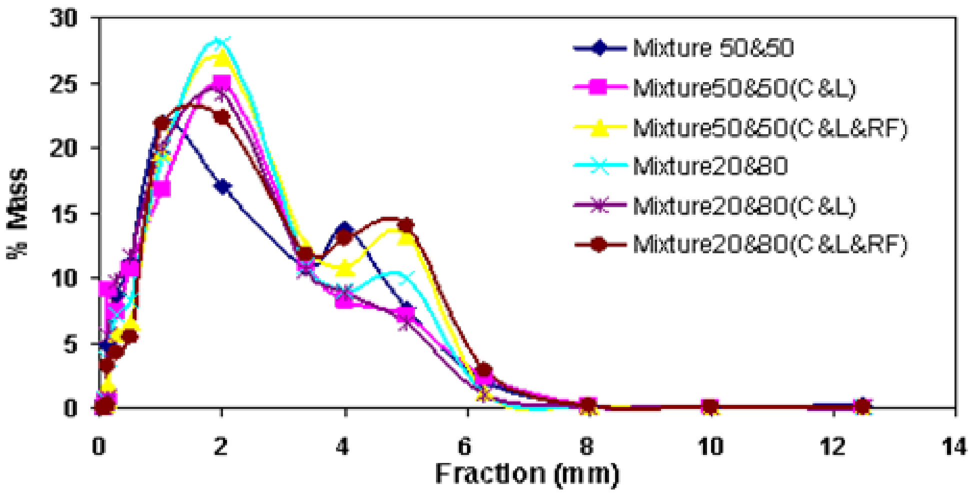


Figure 15. Size distribution of mixture Thabazimbi iron ore: Sishen iron ore with fluxes

IV.2.1.1 Influence of moisture and mean granule diameter on permeability.

The influence of moisture and mean granule diameter on permeability of the optimised mixture of 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes was investigated.

In this part of the study the mixture of 50% Thabazimbi iron ore, 50% Sishen iron ore with fluxes was also investigated, because traditionally Kumba Iron Ore pilot plant uses this mixture for comparison of properties in their sinter experiments.

The fluxes were first used without being sized, after which the fluxes were sized as is shown in Table 8.

The following abbreviations were used to describe these samples:

- Mixture 20&80 (50&50) with fluxes: The mixture 20% Thabazimbi iron ore, 80% Sishen iron ore (50% Thabazimbi iron ore, 50% Sishen iron ore) with fluxes not sized.
- (C&L): Coke and Lime sized.
- (C&L&R.F): Coke, Lime, and Return Fines all sized.

Figure 16 reveals that the permeability of the mixture 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes where the coke, lime and return fines were sized gave the highest permeability with a value of 49.12 J.P.U after 6 minutes of granulation at 4.5% of moisture. A maximum permeability of 44.72 J.P.U was obtained for the mixture of 50% Thabazimbi, 50% Sishen iron ore where the coke, lime and return fines were sized at 5,5% of moisture after 6 minutes of granulation. From Figure 16 it can be seen that the permeabilities of both the 20% Thabazimbi iron ore, 80% Sishen iron ore, and the 50% Thabazimbi iron ore, 50% Sishen iron ore mixtures with fluxes where the coke, lime and return fines were sized were higher than when only the coke and lime were sized as well as when none of the fluxes were sized.

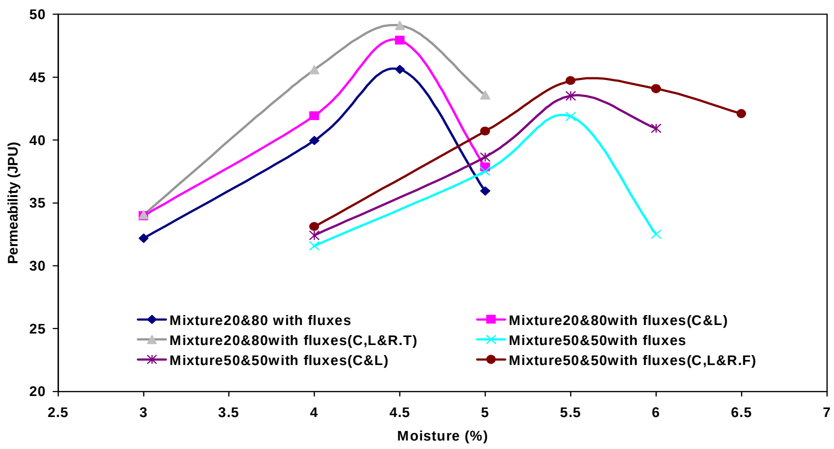


Figure 16. Influence of moisture content on permeability of the different mixtures with fluxes.

The average mean diameter of the mixture 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes changed from 2.36 mm before granulation to 3.88 mm after granulation where the coke, and lime were sized, from 3.00 mm to 4.60 mm where the coke, lime and return fines were sized, while in the mixture 50% Sishen iron ore, 50% Thabazimbi iron ore with fluxes the average mean diameter changed from 2.68 mm to 4.03 mm where the coke and lime were sized and from 2.90 mm to 4.31 mm where the coke, lime and return fines were sized (Tables 11 and 12).

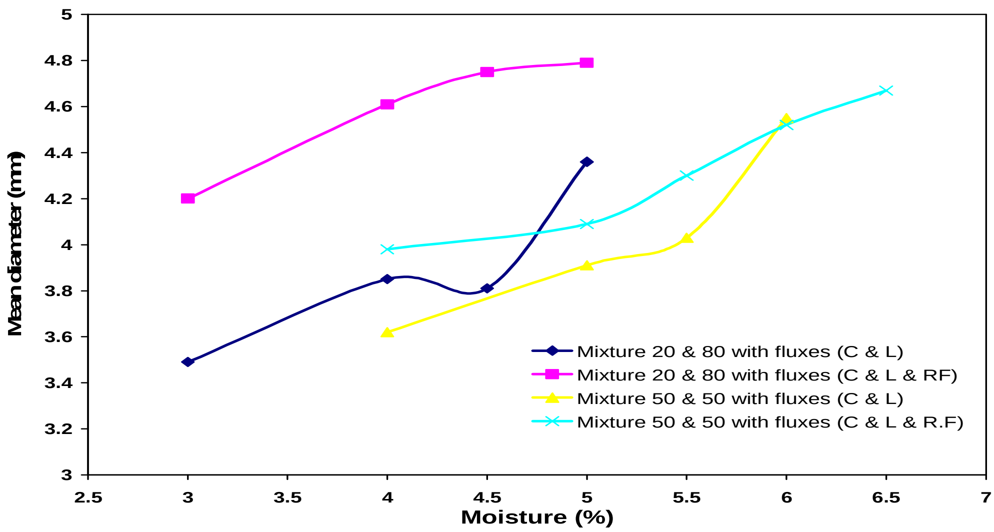


Figure 17. Influence of moisture content on mean granule diameter.

Table 11. Mean granule diameter of 20% Thabazimbi iron ore - 80%Sishen iron ore mixtures.

	20&80 with fluxes(C&L)				20&80 with fluxes(C&L&RF)			
Sample	**H (%)**	**P (JPU)**	**D(mm) B.G**	**D(mm) A.G**	**H (%)**	**P (JPU)**	**D(mm) B.G**	**D(mm) A.G**
1	3	34	2.34	3.49	3	34	2.92	4.20
2	4	42	2.35	3.85	4	46	3.05	4.61
3	4.5	48	2.32	3.81	4.5	49	3.06	4.75
4	5	38	2.41	4.36	5	44	2.92	4.79
Average			2.36	3.88			2.99	4.59

Table 12. Mean granule diameter of 50% Thabazimbi iron ore - 50%Sishen iron ore mixtures.

	50&50 with fluxes(C&L)				50&50 with fluxes(C&L&RF)			
Sample	**H (%)**	**P (JPU)**	**D(mm) B.G**	**D(mm) A.G**	**H (%)**	**P (JPU)**	**D(mm) B.G**	**D(mm) A.G**
1	4	32	2.81	3.62	4	33	2.95	3.98
2	5	39	2.78	3.91	5	41	2.93	4.09
3	5.5	44	2.46	4.03	5.5	45	2.92	4.30
4	6	41	2.65	4.55	6	44	2.89	4.52
5	-	-	-	-	6.5	42	2.81	4.67
Average			2.68	4.03			2.90	4.31

The sizing of the coke, lime, and return fines by removing fine particles increases the mean diameter before granulation and consequently the mean diameter after granulation. The mixture 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes where, coke, lime and return fines were sized has the highest mean diameter after granulation, while the 50% Thabazimbi iron ore- 50% Sishen iron ore mixture where only the coke and lime were sized the lowest .

IV.2.1.2 Influence of granulation time on permeability.

Figure 18 shows the influence of granulation time on permeability.
The mixture 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes had the highest permeability (50.80 JPU) where the coke, lime and return fines were sized, and had 48 JPU where only the coke and lime were sized after 4 minutes of granulation. The mixture 50% Thabazimbi and 50% Sishen with fluxes had a permeability of 44.72 JPU, where the coke, lime and return fines were sized and 43.52 JPU where only the coke and lime were sized, after 6 minutes of granulation.

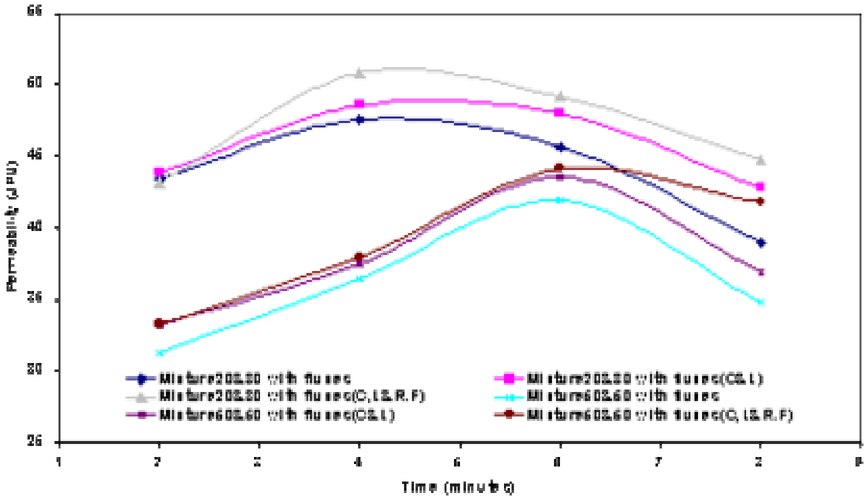


Figure 18. Influence of granulation time on permeability.

The sizing of the return fines increased the permeability from 48 to 50.80 JPU at 4 minutes of granulation for the mixture 20% Thabazimbi iron ore and 80% Sishen iron ore and from 43.52 to 44.72 JPU for the mixture 50%Thabazimbi iron ore and 50% Sishen iron ore at 6 minutes of granulation.

IV.3 Variation in material transfer between granulometric classes.

In this part of the study the fine particles that are involved in the granulation process, the extent of material transfer, and the effective elimination of fines were studied. This was done by comparing the size distribution of the raw material under study before granulation and after granulation for each granulometric class. The results obtained were presented on a semi logarithmic graph, where the ordinate (arithmetic scale) shows the gain or loss as a percentage of the total sample weight, and the abscissa (logarithmic scale) shows the granulation class. Each point represents the difference between the quantities of material before and after granulation for each granulometric class.

It was assumed that [27]:

X: The size limit between the reduced and increased granulometric fraction during the granulation process expressed in mm, considering that the reduced and increased granulometric fractions are the fractions whose relative percentages reduce or increase respectively after granulation.

S: The level of material transfer between the reduced and increased granulometric fractions, expressed as a percentage of the total weight of the sample.

Ex: The efficiency of elimination of the fraction smaller than X mm, during the granulation process.

$(\%<X\text{mm})_{BG}$ = the weight fraction of grains less than X mm in the ore before granulation.
$(\%>X\text{mm})_{BG}$ = the corresponding weight fraction above X mm.
$(\%<X\text{mm})_{AG}$ = the weight fraction of grains less than X mm in the ore after granulation.
$(\%>X\text{mm})_{AG}$ = the corresponding weight fraction above X mm

The expressions of **S** and **Ex** are: $\mathbf{S} = (\%<X\text{mm})_{BG} - (\%<X\text{mm})_{AG}$

$$= (\%>X\text{mm})_{AG} - (\%>X\text{mm})_{BG}$$

$$\mathbf{Ex} = 100 \cdot S/S' \quad \text{Where } S' = (\%<X\text{mm})_{BG}$$

The value of **X** is obtained from the intersection of each curve with the x-axis of the semi logarithmic graph. Figures 19 to 26 illustrate the variation in material transfer of pure Thabazimbi and Sishen iron ores, and of the raw material mixture with fluxes between granulometric classes for different moistures levels at 6 minutes of granulation.

IV.3.1 Pure Thabazimbi and Sishen iron ores

Figures 19 and 20 reveal that the notion of fine and coarse particles depends mainly on the amount of water used for granulation as well as the nature of the ore mineral. Therefore, at a fixed percentage of moisture, fine particles are defined as the limit between the reduced and the increased granulometric fraction.

In other words, the size less than X are considered as the fine particles. In varying the amount of moisture, the intermediate particles will be defined as those particles comprised between X at low moisture and X at high moisture. In the case of Thabazimbi iron ore (Figure 19) particles less than 0.25 mm in diameter are considered fines at a 2% of moisture content.

In varying the moisture from 2% to 8% the intermediate size particles are those with diameters between 0.25 to 1 mm. In conclusion for Thabazimbi iron ore, particles with diameters less than 0.25 mm are fines, the intermediates particles have diameters between 0.25 mm and 1 mm and coarse particles have diameters that exceed 1 mm. From Figure 20, it can be concluded for Sishen iron ore that particles with diameters smaller than 0.66 are fines, the intermediates particles have diameters between 0.66 mm and 1,5 mm and the coarse particles have diameters larger than 1,5 mm.

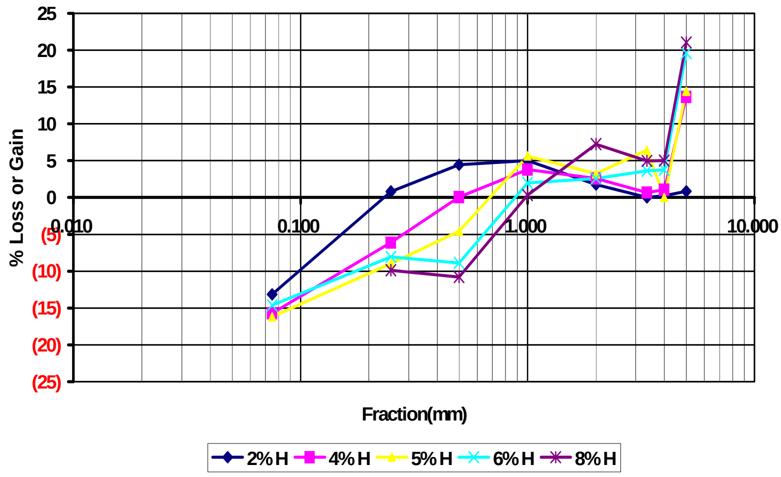


Figure 19. Variation in material transfer between granulometric classes of Thabazimbi iron ore. (H= moisture content)

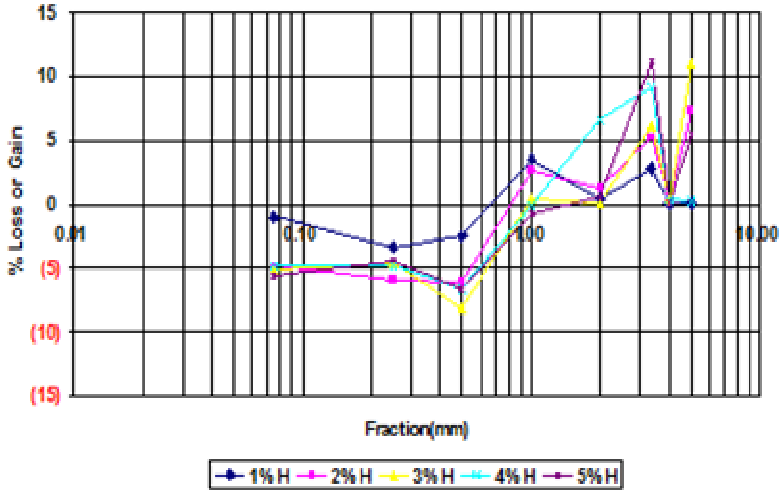


Figure 20. Variation in material transfer between granulometric classes of Sishen iron ore. (H= moisture content)

IV.3.2 Mixture of 50% Thabazimbi iron ore, 50% Sishen iron ore with fluxes.

In the mixture 50% Thabazimbi iron ore and 50% Sishen iron ore with fluxes not sized, fines particle have diameters smaller than 0.48 mm and coarse particles have diameters larger than 1.8 mm (Figure 21). For the mixture 50% Thabazimbi iron ore and 50% Sishen iron ore where the coke and lime were sized, fine particles have diameters smaller than 1 mm and coarse particles have diameters larger than 2.9 mm (Figure 22). For the mixture 50% Thabazimbi iron ore and 50% Sishen iron ore with fluxes where the coke, lime and return fines were sized, fines particles have diameters smaller than 2 mm and coarse particle have diameters larger than 3.35 mm (Figure 23).

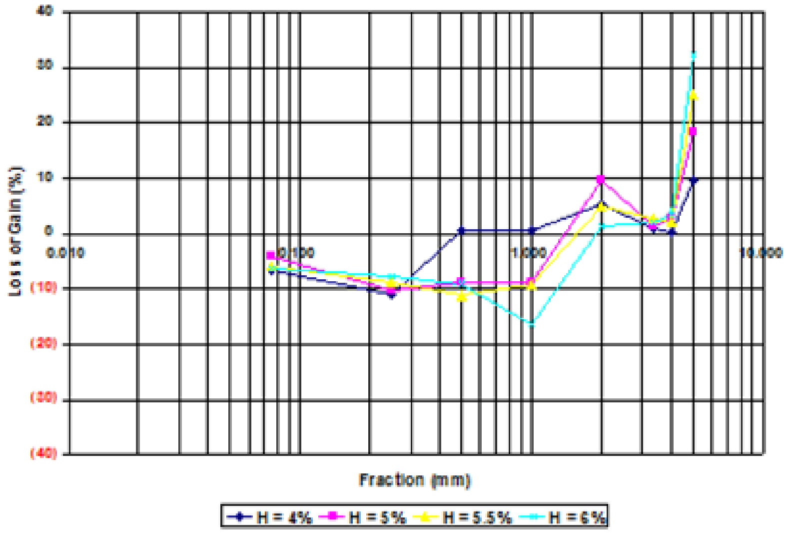


Figure 21. Variation in material transfer between granulometric classes for the mixture 50% Thabazimbi and 50% Sishen with fluxes not sized. (H= moisture content)

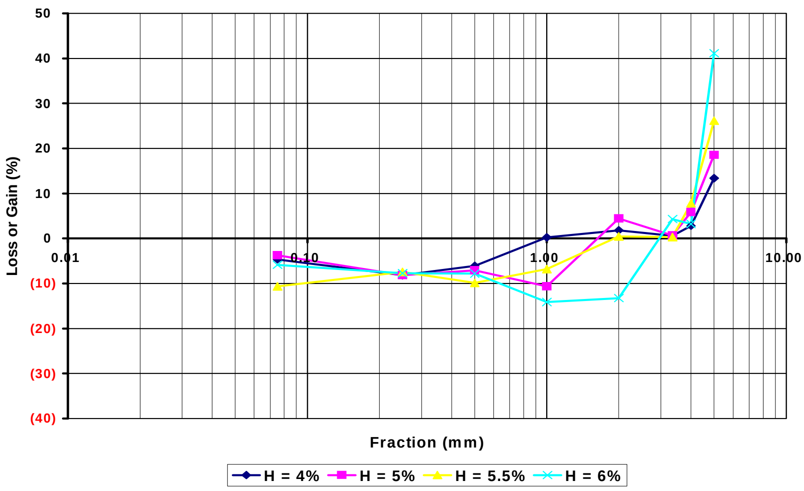


Figure 22. Variation in material transfer between granulometric classes for the mixture 50% Thabazimbi and 50% Sishen with only, coke and lime sized. (H= moisture content)

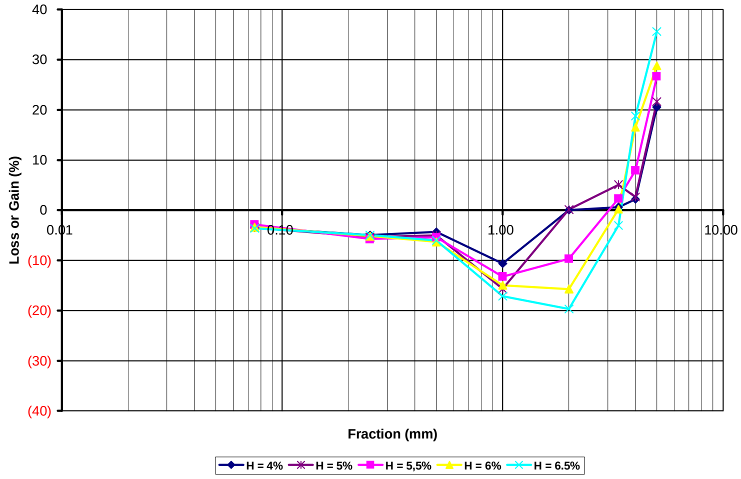


Figure 23. Variation in material transfer between granulometric classes for the mixture 50% Thabazimbi and 50% Sishen with coke, lime and return fines sized.
(H= moisture content)

IV.3.3 Mixture of 20%Thabazimbi, 80% Sishen with fluxes.

In the mixture 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes not sized, fine particles have diameters smaller than 0.9 mm and coarse particles have diameter larger than 2.9 mm (Figure 24). For the mixture 20% Thabazimbi iron ore and 80% Sishen iron ore where the coke and lime were sized, fine particles have diameters smaller than 1.4 mm and coarse particle have diameters larger than 3.35 mm (Figure 25). For the mixture 20% Thabazimbi and 80% Sishen with fluxes where the coke, lime and return fines were sized, fines particles have diameters smaller than 2.4 mm and coarse particle have diameters larger than 3.35 mm (Figure 26).

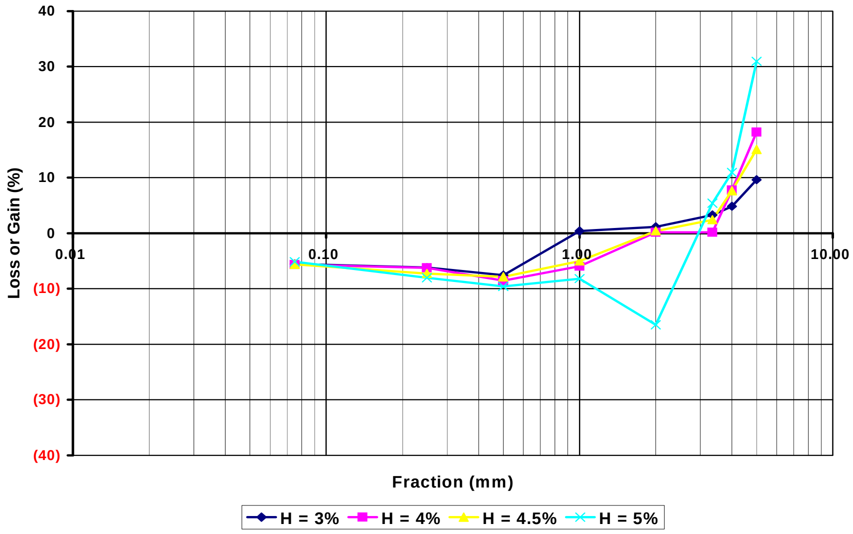


Figure 24. Variation in material transfer between granulometric classes for the mixture 20% Thabazimbi and 80% Sishen with fluxes, not sized. (H= moisture content)

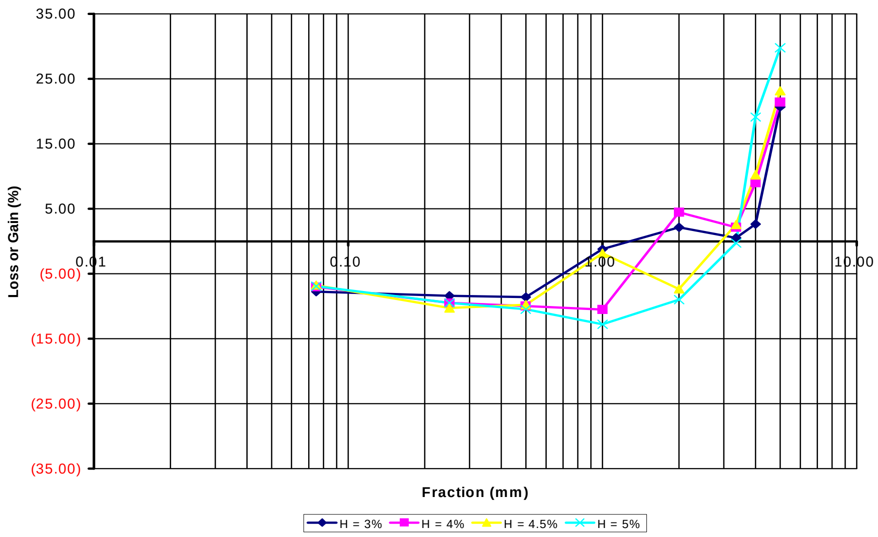


Figure 25. Variation in material transfer between granulometric classes for the mixture 20% Thabazimbi and 80% Sishen with coke and lime sized. (H= moisture content)

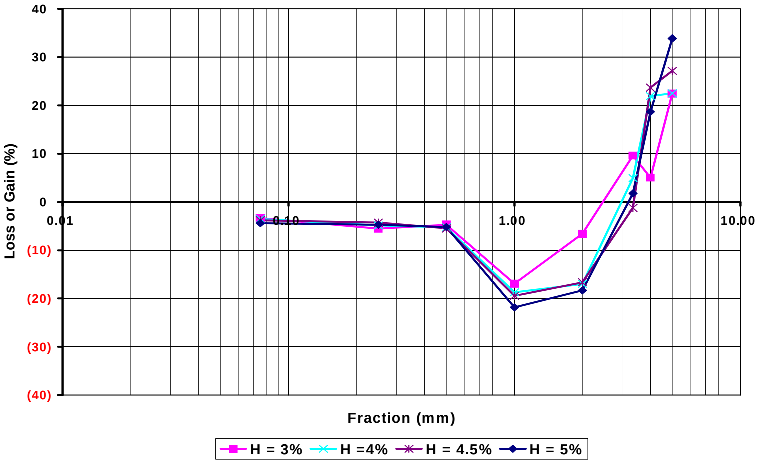


Figure 26. Variation in material transfer between granulometric classes for the mixture 20% Thabazimbi and 80% Sishen with fluxes, coke, lime, and return fines sized. (H= moisture content)

Figures 21 – 26 which show the variation in material transfer between granulometric classes for the mixtures 50% Thabazimbi iron ore - 50% Sishen iron ore and 20% Thabazimbi iron ore - 80% Sishen iron ore with fluxes reveal that the removal of the -0.5 mm size fraction of coke breeze, - 0.5 mm size fraction of return fines and -1 mm size fraction of limestone increase the size limit (X) between the reduced and increased granulometric fractions.

IV.4 Granulation potentials of Thabazimbi and Sishen iron ores and mixtures between them.

The results on the influence of moisture content on permeability and mean granule diameter at 6 minutes of granulation, on Thabazimbi iron ore, Sishen iron ore and their mixtures as well as the variation on material transfer between granulometric classes are summarised in Tables 13 to 20. These results depict the granulation potential of Thabazimbi and Sishen iron ores and their mixtures. It allows the comparison of the potential of granulation of a given iron ore or a mixture between them.

The granulation potential of a given iron ore or an iron ore mixture is better than another one, if its permeability and the amount of material transfer (Ex) is higher at optimum moisture contents and also if its moisture content (H) is less. The value of S indicates the amount of material transfer in mass percentage and the value of Ex shows which fines are eliminated effectively. H is the moisture content in mass percentage on a dry basis and P is the permeability in terms of the Japanese Permeability Unit. D (B.G.) and D (A.G) are respectively the mean diameter before granulation and after granulation expressed in mm. The calculation of S and Ex is shown in Appendix II.

In comparing the granulation potentials of Thabazimbi and Sishen iron ores, (Tables 13 and 14) it can be concluded that the granulation potential of Sishen iron ore is better than that of Thabazimbi iron ore, because Sishen iron ore has a higher permeability (65.18 JPU), at a lower moisture content (2%). The amount of material transfer (Ex = 97%) of Thabazimbi iron ore is higher at optimum moisture contents than for Sishen iron ore (Ex =92.85%). The optimum moisture content of Sishen iron ore (2%) is less than for one of Thabazimbi iron ore (4%).

Table 13. Characterisation of granulation potential of Thabazimbi iron ore.

	H (%)	P (JPU)	X (mm)	S (%)	EX (%)	D (mm) B.G.	D (mm) A.G.
Sample 1	2	13	0.25	13.1	93.3	2.85	2.90
Sample 2	4	43	0.50	21.8	97.0	2.74	3.51
Sample 3	5	36	0.65	25.2	100.0	2.52	3.53
Sample 4	6	34	0.90	31.6	93.9	2.57	3.82
Sample 5	8	25	1.00	38.6	100.0	2.32	3.84

Table 14. Characterisation of granulation potential of Sishen iron ore

	H (%)	P (JPU)	X (mm)	S (%)	EX (%)	D (mm) B.G.	D (mm) A.G.
Sample 1	1	13	0.66	6.9	43.6	3.12	3.20
Sample 2	2	65	0.70	17.0	92.9	2.91	3.50
Sample 3	3	55	1.00	18.0	100.0	2.97	3.68
Sample 4	4	40	1.00	16.2	100.0	3.06	3.45
Sample 5	5	35	1.50	17.3	52.2	2.98	3.58

In comparing the granulation potentials of mixtures containing 50% Thabazimbi iron ore and 50% Sishen iron ore, the mixture where the coke and lime were sized (Table 16) present a better sinter mixture than the mixture where the coke, lime and return fines were sized (Table 17) and where the fluxes were not sized (Table15). Although its permeability (P =43.52 JPU) is slightly less than of the mixture where the coke, lime and return fines were sized (43.52 vs 44.72JPU), it presents a higher efficiency of elimination of fine particles (Ex = 76.22% vs. 59,70%).

Table 15. Granulation potential of mixture 50% Thabazimbi, 50% Sishen with fluxes not sized.

	H (%)	P (JPU)	X (mm)	S (%)	EX (%)	D (mm) B.G.	D (mm) A.G.
Sample 1	4	32	0.48	17.5	98.7	2.51	3.15
Sample 2	5	38	1.50	31.9	61.5	2.45	3.61
Sample 3	5.5	42	1.60	35.1	73.3	2.59	4.01
Sample 4	6	33	1.80	39.3	85.6	2.65	4.34

Table 16. Granulation potential of mixture: 50% Thabazimbi, 50% Sishen with coke and lime sized.

	H (%)	P (JPU)	X (mm)	S (%)	EX (%)	D (mm) B.G.	D (mm) A.G.
Sample 1	4	32	1.00	18.9	91.7	2.81	3.62
Sample 2	5	39	0.90	18.9	94.5	2.78	3.91
Sample 3	5.5	44	2.00	34.7	76.2	2.46	4.03
Sample 4	6	41	2.90	48.7	72.1	2.65	4.55

Table 17. Granulation potential of mixture: 50% Thabazimbi, 50% Sishen with coke, lime and return fines sized.

	H (%)	P (JPU)	X (mm)	S (%)	EX (%)	D (mm) B.G.	D (mm) A.G.
Sample 1	4	33	2.00	23.4	72.6	2.95	3.98
Sample 2	5	41	2.00	29.5	75.5	2.93	4.09
Sample 3	5.5	45	3.00	36.9	59.7	2.92	4.30
Sample 4	6	44	3.00	45.6	73.2	2.89	4.52
Sample 5	6.5	42	3.35	51.4	80.3	2.81	4.67

The granulation potential of the mixture with 20% Thabazimbi iron ore and 80% Sishen iron ore with fluxes where the coke, lime, and return fines were sized (Table 20) was the highest with a better permeability of 49.12 JPU, a high efficiency of elimination of fines (Ex = 86%), and a high level of transfer of fine particles to coarse particles (S = 49.58%).

In conclusion the mixture of 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes where, the coke, lime and return fines were sized and the mixture 50% Thabazimbi, 50% Sishen with fluxes where only the coke and lime where sized have the best granulation potential.

Table 18. Granulation potential of mixture 20% Thabazimbi, 80% Sishen with fluxes not sized.

	H (%)	**P (JPU)**	**X (mm)**	**S (%)**	**EX (%)**	**D (mm) B.G.**	**D (mm) A.G.**
Sample 1	3	32	0.90	19.3	96.2	2.53	3.34
Sample 2	4	40	1.80	26.4	64.1	2.55	3.73
Sample 3	4.5	46	2.00	25.7	63.4	2.64	3.73
Sample 4	5	36	3.00	47.4	66.4	2.53	4.26

Table 19. Granulation potential of mixture: 20% Thabazimbi, 80% Sishen with fluxes, coke and lime sized.

	H (%)	**P (JPU)**	**X (mm)**	**S (%)**	**EX (%)**	**D (mm) B.G.**	**D (mm) A.G.**
Sample 1	3	34	1.40	25.39	89.1	2.34	3.49
Sample 2	4	42	1.70	37.04	76.5	2.35	3.85
Sample 3	4.5	48	3.00	35.97	48.7	2.32	3.81
Sample 4	5	38	3.35	48.61	67.4	2.41	4.36

Table 20. Granulation potential of mixture: 20% Thabazimbi, 80% Sishen with fluxes, coke, lime and return fines sized.

	H (%)	**P (JPU)**	**X (mm)**	**S (%)**	**EX (%)**	**D (mm) B.G.**	**D (mm) A.G.**
Sample 1	3	34.	2.40	31	77.1	2.92	4.20
Sample 2	4	46	3.00	49	85.0	3.05	4.61
Sample 3	4.5	49	3.35	50	86.0	3.06	4.75
Sample 4	5	44	3.20	54	89.3	2.92	4.79

Sintering pot tests were subsequently done on the mixtures 20% Thabazimbi iron ore, 80% Sishen iron ore where the coke, lime and return fines were sized (Mixture II), and on 50% Thabazimbi iron ore, 50% Sishen iron ore (Mixture IV) in which only the coke and lime were sized. The investigation was extended to the mixtures 20% Thabazimbi iron ore, 80% Sishen iron ore where only the coke and lime were sized (Mixture III) and 50% Thabazimbi iron ore, 50% Sishen iron ore (Mixture I) in which the return fines, coke, and lime were sized, because their permeabilities were also high.

IV.5 Mixture Phoenix iron ore –Sishen iron ore with fluxes.

In this part of the study, the pick up of adhering fines by nuclear particles for a blend of Sishen and Phoenix iron ores and as-received fluxes with fluxes was examined. The mixture was constituted from 50% Sishen iron ore and 50% Phoenix iron ore where the Phoenix iron ore was sized as shown in Table 18.

Table 21. Size distribution of Phoenix iron ore

Fraction (mm)	-5 +2	-2 + 0.8	-0.8
Mass (%)	50	20	30

The mixture Phoenix iron ore and Sishen iron ore has a high proportion of material in the (-3.35 + 2) mm, (-2 + 1) mm, (-6 +5) mm and, (-5 +4) mm size fractions, but very little in the + 6 mm size fraction (Figure 27).

Four granulation tests were done in which the moisture content was varied from 3 to 6% (Figure 28), and the granulation time varied between 2 and 10 minutes (Figure 29). It was found that a maximum permeability of 49.63 JPU was obtained at a 5% moisture content after 6 minutes of granulation.

The mean granule diameter of the mixture was about 2.2 mm before granulation and 4.3 mm after granulation at an optimum moisture content of 5%.

After 6 minutes of each granulation experiment, two samples of the granulated mixture were collected and frozen with liquid nitrogen, followed by sieving to different size fractions from 5 to 1 mm (Appendix IV).

Each size fraction was again sieved after it was dried at 110°C for 2 hours, in order to determine which size of particles adhered to which size of particles.

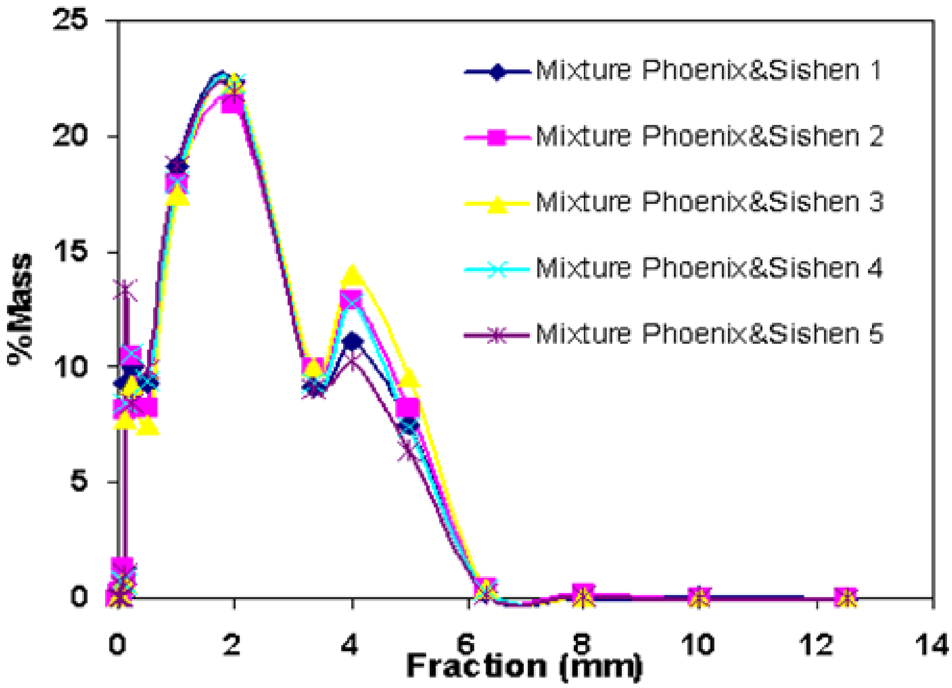


Figure 27. Size distribution of the mixture Phoenix iron ore-Sishen iron ore with fluxes.

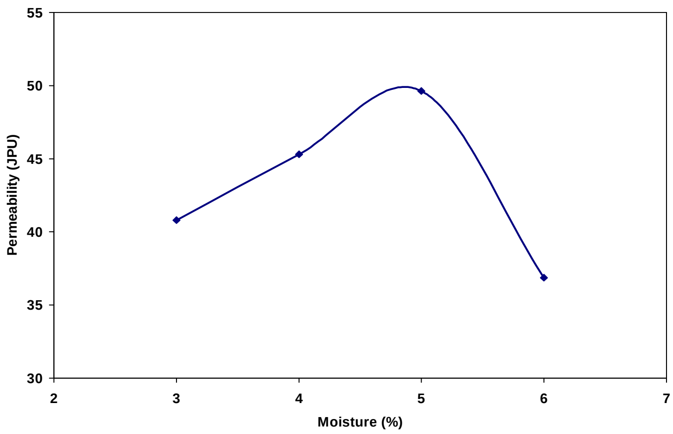


Figure 28. Influence of moisture content on the permeability of the mixture Phoenix iron ore- Sishen iron ore with fluxes.

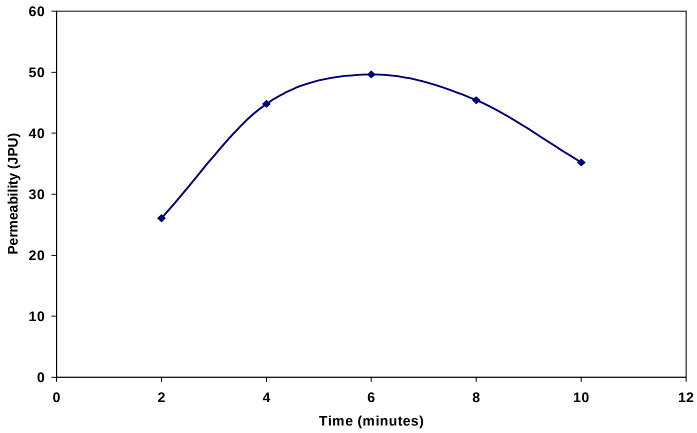


Figure 29. Influence of granulation time on the permeability of the mixture Phoenix iron ore- Sishen iron ore with fluxes.

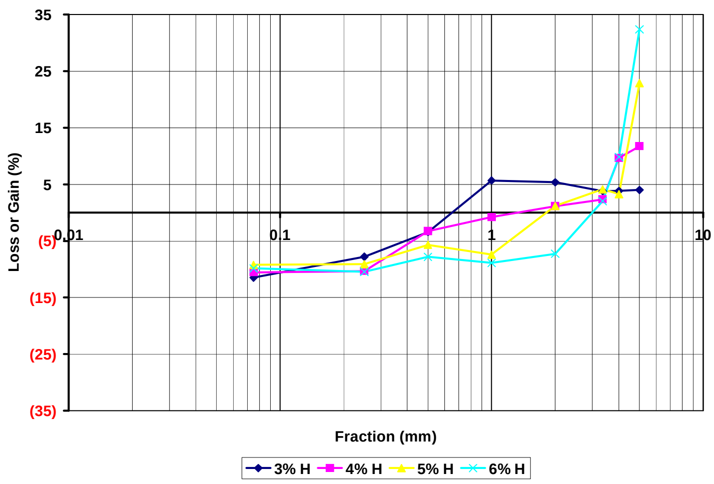


Figure 30. Variation in material transfer between granulometric classes of the mixture Sishen-Phoenix with fluxes not sized. (H= moisture content)

Figure 30 shows that fine particles have diameters less than 0.65 mm and coarse particles have diameters larger than 3 mm. The intermediate particles, which can be either adhering particles or nuclei depending on the moisture content, are between 0.65 and 3 mm in diameter. Figures 31 to 34 show the relationship between the amounts of the fine particles (<1 mm) expressed in mass percentage, which can adhere to nuclear particles (>1 mm) at different moisture contents. Two samples were analysed for each moisture content. The collection of two samples was motivated from the difficulty associated with the sampling of the granulated mixture for the permeability test and the variation of material transfer. It is easier to sample the dry minerals with known methods than to sample the granulated mixture because it is wet and in the form of a slurry. However the curves for the duplicate samples in Figures 31-34 are similar and the standard deviation are small.

Figures 31 and 32 show the behaviour of adhering fine particles to coarse particles at low moisture contents (H=3 and 4 % respectively).

They reveal that, at low moisture contents fine particles adhere more to particles of intermediate size (-3+0.65) mm than coarse particles. It can also be seen that at a 3% moisture contents the classes + 5 mm and (-5 + 4) mm don't participate in granulation, because there is not a sufficient amount of water available for granulation. Class (-1+0.5) mm report mainly to the class (-2+1) mm size fraction (Figure 31, Table 22). By increasing the water content from below the optimum moisture, all the classes start to participate in granulation (Figure 32, Table 23).

The trends of the curves show that, fine particles start to adhere to nuclear particles in ascending order of size, from 1 to 5 mm.

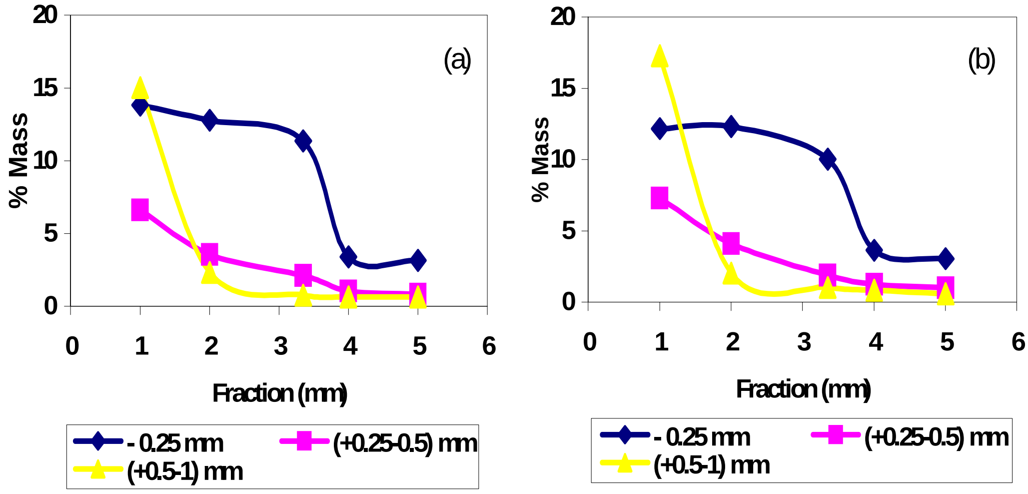


Figure 31. Adhesion of fine particles (x<1 mm) to coarse particles (x>1 mm) at 3% moisture content.

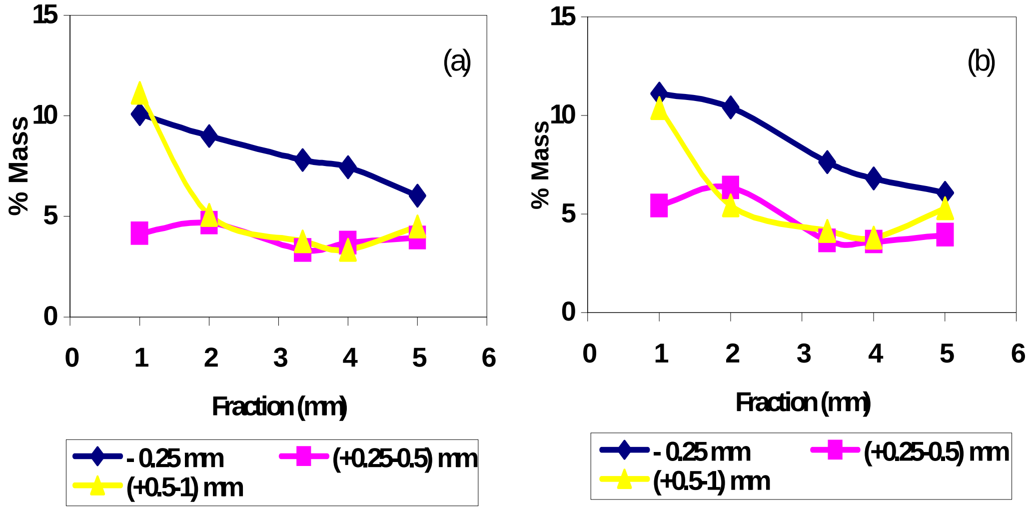


Figure 32. Adhesion of fine particles (x<1 mm) to nuclear particles (x>1 mm) at 4% moisture content.

Table 22. Sieves analysis of granulated Phoenix iron ore-Sishen iron ore-unsized fluxes mixture at 3% of moisture content.

%(-0.25 mm)

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	3.16	3.40	11.35	12.78	13.81
Sample b	3.04	3.64	10.02	12.31	12.17
Average	3.10	3.52	10.69	12.55	12.99
Standard deviation	0.08	0.17	0.94	0.33	1.16

%(+0.25 – 0.5) mm

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	0.83	1.05	2.12	3.55	6.62
Sample b	1.01	1.26	1.89	4.10	7.30
Average	0.92	1.15	2.00	3.83	6.96
Standard deviation	0.13	0.15	0.16	0.39	0.48

%(+ 0.5 – 1) mm

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	0.66	0.65	0.76	2.34	15.03
Sample b	0.58	0.84	1.02	2.05	17.28
Average	0.62	0.75	0.87	2.20	16.15
Standard deviation	0.06	0.13	0.18	0.21	1.59

Table 23. Sieves analysis of granulated Phoenix iron ore-Sishen iron ore-unsized fluxes mixture at 4% of moisture content.

%(-0.25 mm)

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	6.02	7.43	7.80	8.99	10.08
Sample b	6.08	6.80	7.63	10.42	11.12
Average	6.05	7.12	7.72	9.71	10.60
Standard deviation	0.04	0.45	0.12	1.01	0.74

%(+0.25 – 0.5) mm

Fraction (mm)	**+ 5**	**(- 5 + 4)**	**(-4 + 3.35)**	**(-3.35 + 2)**	**(-2 + 1)**
Sample a	3.94	3.69	3.32	4.67	4.15
Sample b	3.95	3.60	3.65	6.34	5.41
Average	3.95	3.65	3.49	5.50	4.78
Standard deviation	0.01	0.06	0.23	1.18	0.89

%(+ 0.5 – 1) mm

Fraction (mm)	**+ 5**	**(- 5 + 4)**	**(-4 + 3.35)**	**(-3.35 + 2)**	**(-2 + 1)**
Sample a	4.49	3.34	3.76	5.07	11.13
Sample b	5.29	3.80	4.15	5.44	10.37
Average	4.89	3.57	3.96	5.26	10.75
Standard deviation	0.57	0.33	0.28	0.26	0.54

Figures 33a and 33b as well as Table 24 show the behaviour at the optimum moisture content of 5%. At the optimum moisture content the – 0.25 mm and (– 0.5 + 0.25) mm size fractions are distributed almost equally between intermediate and nuclear particles. Class (–1 + 0.5) mm adhere preferentially to the (-2 + 1) mm size fraction.

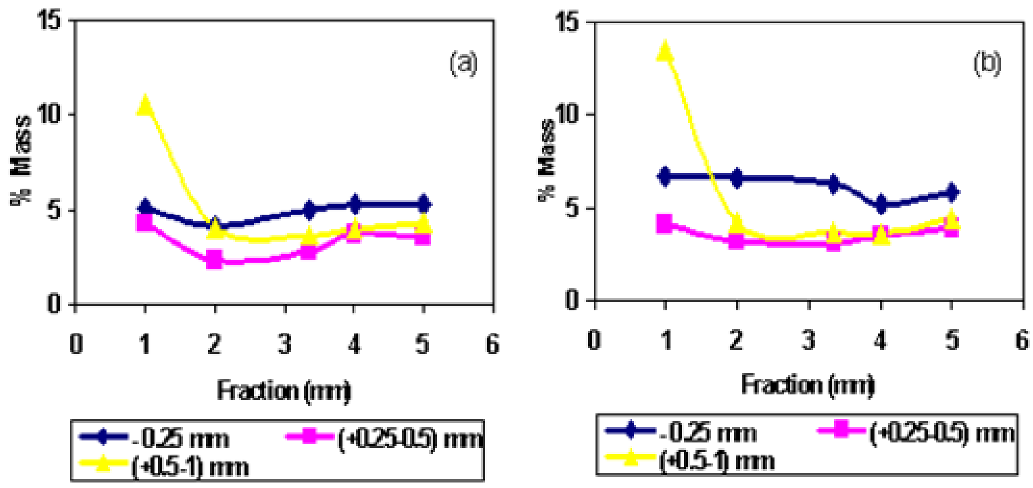


Figure 33. Adhesion of fine particles (x< 1 mm) to nuclear particles (x >1 mm) at 5% of moisture.

Table 24. Sieves analysis of granulated Phoenix iron ore-Sishen iron ore-unsized fluxes mixture at 5% of moisture content.

%(-0.25 mm)

Fraction (mm)	**+ 5**	**(- 5 + 4)**	**(-4 + 3.35)**	**(-3.35 + 2)**	**(-2 + 1)**
Sample a	5.29	5.26	4.99	4.15	5.06
Sample b	5.84	5.16	6.28	6.61	6.67
Average	5.57	5.21	5.64	5.38	5.87
Standard deviation	0.39	0.07	0.91	1.74	1.14

%(+0.25 – 0.5) mm

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	3.54	3.73	2.80	2.31	4.27
Sample b	3.89	3.46	3.08	3.19	4.07
Average	3.72	3.60	2.94	2.75	4.17
Standard deviation	0.25	0.19	0.20	0.62	0.14

%(+ 0.5 – 1) mm

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	4.30	3.98	3.65	4.06	10.58
Sample b	4.40	3.58	3.67	4.18	13.50
Average	4.35	3.78	3.66	4.12	12.04
Standard deviation	0.07	0.28	0.01	0.08	2.06

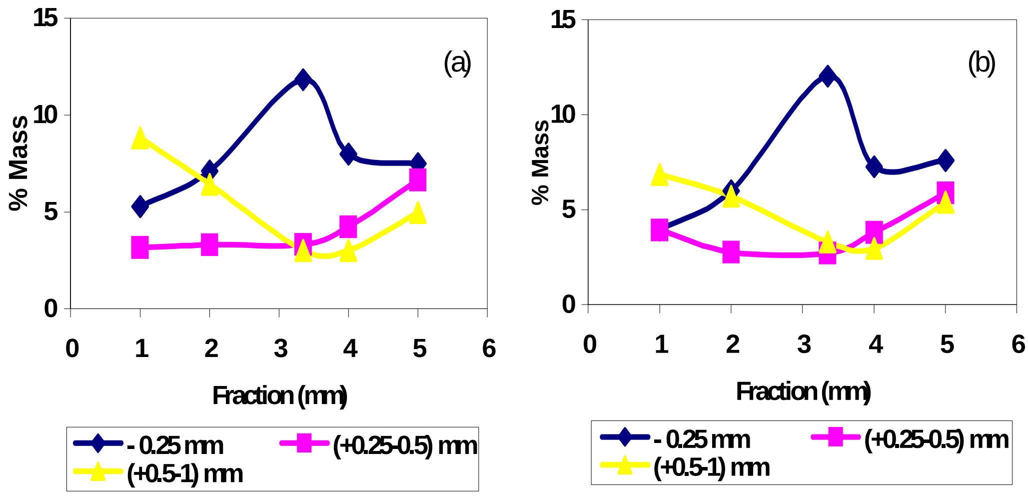


Figure 34. Adhesion of fine particles (x< 1 mm) to nuclear particles (x>1 mm) at 6% moisture content.

Figures 34a and 34b show the adhesion of fine particles to nuclear particles at a high moisture content of 6%. Above the optimum moisture content, all classes take part in granulation. Class –0.25 mm report preferentially to (-4 + 3.35 mm) size fraction, while class (–1+0.5) mm adhere preferentially to the (-2 + 1) mm size fraction and class (–0.5 + 0.25) mm adhere preferentially to the +5 mm size fraction.

Table 25. Sieves analysis of granulated Phoenix iron ore-Sishen iron ore-unsized fluxes mixture at 6 % of moisture content.

%(-0.25 mm)

Fraction (mm)	**+ 5**	**(- 5 + 4)**	**(-4 + 3.35)**	**(-3.35 + 2)**	**(-2 + 1)**
Sample a	7.50	7.97	11.83	7.12	5.27
Sample b	7.60	7.26	12.03	5.99	3.92
Average	7.55	7.62	11.93	6.56	4.59
Standard deviation	0.07	0.50	0.14	0.80	0.96

%(+0.25 – 0.5) mm

Fraction (mm)	**+ 5**	**(- 5 + 4)**	**(-4 + 3.35)**	**(-3.35 + 2)**	**(-2 + 1)**
Sample a	6.65	4.22	3.33	3.31	3.16
Sample b	5.87	3.80	2.71	2.76	3.92
Average	6.26	4.01	3.02	3.04	3.54
Standard deviation	0.55	0.30	0.44	0.39	0.53

%(+ 0.5 – 1) mm

Fraction (mm)	+ 5	(- 5 + 4)	(-4 + 3.35)	(-3.35 + 2)	(-2 + 1)
Sample a	4.96	3.02	3.01	6.43	8.83
Sample b	5.40	2.96	3.30	5.71	6.85
Average	5.18	2.99	3.16	6.07	7.84
Standard deviation	0.31	0.04	0.21	0.51	1.40

IV.6 Sintering.

Tables 26 to 30 summarise the results from 18 sinter pot tests that were performed on the optimised mixtures. The compositions of the mixture are shown in Tables 6 and 7. This was done in order to evaluate how optimisation of the grain size distribution of the sinter mixture effects the sintering time, sinter yield, productivity, and sinter quality. Tables 26 and 27 represent respectively the sintering pot test results of mixtures I and II, where the coke, lime and return fines were sized. Tables 28 and 29 represent the sintering pot test results of mixtures III and IV where only the coke and lime were sized. The ratio of Thabazimbi iron ore and Sishen iron ore was 50 – 50% in mixtures I and IV, and 20 – 80% in the mixtures II and III. The quality of the produced sinter was evaluated by taking into account the sinter specifications especially the ratio of fines (0.95-1.05), the amount of FeO (7.0-9.0 mass %), and the productivity.

IV.6.1 Definitions of sintering process parameters [31].

The main purpose of sinter pot studies is to quantify the common indicators of performance, which are: Productivity, yield, sintering time, coke rate, sinter ratio fine and sinter quality.

Productivity.

The productivity or production rate is a very important parameter whereby the capacity of the sinter plant is judged. It is expressed as the mass of sinter in tons (+ 5 mm) produced per square meter of the pot per day ($t/m^2/24h$). It is calculated from the sintering time, the cross sectional area of the pot grate and the weight of product sinter recovered from the test, less the weight of the hearth layer.

Sinter fines ratio.

The sinter fines ratio is expressed as the weight of fines generated over the weight of fines returned to green feed. It needs to be close to 1 as possible. A sinter is considered to be ‘in’ or acceptable if the ratio is between 0.95 and 1.05.

Fuel Rate.

The fuel rate is defined as the weight (in kilograms) of dry coke required to produce one tone of product sinter. It is expressed in kilograms per tonne of sinter produced.

Sinter FeO content.

The sinter FeO content is a measure of the magnetite content of the sinter. It is the most popular technique to control the sinter plant coke rate. A value of between 7 –9 mass percent is acceptable for the sinter plant.

Coke in Mixture.
The coke in the sinter mixture is expressed as a mass percentage on ore basis.

Return Fines. The sinter return fines is the mass percent of - 5 mm material. It is expressed in mass percentage.

Sintering time.

The sintering time is defined as the time from the start of bed ignition to the time when the waste gas temperature reaches a maximum. It is expressed in minutes.

Yield.

The yield is the ratio of mass of sinter produced to the total mass of raw materials fed into the process, expressed as a percentage.

IV.6.2 Base case.

There is no specified sintering time, productivity, or fuel consumption whereby the effectiveness of the sintering process is evaluated. A short sintering time with associated high productivity is considered to be good.

At Kumba Iron Ore pilot plant, the productivity for a 50% Thabazimbi iron ore 50% Sishen iron ore mixture with unsized fluxes is often less than 30 tons per day per square meter and the sintering time more than 22 minutes. In Table 30, the base case is a mixture of 50% Thabazimbi iron ore, 50% Sishen iron ore with unsized fluxes.

Many sintering tests were done on the 4 mixtures, and for each mixture one sinter test were taken for analysis of the quality of the sinter according to the sinter specifications in terms of the ratio of fines (0.95 – 1.05), the FeO content (7 – 9), the productivity, the sintering time and the -5 mm size fraction. A high productivity, a short time and a less amount of - 5 mm size fraction of sinter were preferred. The Test 9 for mixture I, Test 4 for mixture II, Test 2 for mixture III and Test 3 for mixture IV were selected. In each mixture the test 1 were done in the aim to produce return fines which can be used for others test.

Table 26. Sintering results of mixture I

Test	Prod.	Ratio	Fuel	FeO	Coke	R.F	Time	-5 mm
1	30.18	1.068	83.33	7.33	4.50	26.00	22.38	33.838
2	32.01	0.889	87.79	8.48	4.75	24.00	20.37	36.16
3	31.46	0.934	88.30	8.69	4.75	25.00	20.82	36.208
4	34.55	0.929	85.34	7.98	4.60	26.00	18.97	37.802
5	33.22	1.039	85.28	9.02	4.50	28.00	19.95	36.418
6	30.82	0.952	82.85	8.53	4.40	27.00	21.27	38.914
7	39.27	1.14	73.86	6.78	4.40	27.00	18.35	31.844
8	30.92	1.012	81.52	8.21	4.40	28.00	21.52	37.882
9	31.17	1.035	80.6	8.38	4.40	28.00	21.15	36.284
Average	32.62	1.000	83.21	8.16	4.52	26.56	20.53	36.150
Standard Deviation	2.83	0.08	4.37	0.70			1.27	2.16

Table 27. Sintering results of mixture II

Test	Prod.	Ratio	Fuel	FeO	Coke	R.F	Time	-5 mm
1	30.38	1.020	79.88	8.19	4.40	28.00	21.92	36.880
2	31.06	0.977	83.19	8.05	4.40	28.00	20.27	37.900
3	33.05	0.959	82.33	8.18	4.40	28.00	19.22	38.536
4	31.89	1.003	79.38	7.91	4.40	28.00	20.98	37.426
Average	31.60	0.990	81.20	8.08	4.40	28.00	20.60	37.686
Standard Deviation	1.15	0.03	1.86	0.13			1.14	0.70

Table 28. Sintering results of mixture III

Test	Prod.	Ratio	Fuel	FeO	Coke	R.F	Time	-5 mm
1	31.44	1.032	78.19	7.46	4.40	28.00	21.45	36.142
2	30.97	0.995	80.44	7.78	4.50	27.00	21.63	36.110
Average	31.21	1.014	79.32	7.62	4.45	27.50	21.54	36.126
Standard Deviation	0.33	0.03	1.59	0.23			0.13	0.02

Table 29. Sintering results of mixture IV

Test	Prod.	Ratio	Fuel	FeO	Coke	R.F	Time	-5mm
1	32.31	1.040	82.27	7.89	4.40	28.00	20.08	36.296
2	33.81	1.057	80.82	7.78	4.50	27.00	20.10	34.658
3	28.81	1.043	80.96	8.55	4.60	26.00	23.27	32.674
Average	31.64	1.047	81.35	8.07	4.50	27.00	21.15	34.543
Standard Deviation	2.57	0.01	0.80	0.42			1.84	1.82

Table 30 shows the sintering properties of the sinter retained for each type of sinter mixture. It reveals that the sintering properties varied slightly and that the sinter results of all the tests on mixtures I –IV are very similar. All the sinter properties of the optimised mixtures are better than those of the base case sinter except for the TI (%+6.3mm). The sintering time was shortened in all the tested mixture, and the product yield and productivity have been improved. The sintering times for all the produced sinters are less than 22 minutes, compared to 26 minutes for the base case sinter. The yields of sinter mixtures I – IV range between 82 and 84%, which are substantially higher than for the base case sinter (72%). The productivities of the produced sinters range between 31 – 34t/day/m^2, compared to 24.3t/day/m^2 for the base case sinter. Sizing of the coke, lime, and return fines also decreased the coke rate (< 81 kg/t. sinter) compared to the base case (> 90 kg/t. sinter). The RDI of all the produced sinters did not reach the acceptable requirement of RDI-$1_{-0.50} \geq 5\%$ and RDI-$1_{+3.15} > 70\%$.

Table 30. The sintering properties of the optimised mixtures.

	Mixture I	Mixture II	Mixture III	Mixture IV	Base case
Productivity. (t/24h/m^2)	31.17	31.89	30.97	33.81	24.30
Coke rate. (Kg/t.sinter)	80.60	79.38	80.44	80.82	93.26
Yield (%)	82.28	83.93	83.63	81.91	71.91
Sintering time (minutes)	21.15	20.98	21.63	20.10	25.70
TI (% + 6.3 mm)	71.00	71.15	71.42	71.34	73.75
TI (% -6.3 + 0.5 mm)	23.90	23.16	23.00	23.55	20.44
AI (% -0.5 mm)	5.10	5.69	5.58	5.11	5.81
RDI (% +6.30 mm)	29.15	19.70	25.00	30.30	21.88
RDI (% +3.15 mm)	64.50	57.95	60.75	66.70	62.31
RDI (% -0.50 mm)	5.25	5.90	5.70	5.00	5.53
RI (%/min)	1.45	1.52	1.25	1.15	1.60
Moisture (%)	5.50	4.50	4.50	5.50	5.25
G.I*	198.94	196.51	197.33	197.94	197.61

* As defined by Kumba Iron Ore (section III.2.2.1)

In comparing the properties of the four sinters, the sinter made from mixture IV in which the blend contained 50% Thabazimbi iron ore and 50% Sishen iron ore, and in which the coke and limestone were sized, had the shortest sintering time (20.10 min.), the highest productivity (33.81t/24h/m^2), a good RI (1.15%/min.), the highest [RDI (% +3.15mm)] (66.70%) and the lowest [RDI (% - 0.5mm)] (5%). Mixture II that contained 20% Thabazimbi iron ore and 80% Sishen iron ore, in which, coke, lime, and return fines were sized has the highest Yield (83.93%) and lowest coke rate (79.4kg/t.sinter), and is considered to be second best to Mixture IV with regards to the productivity and sintering time. Appendix III gives the results of chemical compositions of the sinters, as were determined by XRF analysis. The chemical compositions of all the mixtures are almost the same with high iron oxide contents, (~ 81 mass %), lime (9.3 – 9.6 mass %), silica (4.7 – 5.0 mass %), MgO (~ 2.9 mass %) and alumina (1.3 – 1.5 mass %).

Quantification of the phases present in the produced sinters was done by the manual point counting technique (Table 31). Figure 35 shows the mineral compositions of the 5 sinters investigated. Mixture III contained the highest amount of total SFCA, followed by mixture I, mixture II, the base case and mixture IV. Mixture III has more relict hematite, and less magnetite than mixtures I, II, and IV. Mixture IV although presenting good sintering properties has the lowest amounts of total SFCA, acicular SFCA and columnar SFCA, and also contains more magnesioferrite than mixture I, II and III. All the mixtures contain more relict hematite than the base case sinter.

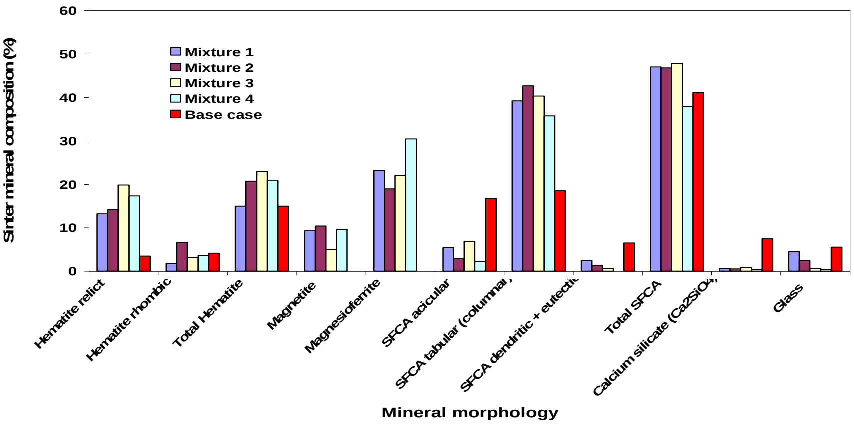


Figure 35. Mineral composition of sinters.

Table 31. Mineralogical and morphological analysis (vol. %)

Mineral morphology	Mixture I	Mixture II	Mixture III	Mixture IV	Base case
Hematite relict	13.2	14.1	19.8	17.3	3.5
Hematite rhombic	1.8	6.6	3.1	3.6	4.1
Hematite Finely granular	-	-	-	-	1.9
Hematite skeletal	-	-	-	-	5.5
Total Hematite	15	20.7	22.9	20.9	15
Magnetite	9.3	10.4	5.0	9.6	-
Magnesioferrite	23.2	18.9	22.0	30.4	-
Total Spinel(magnetite + magnesioferrite)	32.5	29.3	27.0	40.0	30.2
SFCA acicular	5.4	2.9	6.9	2.2	16.7
SFCA tabular (columnar)	39.2	42.6	40.3	35.7	18.5
SFCA dendritic + eutectic	2.4	1.3	0.6	0.0	6.5
Total SFCA	47	46.8	47.8	37.9	41.1
Calcium silicate (Ca_2SiO_4)	0.6	0.5	0.9	0.4	7.4
Glass	4.5	2.4	0.6	0.4	5.5
Periclase	0.0	0.0	0.3	0.0	-

CHAPTER V CONCLUSIONS

Optimisation of the grain size distribution of the raw material mixture in the production of iron sinter was studied by using granulation and permeability tests. The following conclusions can be drawn from the test results:

Sishen iron ore has less fine particles, and is more permeable than Thabazimbi iron ore.

The permeability of the granulated mixture of Thabazimbi iron ore and Sishen iron ore without fluxes can be increased by increasing the Sishen iron ore content in the blend. That is presumably due to the fact that the Sishen iron ore has less fine particles than Thabazimbi iron ore.

The granulation effectiveness and the permeability in terms of Japanese Permeability Unit (JPU), was the best at any granulation time (2-10 minutes) for the mixture that contained 20% Thabazimbi iron ore, 80% Sishen iron ore and fluxes where the coke, lime and return fines were sized.

Graphs representing the influence of moisture content on permeability follow a gaussian curve. The plots of bed permeability versus moisture content are not therefore straight lines, but inverted V-shapes: As water addition increases, the permeability increases and the granulation effectiveness improves resulting in the formation of large particles, but when water addition is increasing beyond the optimum value bed permeability deteriorates.

The growth in mean granule diameter during granulation is a function of the initial mean diameter before granulation, the amount of moisture, and the granulation time. As the time increases, the mean granule diameter increases up to a certain value and then starts to decrease. With further increase in time the mean granule restarts the same phenomenon. The same phenomenon was observed when the influence of moisture content on the mean granule diameter was examined. The trends of these curves have sinusoidal forms.

The mean granule diameter does not predict the permeability of the bed.

Four sinter compositions, in which different Thabazimbi iron ore: Sishen iron ore ratios were used, and the sized fluxes to different degrees, were selected on the basis of their permeabilities for sinter pot tests. These sinter were: Mixture I, (50% Thabazimbi iron ore, 50% Sishen iron ore, with coke, lime and return fines sized), Mixture II (20% Thabazimbi iron ore, 80% Sishen iron ore, with coke, lime and return fines sized), Mixture III (20% Thabazimbi iron ore, 80% Sishen iron ore with coke and lime sized), and Mixture IV (50% Thabazimbi iron ore , 50% Sishen iron ore, with coke and lime sized). The sinter properties of the four optimised sinters were found to be similar, but better than the base case sinter in which the fluxes were not sized. Mixture IV showed the best sinter properties with regard to the shortest sintering time and the highest productivity, with acceptable, (RI>1% min), TI (>70%) and lowest [RDI (% -0.50 mm)] (5%).

CHAPTER VI RECOMMENDATIONS FOR FUTURE WORK

The optimisation of the grain size distribution of the sinter mixture is dependant on the composition of the raw materials and its particle size distribution, while the heat pattern also influences sinter quality.

In this first study the optimisation of the grain size distribution was investigated by monitoring the granulation characteristic. (Green permeability, moisture content, and granulation time).

Because granulation is an important step in producing iron sinter, it suggested that different sequences whereby coke breeze and limestone are coated on to the surface of the quasi-particle, be examined during granulation. [26]

The effect of heat distribution through the sinter bed, on sinter quality, should also be examined.

REFERENCES.

[1]. ANIL K. BISWAS. 1981. **“Principles of Blast Furnace Ironmaking**” *University of Queensland, Brisbane, Australia.* Page 194.

[2]. VENKATARAMANA R., GUPTA S.S. & KAPUR P.C 1999. “**A Combined Model for Granule Size Distribution and Cold Bed Permeability in the Wet Stage of Iron Ore Sintering Process**” *Int. J. of Mineral Processing*, **57**, pages 43-58.

[3]. WILLIAM J. RANKIN& JOHN F. GANNON. “**The Effect of Raw Mixture Properties on Bed Permeability during Sintering**”. *ISIJ International*, Vol. 29 (1989), No. 1, pages 33-42.

[4]. GERHARD C., LAWRENCE G., OKKAR P., GERHARD P., HANS S., JOHANNES W. “Perfect **Sinter – The Dream of the Blast Furnace Operator**” *Iron& Steel Review*, March 2002, pages 2-6.

[5]. YASUSHI I., YASUTO S. & HIDEO T. “**Improvement of Sinter Quality based on the Mineralogical Properties of Ores**.” *Nippon Steel Corporation, Japan.*

[6]. JACOBUS W. J., MEng thesis 2002. **“The Variation of Sinter Strength in the Sinter Bed due to the Mineral Phase Distribution**.” *University of Pretoria*, pages1-2.

[7]. PETERS K.H., BEER H., KROPLA H.W and MULLER H. 1990 “**Effect of Coke Size Distribution in the Mix on the Iron ore Sintering Process**”. *Proceeding of the sixth International Iron and Steel Congress, Nagoya, ISIJ,* pages 103-109.

[8]. HOSOTANI Y., KONNO N., YAMAGUCHI K., ORIMOTO T., INAZUMI T. **“Reduction Properties of Sinter with fine Dispersed Pores at High Temperatures of 1273K and Above”** *ISIJ International*, Vol. 45 (1996), No. 12, pages 1439-1447.

[9]. Personal Communication with Kumba Iron Ore Personnel.

[10]. BA Wills “**Mineral Processing Technology**” 3rd edition, Camborne school of Mines, Cornwall, England. Pages 96,97.

[11]. ALLEN T.1990. “**Particle Size Measurement**.” 4th Edition, Chapman*&Hall, London, New York.* Page 125.

[12]. CADLE R.D. 1980. **"Testing and Characterisation of Powders and Fine particles**". Pages 56-65. *National Centre Atmospheric research, USA.*

[13]. "**Particle Size Measurement and Distribution**" [online] Available.

http://www.engin.umich.edu/class/che360/coursepack/ch15-PSD.doc

[14]. FERRARIS C.F., HACKLEY V.A, AVILES A.I. & BUCHANAN C.E., May 2002
"**ASTM Round-Robin Test on Particle Size Distribution of Portland Cement**." *National Institute of Standards and Technology Internal Report 6883, U.S. Department of Commerce Technology Administration.*

[15]. FORMOSO A., MORO A., FERNANDEZ G., MENENDEZ J.L., MUNIZ M. &CORES A. 2003 "**Influence of Nature and Particle Size Distribution on Granulation of Iron ore Mixtures used in a Sinter strand**." *Iron making and Steelmaking*, vol. 30, No. 6, page 447-460.

[16]. LISTER J.D., WATERS A.G., NICOL S.K. 1989 "**Mechanisms of Iron ore Granulation**" *5th International Symposium on Agglomeration, Brisbane, Australia*. pages 33-49.

[17]. LOO C.E. & LEANEY J.C.M. April 2002 "**Characterising the Contribution of the High-Temperature zone to Iron ore Sinter Bed Permeability**." *Trans.Institution of Mining and Metallurgy*.C11- C17

[18]. POOT E, MEUNIER G, VIDAL R. "**Contribution to the Rational Composition of the Raw Material Mix for the Production of Ultra High Reducible Sinter."** *Centre de Recherches Metallurgiques, Liege, Belgium*. Pages 337-345.

[19]. SAHOO K.C., LAHIRI D.K., SUNDERMURTHY V., BARPANDA S. **"Effect of Ultrafines on Sinter Quality."** 1991. *3rd International Symposium on Beneficiation and Agglomeration, Bhubaneswar, India.* Pages 421-433.

[20]. DAWSON PR. 1993. "**Research Studies on Sintering and Sinter Quality**." *Ironmaking and Steelmaking* vol 20. No 2. Pages 137-143.

[21]. MUKHERJEE, T. ET. AL 1985. "**Structure of Fluxed Sinter**" *Ironmaking and Steelmaking* vol. 12 no. 4. Pages C151-C155.

[22]. K Vreugdenburg, MS Schoeman, A Garbers-Craig, PA Botha."**Applied Mineralogy in Sinter Processes**" 12-13 October 2004, *In house Kumba Iron Ore Course.*

[23]. WILHEMINA FREDRIKA VAN DER VYVER. 1998 "**Evaluation of the REAS test for Blast Furnace charge materials**". *MSc Thesis, University of Pretoria,*
pages 13-23.

[24]. VOLKER. J. RITZ, HEINRICH. A.KORTMANN. 1998. "**Reduction, Softening and Melting Properties of Pellets, Sinters, Lumpy Ore and Mixed Blast furnace Burden**."*ICSTI/Ironmaking conference proceedings* Pages 1635-1654.

[25]. BHAGAT R.P. 1999. **"Factors affecting Return sinter fines regimed and Strand productivity in Iron ore Sintering"** *Mineral processing division, ISIJ International*, Vol. 39(1999), No. 9, pages 889-895.

[26]. OYOMA N., SATO H., TAKEDA K. ARIYAMA T., MASUMOTO S. JINNO T. FUJII N. 2005. **"Development of Coating Granulation Process at Commercial Plant for Improving Productivity and Reducibility**" *ISIJ International*, Vol. 45 (2005), No. 6, pages 817-826.

[27]. Li-HENG HSIEH. **"Effect of Raw Material Composition on the Sintering Properties**" *ISIJ International*, Vol. 45 (2005), No. 4, pages 551-559.

[28]. C.E LOO, D.J WONG. **"Fundamental Factors Determining Laboratory Sintering Results**" *ISIJ International*, Vol. 45 (2005), No. 4, pages 449-458.

[29]. C.E LOO. **"A Perspective of Goethitic Ore Sintering Fundamentals**" *ISIJ International*, Vol. 45 (2005), No. 4, pages 436-448.

[30]. J. OKAZAKI, K> HIGUCHI **"Marra Mamba Ore, Its Mineralogical Properties and Evaluation for Utilization**" *ISIJ International*, Vol. 45 (2005), No. 4, pages 544-550.

[31]. T. MAEDA, C. FUKUMOTO, T. MATSUMURA, K. NISHIOKA, M. SHIMIZU
"Effect of Adding Moisture and Wettability on Granulation of Iron Ore". *ISIJ International*, Vol. 45 (2005), No. 4, pages 477-484.

APPENDIX I

Sieves analysis of Thabazimbi iron ore.

Thabazimbi 1

Fraction (mm)	Mass(g)	%mass	Cum.Mass (%)
12.50	18.00	0.18	0.18
10.00	40.00	0.40	0.58
8.00	96.10	0.96	1.54
6.30	724.90	7.25	8.79
5.00	1248.00	12.48	21.28
4.00	834.20	8.34	29.62
3.35	759.70	7.60	37.22
2.00	1796.30	17.97	55.19
1.00	1502.80	15.03	70.22
-1.00	2977.00	29.78	100.00
Total	9997.00	100.00	

second input (-1 mm)			
Fraction (mm)	Mass(g)	%mass	Cum. Mass(%)
0.50	120.80	28.69	28.69
0.25	101.30	24.06	52.74
0.13	85.60	20.33	73.07
0.11	16.40	3.89	76.97
0.08	36.00	8.55	85.51
0.05	38.20	9.07	94.59
0.05	15.40	3.66	98.24
-0.05	7.40	1.76	100.00
Total	421.10	100.00	

sieve analysis			Linear		Geometric	
Fraction (mm)	%mass	Cum. Mass	Dp	calc	Dp	Calc
12.50	0.18	0.18	14.25	0.03		
10.00	0.40	0.58	11.25	0.05	11.18	0.04
8.00	0.96	1.54	9.00	0.09	8.94	0.09
6.30	7.25	8.79	7.15	0.52	7.10	0.51
5.00	12.48	21.28	5.65	0.71	5.61	0.70
4.00	8.34	29.62	4.50	0.38	4.47	0.37
3.35	7.60	37.22	3.68	0.28	3.66	0.28
2.00	17.97	55.19	2.68	0.48	2.59	0.47
1.00	15.03	70.22	1.50	0.23	1.41	0.21
0.50	8.54	78.76	0.75	0.06	0.71	0.06
0.25	7.16	85.93	0.38	0.03	0.35	0.03
0.13	6.05	91.98	0.19	0.01	0.18	0.01
0.11	1.16	93.14	0.12	0.00	0.12	0.00
0.08	2.55	95.69	0.09	0.00	0.09	0.00
0.05	2.70	98.39	0.06	0.00	0.06	0.00
0.05	1.09	99.48	0.05	0.00	0.05	0.00
-0.05	0.52	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.85		2.78

APPENDIX I

Sieves analysis of Thabazimbi iron ore.

Thabazimbi 2

Fraction (mm)	Mass(g)	%mass	Cum. Mass (%)
12.50	9.50	0.10	0.10
10.00	41.00	0.41	0.51
8.00	62.50	0.63	1.13
6.30	709.40	7.09	8.22
5.00	1132.50	11.33	19.55
4.00	827.00	8.27	27.82
3.35	736.90	7.37	35.19
2.00	1873.50	18.74	53.93
1.00	1532.60	15.33	69.25
-1.00	3074.50	30.75	100.00
Total	9999.40	100.00	

second input (-1 mm)			
Fraction(mm)	Mass(g)	%mass	Cum.Mass (%)
0.50	204.80	26.82	26.82
0.25	168.30	22.04	48.85
0.13	163.00	21.34	70.20
0.11	23.80	3.12	73.31
0.08	82.70	10.83	84.14
0.05	62.70	8.21	92.35
0.05	34.90	4.57	96.92
-0.05	23.50	3.08	100.00
Total	763.70	100.00	

sieve analysis			Linear		Geometric	
Fraction (mm)	%mass	Cum. Mass	Dp	calc	Dp	Calc
12.50	0.10	0.10	14.25	0.01		
10.00	0.41	0.51	11.25	0.05	11.18	0.05
8.00	0.63	1.13	9.00	0.06	8.94	0.06
6.30	7.09	8.22	7.15	0.51	7.10	0.50
5.00	11.33	19.55	5.65	0.64	5.61	0.64
4.00	8.27	27.82	4.50	0.37	4.47	0.37
3.35	7.37	35.19	3.68	0.27	3.66	0.27
2.00	18.74	53.93	2.68	0.50	2.59	0.49
1.00	15.33	69.26	1.50	0.23	1.41	0.22
0.50	8.25	77.51	0.75	0.06	0.71	0.06
0.25	6.78	84.28	0.38	0.03	0.35	0.02
0.13	6.56	90.85	0.19	0.01	0.18	0.01
0.11	0.96	91.80	0.12	0.00	0.12	0.00
0.08	3.33	95.13	0.09	0.00	0.09	0.00
0.05	2.52	97.66	0.06	0.00	0.06	0.00
0.05	1.41	99.06	0.05	0.00	0.05	0.00
-0.05	0.95	100.01	0.02	0.00	0.03	0.00
Total	100.01			2.74		2.68

APPENDIX I

Sieves analysis of Thabazimbi iron ore.

Thabazimbi 3

Fraction (mm)	Mass (g)	%Mass	Cum. Mass
12.50	0.00	0.00	0.00
10.00	20.40	0.20	0.20
8.00	51.50	0.52	0.72
6.30	635.00	6.36	7.08
5.00	931.30	9.33	16.40
4.00	980.60	9.82	26.22
3.35	446.40	4.47	30.69
2.00	1807.20	18.10	48.79
1.00	1641.60	16.44	65.22
-1.00	3473.00	34.78	100.00
Total	9987.00	100.00	

Second input (-1 mm)			
Fraction (mm)	Mass (g)	%Mass	Cum.Mass
0.50	112.30	27.63	27.63
0.25	104.80	25.78	53.41
0.13	102.20	25.14	78.55
0.11	29.70	7.31	85.85
0.08	35.50	8.73	94.59
0.05	14.70	3.62	98.20
0.05	6.40	1.57	99.78
-0.05	0.90	0.22	100.00
Total	406.50	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.20	0.20	11.25	0.02	11.18	0.02
8.00	0.52	0.72	9.00	0.05	8.94	0.05
6.30	6.36	7.08	7.15	0.45	7.10	0.45
5.00	9.33	16.40	5.65	0.53	5.61	0.52
4.00	9.82	26.22	4.50	0.44	4.47	0.44
3.35	4.47	30.69	3.68	0.16	3.66	0.16
2.00	18.10	48.79	2.68	0.48	2.59	0.47
1.00	16.44	65.22	1.50	0.25	1.41	0.23
0.50	9.61	74.83	0.75	0.07	0.71	0.07
0.25	8.97	83.80	0.38	0.03	0.35	0.03
0.13	8.74	92.54	0.19	0.02	0.18	0.02
0.11	2.54	95.08	0.12	0.00	0.12	0.00
0.08	3.04	98.12	0.09	0.00	0.09	0.00
0.05	1.26	99.38	0.06	0.00	0.06	0.00
0.05	0.55	99.92	0.05	0.00	0.05	0.00
-0.05	0.08	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.52		2.47

APPENDIX I

Sieves analysis of Thabazimbi iron ore.

Thabazimbi 4

Fraction (mm)	Mass (g)	%Mass	Cum. Mass
12.50	6.30	0.06	0.06
10.00	41.20	0.41	0.48
8.00	56.60	0.57	1.04
6.30	600.00	6.00	7.04
5.00	993.00	9.93	16.98
4.00	773.70	7.74	24.72
3.35	691.10	6.91	31.63
2.00	1842.80	18.43	50.06
1.00	1628.90	16.29	66.36
-1.00	3363.10	33.64	100.00
Total	9996.70	100.00	

Second input (-1 mm)			
Fraction (mm)	Mass (g)	%Mass	Cum. Mass
0.50	150.80	32.04	32.04
0.25	114.00	24.22	56.25
0.13	141.30	30.02	86.27
0.11	28.80	6.12	92.39
0.08	32.10	6.82	99.21
0.05	0.22	0.05	99.26
0.05	3.10	0.66	99.92
-0.05	0.40	0.08	100.00
Total	470.72	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.06	0.06	14.25	0.01		
10.00	0.41	0.48	11.25	0.05	11.18	0.05
8.00	0.57	1.04	9.00	0.05	8.94	0.05
6.30	6.00	7.04	7.15	0.43	7.10	0.43
5.00	9.93	16.98	5.65	0.56	5.61	0.56
4.00	7.74	24.72	4.50	0.35	4.47	0.35
3.35	6.91	31.63	3.68	0.25	3.66	0.25
2.00	18.43	50.06	2.68	0.49	2.59	0.48
1.00	16.29	66.36	1.50	0.24	1.41	0.23
0.50	10.78	77.14	0.75	0.08	0.71	0.08
0.25	8.15	85.28	0.38	0.03	0.35	0.03
0.13	10.10	95.38	0.19	0.02	0.18	0.02
0.11	2.06	97.44	0.12	0.00	0.12	0.00
0.08	2.29	99.73	0.09	0.00	0.09	0.00
0.05	0.02	99.75	0.06	0.00	0.06	0.00
0.05	0.22	99.97	0.05	0.00	0.05	0.00
-0.05	0.03	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.57		2.51

APPENDIX I

Sieves analysis of Thabazimbi iron ore.

Thabazimbi 5

Fraction (mm)	Mass (g)	%Mass	Cum. Mass
12.50	16.00	0.16	0.16
10.00	32.30	0.32	0.48
8.00	68.00	0.68	1.16
6.30	509.50	5.10	6.27
5.00	798.80	8.00	14.26
4.00	662.90	6.64	20.90
3.35	610.00	6.11	27.01
2.00	1708.50	17.11	44.11
1.00	1728.00	17.30	61.41
-1.00	3854.00	38.59	100.00
Total	9988.00	100.00	

Second input (-1 mm)			
Fraction (mm)	Mass (g)	%Mass	Cum. Mass
0.50	138.50	27.99	27.99
0.25	126.80	25.62	53.61
0.13	108.00	21.82	75.43
0.11	31.00	6.26	81.69
0.08	45.20	9.13	90.83
0.05	31.40	6.34	97.17
0.05	8.20	1.66	98.83
-0.05	5.80	1.17	100.00
Total	494.90	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.16	0.16	14.25	0.02		
10.00	0.32	0.48	11.25	0.04	11.18	0.04
8.00	0.68	1.16	9.00	0.06	8.94	0.06
6.30	5.10	6.27	7.15	0.36	7.10	0.36
5.00	8.00	14.26	5.65	0.45	5.61	0.45
4.00	6.64	20.90	4.50	0.30	4.47	0.30
3.35	6.11	27.01	3.68	0.22	3.66	0.22
2.00	17.11	44.11	2.68	0.46	2.59	0.44
1.00	17.30	61.41	1.50	0.26	1.41	0.24
0.50	10.80	72.21	0.75	0.08	0.71	0.08
0.25	9.89	82.10	0.38	0.04	0.35	0.03
0.13	8.42	90.52	0.19	0.02	0.18	0.01
0.11	2.42	92.94	0.12	0.00	0.12	0.00
0.08	3.52	96.46	0.09	0.00	0.09	0.00
0.05	2.45	98.91	0.06	0.00	0.06	0.00
0.05	0.64	99.55	0.05	0.00	0.05	0.00
-0.05	0.45	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.32		2.25

APPENDIX I

Sieves analysis of Sishen iron ore.

Sishen 1

Fraction (mm)	Mass (g)	%Mass	Cum.Mass
12.50	0.00	0.00	0.00
10.00	39.50	0.40	0.40
8.00	150.50	1.51	1.90
6.30	349.70	3.50	5.40
5.00	1081.30	10.82	16.23
4.00	1970.00	19.72	35.94
3.35	598.80	5.99	41.94
2.00	2596.80	25.99	67.93
1.00	1635.00	16.37	84.30
-1.00	1569.00	15.70	100.00
Total	9990.60	100.00	

Second input (-1mm)			
Fraction (mm)	Mass (g)	%Mass	Cum.Mass
0.50	214.40	58.68	58.68
0.25	100.90	27.61	86.29
0.13	48.80	13.36	99.64
0.11	1.00	0.27	99.92
0.08	0.10	0.03	99.95
0.05	0.20	0.05	100.00
0.05	0.00	0.00	100.00
-0.05	0.00	0.00	100.00
Total	365.40	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.40	0.40	11.25	0.04	11.18	0.04
8.00	1.51	1.90	9.00	0.14	8.94	0.13
6.30	3.50	5.40	7.15	0.25	7.10	0.25
5.00	10.82	16.23	5.65	0.61	5.61	0.61
4.00	19.72	35.94	4.50	0.89	4.47	0.88
3.35	5.99	41.94	3.68	0.22	3.66	0.22
2.00	25.99	67.93	2.68	0.70	2.59	0.67
1.00	16.37	84.30	1.50	0.25	1.41	0.23
0.50	9.21	93.51	0.75	0.07	0.71	0.07
0.25	4.34	97.85	0.38	0.02	0.35	0.02
0.13	2.10	99.94	0.19	0.00	0.18	0.00
0.11	0.04	99.99	0.12	0.00	0.12	0.00
0.08	0.00	99.99	0.09	0.00	0.09	0.00
0.05	0.01	100.00	0.06	0.00	0.06	0.00
0.05	0.00	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			3.18		3.12

APPENDIX I

Sieves analysis of Sishen iron ore.

Sishen 2

Fraction (mm)	Mass (g)	%Mass	Cum. Mass
12.50	0.00	0.00	0.00
10.00	20.10	0.20	0.20
8.00	98.60	0.99	1.19
6.30	287.20	2.87	4.06
5.00	795.70	7.96	12.02
4.00	1898.80	18.99	31.01
3.35	907.30	9.07	40.08
2.00	2559.90	25.60	65.68
1.00	1588.70	15.89	81.57
-1.00	1828.60	18.29	100.00
Total	9999.40	100.00	

Second input (-1 mm)			
Fraction (mm)	Mass (g)	%Mass	Cum.Mass
0.50	164.40	40.83	40.83
0.25	131.30	32.61	73.45
0.13	95.60	23.75	97.19
0.11	5.50	1.37	98.56
0.08	3.80	0.94	99.50
0.05	1.40	0.35	99.85
0.05	0.50	0.12	99.98
-0.05	0.10	0.02	100.00
Total	402.60	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.20	0.20	11.25	0.02	11.18	0.02
8.00	0.99	1.19	9.00	0.09	8.94	0.09
6.30	2.87	4.06	7.15	0.21	7.10	0.20
5.00	7.96	12.02	5.65	0.45	5.61	0.45
4.00	18.99	31.01	4.50	0.85	4.47	0.85
3.35	9.07	40.08	3.68	0.33	3.66	0.33
2.00	25.60	65.68	2.68	0.68	2.59	0.66
1.00	15.89	81.57	1.50	0.24	1.41	0.22
0.50	7.47	89.04	0.75	0.06	0.71	0.05
0.25	5.96	95.00	0.38	0.02	0.35	0.02
0.13	4.34	99.34	0.19	0.01	0.18	0.01
0.11	0.25	99.59	0.12	0.00	0.12	0.00
0.08	0.17	99.77	0.09	0.00	0.09	0.00
0.05	0.06	99.83	0.06	0.00	0.06	0.00
0.05	0.02	99.85	0.05	0.00	0.05	0.00
-0.05	0.00	99.86	0.02	0.00	0.03	0.00
Total	99.86			2.96		2.91

APPENDIX I

Sieves analysis of Sishen iron ore.

Sishen 3

Fraction (mm)	Mass (g)	%Mass	Cum. Mass
12.50	4.30	0.04	0.04
10.00	67.70	0.68	0.72
8.00	161.10	1.61	2.33
6.30	287.30	2.87	5.21
5.00	791.20	7.92	13.12
4.00	1956.10	19.57	32.69
3.35	629.10	6.29	38.98
2.00	2652.00	26.53	65.52
1.00	1651.00	16.52	82.03
-1.00	1796.00	17.97	100.00
Total	9995.80	100.00	

Second input (-1 mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	179.40	45.48	45.48
0.25	102.30	25.93	71.41
0.13	74.90	18.99	90.39
0.11	12.60	3.19	93.59
0.08	0.39	0.10	93.69
0.05	0.01	0.00	93.69
0.05	13.40	3.40	97.08
-0.05	11.50	2.92	100.00
Total	394.50	100.00	

	Sieve analysis		Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.04	0.04	14.25	0.01		
10.00	0.68	0.72	11.25	0.08	11.18	0.08
8.00	1.61	2.33	9.00	0.15	8.94	0.14
6.30	2.87	5.21	7.15	0.21	7.10	0.20
5.00	7.92	13.12	5.65	0.45	5.61	0.44
4.00	19.57	32.69	4.50	0.88	4.47	0.88
3.35	6.29	38.98	3.68	0.23	3.66	0.23
2.00	26.53	65.52	2.68	0.71	2.59	0.69
1.00	16.52	82.03	1.50	0.25	1.41	0.23
0.50	8.17	90.20	0.75	0.06	0.71	0.06
0.25	4.66	94.86	0.38	0.02	0.35	0.02
0.13	3.41	98.27	0.19	0.01	0.18	0.01
0.11	0.57	98.85	0.12	0.00	0.12	0.00
0.08	0.02	98.87	0.09	0.00	0.09	0.00
0.05	0.00	98.87	0.06	0.00	0.06	0.00
0.05	0.61	99.48	0.05	0.00	0.05	0.00
-0.05	0.52	100.00	0.02	0.00	0.03	0.00
Total	100.00			3.04		2.98

APPENDIX I

Sieves analysis of Sishen iron ore.

Sishen 4

Fraction (mm)	Mass (g)	%Mass	Cum.Mass
12.50	0.00	0.00	0.00
10.00	29.30	0.29	0.29
8.00	178.00	1.78	2.07
6.30	387.50	3.88	5.95
5.00	842.70	8.43	14.38
4.00	1961.70	19.62	34.00
3.35	712.70	7.13	41.13
2.00	2671.20	26.72	67.84
1.00	1591.00	15.91	83.75
-1.00	1624.30	16.25	100.00
Total	9998.40	100.00	

Second input (-1 mm)			
Fraction (mm)	Mass (g)	%Mass	Cum.Mass
0.50	165.40	40.66	40.66
0.25	120.80	29.70	70.35
0.13	99.70	24.51	94.86
0.11	4.20	1.03	95.89
0.08	12.00	2.95	98.84
0.05	2.40	0.59	99.43
0.05	1.80	0.44	99.88
-0.05	0.50	0.12	100.00
Total	406.80	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.29	0.29	11.25	0.03	11.18	0.03
8.00	1.78	2.07	9.00	0.16	8.94	0.16
6.30	3.88	5.95	7.15	0.28	7.10	0.28
5.00	8.43	14.38	5.65	0.48	5.61	0.47
4.00	19.62	34.00	4.50	0.88	4.47	0.88
3.35	7.13	41.13	3.68	0.26	3.66	0.26
2.00	26.72	67.85	2.68	0.71	2.59	0.69
1.00	15.91	83.76	1.50	0.24	1.41	0.23
0.50	6.61	90.36	0.75	0.05	0.71	0.05
0.25	4.82	95.18	0.38	0.02	0.35	0.02
0.13	3.98	99.17	0.19	0.01	0.18	0.01
0.11	0.17	99.33	0.12	0.00	0.12	0.00
0.08	0.48	99.81	0.09	0.00	0.09	0.00
0.05	0.10	99.91	0.06	0.00	0.06	0.00
0.05	0.07	99.98	0.05	0.00	0.05	0.00
-0.05	0.02	100.00	0.02	0.00	0.03	0.00
Total	100.00			3.12		3.07

APPENDIX I

Sieves analysis of Sishen iron ore.

Sishen 5

Fraction	Mass (g)	%Mass	Cum.Mass
12.50	0.00	0.00	0.00
10.00	46.10	0.46	0.46
8.00	104.70	1.05	1.51
6.30	303.60	3.04	4.55
5.00	864.50	8.66	13.22
4.00	1970.30	19.75	32.97
3.35	681.10	6.83	39.79
2.00	2709.00	27.15	66.94
1.00	1578.60	15.82	82.77
-1.00	1719.60	17.23	100.00
Total	9977.50	100.00	

Second input (-1 mm)			
Fraction	Mass (g)	%Mass	Cum.Mass
0.50	165.80	42.20	42.20
0.25	100.10	25.48	67.68
0.13	87.30	22.22	89.90
0.11	3.70	0.94	90.84
0.08	15.00	3.82	94.66
0.05	10.70	2.72	97.38
0.05	8.00	2.04	99.41
-0.05	2.30	0.59	100.00
Total	392.90	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.46	0.46	11.25	0.05	11.18	0.05
8.00	1.05	1.51	9.00	0.09	8.94	0.09
6.30	3.04	4.55	7.15	0.22	7.10	0.22
5.00	8.66	13.22	5.65	0.49	5.61	0.49
4.00	19.75	32.97	4.50	0.89	4.47	0.88
3.35	6.83	39.79	3.68	0.25	3.66	0.25
2.00	27.15	66.94	2.68	0.73	2.59	0.70
1.00	15.82	82.77	1.50	0.24	1.41	0.22
0.50	7.27	90.04	0.75	0.05	0.71	0.05
0.25	4.39	94.43	0.38	0.02	0.35	0.02
0.13	3.83	98.26	0.19	0.01	0.18	0.01
0.11	0.16	98.42	0.12	0.00	0.12	0.00
0.08	0.66	99.08	0.09	0.00	0.09	0.00
0.05	0.47	99.55	0.06	0.00	0.06	0.00
0.05	0.35	99.90	0.05	0.00	0.05	0.00
-0.05	0.10	100.00	0.02	0.00	0.03	0.00
Total	100.00			3.04		2.98

APPENDIX I

Sieves analysis of Phoenix-Sishen iron ore.

Phoenix-Sishen 1

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	0.00	0.00	0.00
10.00	4.50	0.05	0.05
8.00	4.00	0.04	0.09
6.30	26.60	0.27	0.35
5.00	748.50	7.49	7.84
4.00	1113.10	11.14	18.99
3.35	915.10	9.16	28.15
2.00	2229.40	22.32	50.47
1.00	1873.40	18.75	69.22
-1.00	3074.50	30.78	100.00
Total	9989.10	100.00	

Second input (-1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	182.20	30.19	30.19
0.25	195.80	32.44	62.62
0.13	183.40	30.38	93.01
0.11	24.90	4.13	97.13
0.08	14.20	2.35	99.49
0.05	2.60	0.43	99.92
0.05	0.40	0.07	99.98
-0.05	0.10	0.02	100.00
Total	603.60	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.05	0.05	11.25	0.01	11.18	0.01
8.00	0.04	0.09	9.00	0.00	8.94	0.00
6.30	0.27	0.35	7.15	0.02	7.10	0.02
5.00	7.49	7.84	5.65	0.42	5.61	0.42
4.00	11.14	18.99	4.50	0.50	4.47	0.50
3.35	9.16	28.15	3.68	0.34	3.66	0.34
2.00	22.32	50.47	2.68	0.60	2.59	0.58
1.00	18.75	69.22	1.50	0.28	1.41	0.27
0.50	9.29	78.51	0.75	0.07	0.71	0.07
0.25	9.98	88.50	0.38	0.04	0.35	0.04
0.13	9.35	97.85	0.19	0.02	0.18	0.02
0.11	1.27	99.12	0.12	0.00	0.12	0.00
0.08	0.72	99.84	0.09	0.00	0.09	0.00
0.05	0.13	99.97	0.06	0.00	0.06	0.00
0.05	0.02	99.99	0.05	0.00	0.05	0.00
-0.05	0.01	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.29		2.24

APPENDIX I

Sieves analysis of Phoenix-Sishen iron ore.

Phoenix-Sishen 2

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	0.00	0.00	0.00
10.00	3.50	0.04	0.04
8.00	15.40	0.15	0.19
6.30	44.00	0.44	0.63
5.00	817.60	8.18	8.81
4.00	1289.30	12.90	21.72
3.35	987.80	9.89	31.60
2.00	2134.00	21.36	52.96
1.00	1788.50	17.90	70.86
-1.00	2911.70	29.14	100.00
Total	9991.80	100.00	

Second input (-1mm)			
Fraction (mm)	Mass (g)	%Mass	Cum. Mass
0.50	165.30	28.01	28.01
0.25	211.50	35.84	63.84
0.13	164.30	27.84	91.68
0.11	15.60	2.64	94.32
0.08	26.70	4.52	98.85
0.05	5.50	0.93	99.78
0.05	0.90	0.15	99.93
-0.05	0.40	0.07	100.00
Total	590.20	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.04	0.04	11.25	0.00	11.18	0.00
8.00	0.15	0.19	9.00	0.01	8.94	0.01
6.30	0.44	0.63	7.15	0.03	7.10	0.03
5.00	8.18	8.81	5.65	0.46	5.61	0.46
4.00	12.90	21.72	4.50	0.58	4.47	0.58
3.35	9.89	31.60	3.68	0.36	3.66	0.36
2.00	21.36	52.96	2.68	0.57	2.59	0.55
1.00	17.90	70.86	1.50	0.27	1.41	0.25
0.50	8.16	79.02	0.75	0.06	0.71	0.06
0.25	10.44	89.46	0.38	0.04	0.35	0.04
0.13	8.11	97.58	0.19	0.02	0.18	0.01
0.11	0.77	98.35	0.12	0.00	0.12	0.00
0.08	1.32	99.66	0.09	0.00	0.09	0.00
0.05	0.27	99.94	0.06	0.00	0.06	0.00
0.05	0.04	99.98	0.05	0.00	0.05	0.00
-0.05	0.02	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.41		2.36

APPENDIX I

Sieves analysis of Phoenix-Sishen iron ore.

Phoenix-Sishen 3

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	0.00	0.00	0.00
10.00	4.40	0.04	0.04
8.00	9.00	0.09	0.13
6.30	46.90	0.47	0.60
5.00	957.50	9.59	10.19
4.00	1403.30	14.05	24.24
3.35	1001.20	10.02	34.26
2.00	2227.10	22.30	56.56
1.00	1749.10	17.51	74.07
-1.00	2589.80	25.93	100.00
Total	9988.30	100.00	

Second input (-1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	222.00	28.76	28.76
0.25	275.60	35.70	64.46
0.13	230.70	29.88	94.34
0.11	19.50	2.53	96.87
0.08	19.80	2.56	99.43
0.05	3.70	0.48	99.91
0.05	0.30	0.04	99.95
-0.05	0.40	0.05	100.00
Total	772.00	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.04	0.04	11.25	0.00	11.18	0.00
8.00	0.09	0.13	9.00	0.01	8.94	0.01
6.30	0.47	0.60	7.15	0.03	7.10	0.03
5.00	9.59	10.19	5.65	0.54	5.61	0.54
4.00	14.05	24.24	4.50	0.63	4.47	0.63
3.35	10.02	34.26	3.68	0.37	3.66	0.37
2.00	22.30	56.56	2.68	0.60	2.59	0.58
1.00	17.51	74.07	1.50	0.26	1.41	0.25
0.50	7.46	81.53	0.75	0.06	0.71	0.05
0.25	9.26	90.78	0.38	0.03	0.35	0.03
0.13	7.75	98.53	0.19	0.01	0.18	0.01
0.11	0.65	99.19	0.12	0.00	0.12	0.00
0.08	0.67	99.85	0.09	0.00	0.09	0.00
0.05	0.12	99.98	0.06	0.00	0.06	0.00
0.05	0.01	99.99	0.05	0.00	0.05	0.00
-0.05	0.01	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.55		2.50

APPENDIX I

Sieves analysis of Phoenix-Sishen iron ore.

Phoenix-Sishen 4

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	0.00	0.00	0.00
10.00	0.00	0.00	0.00
8.00	7.20	0.07	0.07
6.30	37.20	0.37	0.44
5.00	738.80	7.40	7.84
4.00	1271.50	12.73	20.57
3.35	933.50	9.35	29.92
2.00	2222.80	22.26	52.18
1.00	1799.30	18.02	70.19
-1.00	2977.20	29.81	100.00
Total	9987.50	100.00	

Second input (-1 mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	199.00	31.46	31.46
0.25	224.70	35.52	66.98
0.13	178.50	28.22	95.19
0.11	12.00	1.90	97.09
0.08	16.00	2.53	99.62
0.05	2.00	0.32	99.94
0.05	0.30	0.05	99.98
-0.05	0.10	0.02	100.00
Total	632.60	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.00	0.00	11.25	0.00	11.18	0.00
8.00	0.07	0.07	9.00	0.01	8.94	0.01
6.30	0.37	0.44	7.15	0.03	7.10	0.03
5.00	7.40	7.84	5.65	0.42	5.61	0.42
4.00	12.73	20.57	4.50	0.57	4.47	0.57
3.35	9.35	29.92	3.68	0.34	3.66	0.34
2.00	22.26	52.18	2.68	0.60	2.59	0.58
1.00	18.02	70.19	1.50	0.27	1.41	0.25
0.50	9.38	79.57	0.75	0.07	0.71	0.07
0.25	10.59	90.16	0.38	0.04	0.35	0.04
0.13	8.41	98.57	0.19	0.02	0.18	0.01
0.11	0.57	99.13	0.12	0.00	0.12	0.00
0.08	0.75	99.89	0.09	0.00	0.09	0.00
0.05	0.09	99.98	0.06	0.00	0.06	0.00
0.05	0.01	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.36		2.31

APPENDIX I

Sieves analysis of Phoenix-Sishen iron ore.

Phoenix-Sishen 5

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	0.00	0.00	0.00
10.00	0.00	0.00	0.00
8.00	5.30	0.05	0.05
6.30	21.00	0.21	0.26
5.00	640.70	6.41	6.68
4.00	1024.90	10.26	16.94
3.35	903.00	9.04	25.98
2.00	2184.50	21.87	47.85
1.00	1873.30	18.75	66.60
-1.00	3336.40	33.40	100.00
Total	9989.10	100.00	

Second input (-1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	237.10	29.68	29.68
0.25	201.90	25.28	54.96
0.13	319.60	40.01	94.97
0.11	23.90	2.99	97.96
0.08	13.20	1.65	99.61
0.05	2.20	0.28	99.89
0.05	0.80	0.10	99.99
-0.05	0.10	0.01	100.00
Total	798.80	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.00	0.00	14.25	0.00		
10.00	0.00	0.00	11.25	0.00	11.18	0.00
8.00	0.05	0.05	9.00	0.00	8.94	0.00
6.30	0.21	0.26	7.15	0.02	7.10	0.01
5.00	6.41	6.68	5.65	0.36	5.61	0.36
4.00	10.26	16.94	4.50	0.46	4.47	0.46
3.35	9.04	25.98	3.68	0.33	3.66	0.33
2.00	21.87	47.85	2.68	0.58	2.59	0.57
1.00	18.75	66.60	1.50	0.28	1.41	0.27
0.50	9.91	76.51	0.75	0.07	0.71	0.07
0.25	8.44	84.96	0.38	0.03	0.35	0.03
0.13	13.36	98.32	0.19	0.03	0.18	0.02
0.11	1.00	99.32	0.12	0.00	0.12	0.00
0.08	0.55	99.87	0.09	0.00	0.09	0.00
0.05	0.09	99.96	0.06	0.00	0.06	0.00
0.05	0.03	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.18		2.13

APPENDIX I

Sieves analysis of the mixture 20% Thabazimbi iron ore, 80% Sishen iron ore without fluxes.

Fraction (mm)	Mass (g)	%Mass	Cum.Mass
12.50	3.60	0.04	0.04
10.00	39.60	0.40	0.43
8.00	139.62	1.40	1.83
6.30	424.74	4.25	6.08
5.00	1114.64	11.16	17.24
4.00	1742.84	17.44	34.68
3.35	630.98	6.31	40.99
2.00	2436.70	24.39	65.38
1.00	1608.56	16.10	81.48
-1.00	1850.60	18.52	100.00
Total	9991.88	100.00	

Second input (-1mm)			
Fraction 9 (mm)	Mass (g)	%Mass	Cum. Mass
0.50	212.48	47.74	47.74
0.25	114.38	25.70	73.44
0.13	71.64	16.10	89.54
0.11	5.56	1.25	90.79
0.08	16.62	3.73	94.52
0.05	12.70	2.85	97.38
0.05	6.98	1.57	98.94
-0.05	4.70	1.06	100.00
Total	445.06	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.04	0.04	14.25	0.01		
10.00	0.40	0.43	11.25	0.04	11.18	0.04
8.00	1.40	1.83	9.00	0.13	8.94	0.12
6.30	4.25	6.08	7.15	0.30	7.10	0.30
5.00	11.16	17.24	5.65	0.63	5.61	0.63
4.00	17.44	34.68	4.50	0.78	4.47	0.78
3.35	6.31	40.99	3.68	0.23	3.66	0.23
2.00	24.39	65.38	2.68	0.65	2.59	0.63
1.00	16.10	81.48	1.50	0.24	1.41	0.23
0.50	8.84	90.32	0.75	0.07	0.71	0.06
0.25	4.76	95.08	0.38	0.02	0.35	0.02
0.13	2.98	98.06	0.19	0.01	0.18	0.01
0.11	0.23	98.29	0.12	0.00	0.12	0.00
0.08	0.69	98.99	0.09	0.00	0.09	0.00
0.05	0.53	99.51	0.06	0.00	0.06	0.00
0.05	0.29	99.80	0.05	0.00	0.05	0.00
-0.05	0.20	100.00	0.00	0.00	0.03	0.00
Total	100.00			3.11		3.05

APPENDIX I

Sieves analysis of the mixture 40% Thabazimbi iron ore, 60% Sishen iron ore without fluxes.

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	3.60	0.04	0.04
10.00	39.60	0.40	0.43
8.00	139.62	1.40	1.83
6.30	424.74	4.25	6.08
5.00	1114.64	11.16	17.24
4.00	1742.84	17.44	34.68
3.35	630.98	6.31	40.99
2.00	2436.70	24.39	65.38
1.00	1608.56	16.10	81.48
-1.00	1850.60	18.52	100.00
Total	9991.88	100.00	

Second input (-1mm)			
Fraction (mm)	Mass (g)	%Mass	Cum. Mass
0.50	212.48	47.74	47.74
0.25	114.38	25.70	73.44
0.13	71.64	16.10	89.54
0.11	5.56	1.25	90.79
0.08	16.62	3.73	94.52
0.05	12.70	2.85	97.38
0.05	6.98	1.57	98.94
-0.05	4.70	1.06	100.00
Total	445.06	100.00	

Sieve analysis			Linear		Geometric	
Fraction (mm)	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.04	0.04	14.25	0.01		
10.00	0.40	0.43	11.25	0.04	11.18	0.04
8.00	1.40	1.83	9.00	0.13	8.94	0.12
6.30	4.25	6.08	7.15	0.30	7.10	0.30
5.00	11.16	17.24	5.65	0.63	5.61	0.63
4.00	17.44	34.68	4.50	0.78	4.47	0.78
3.35	6.31	40.99	3.68	0.23	3.66	0.23
2.00	24.39	65.38	2.68	0.65	2.59	0.63
1.00	16.10	81.48	1.50	0.24	1.41	0.23
0.50	8.84	90.32	0.75	0.07	0.71	0.06
0.25	4.76	95.08	0.38	0.02	0.35	0.02
0.13	2.98	98.06	0.19	0.01	0.18	0.01
0.11	0.23	98.29	0.12	0.00	0.12	0.00
0.08	0.69	98.99	0.09	0.00	0.09	0.00
0.05	0.53	99.51	0.06	0.00	0.06	0.00
0.05	0.29	99.80	0.05	0.00	0.05	0.00
-0.05	0.20	100.00	0.00	0.00	0.03	0.00
Total	100.00			3.11		3.05

APPENDIX I

Sieves analysis of the mixture 50% Thabazimbi iron ore, 50% Sishen iron ore without fluxes.

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	3.15	0.03	0.03
10.00	35.25	0.35	0.38
8.00	117.30	1.17	1.56
6.30	493.75	4.94	6.50
5.00	917.85	9.18	15.68
4.00	1367.70	13.68	29.36
3.35	701.90	7.02	36.38
2.00	2257.00	22.58	58.95
1.00	1609.95	16.10	75.06
-1.00	2493.70	24.94	100.00
Total	9997.55	100.00	

Second input (-1mm)			
Fraction (mm)	Mass (g)	%Mass	Cum. Mass
0.50	158.10	36.03	36.03
0.25	117.40	26.76	62.79
0.13	120.50	27.46	90.25
0.11	16.50	3.76	94.01
0.08	22.05	5.03	99.04
0.05	1.31	0.30	99.34
0.05	2.45	0.56	99.90
-0.05	0.45	0.10	100.00
Total	438.76	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.03	0.03	14.25	0.00		
10.00	0.35	0.38	11.25	0.04	11.18	0.04
8.00	1.17	1.56	9.00	0.11	8.94	0.10
6.30	4.94	6.50	7.15	0.35	7.10	0.35
5.00	9.18	15.68	5.65	0.52	5.61	0.52
4.00	13.68	29.36	4.50	0.62	4.47	0.61
3.35	7.02	36.38	3.68	0.26	3.66	0.26
2.00	22.58	58.95	2.68	0.60	2.59	0.58
1.00	16.10	75.06	1.50	0.24	1.41	0.23
0.50	8.99	84.04	0.75	0.07	0.71	0.06
0.25	6.67	90.72	0.38	0.03	0.35	0.02
0.13	6.85	97.57	0.19	0.01	0.18	0.01
0.11	0.94	98.51	0.12	0.00	0.12	0.00
0.08	1.25	99.76	0.09	0.00	0.09	0.00
0.05	0.07	99.84	0.06	0.00	0.06	0.00
0.05	0.14	99.97	0.05	0.00	0.05	0.00
-0.05	0.03	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.85		2.79

APPENDIX I

Sieves analysis of the mixture 60% Thabazimbi iron ore, 40% Sishen iron ore without fluxes.

Fraction (mm)	Mass (g)	%Mass	Cum.Mass
12.50	1.72	0.02	0.02
10.00	39.32	0.39	0.41
8.00	95.34	0.95	1.37
6.30	495.92	4.96	6.33
5.00	875.26	8.76	15.09
4.00	1370.80	13.72	28.81
3.35	519.48	5.20	34.01
2.00	2145.12	21.47	55.48
1.00	1645.36	16.47	71.95
-1.00	2802.20	28.05	100.00
Total	9990.52	100.00	

Second input (-1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	139.14	34.63	34.63
0.25	103.80	25.83	60.46
0.13	91.28	22.72	83.18
0.11	22.86	5.69	88.87
0.08	21.55	5.36	94.23
0.05	8.82	2.20	96.43
0.05	9.20	2.29	98.72
-0.05	5.14	1.28	100.00
Total	401.79	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.02	0.02	14.25	0.00		
10.00	0.39	0.41	11.25	0.04	11.18	0.04
8.00	0.95	1.37	9.00	0.09	8.94	0.09
6.30	4.96	6.33	7.15	0.35	7.10	0.35
5.00	8.76	15.09	5.65	0.49	5.61	0.49
4.00	13.72	28.81	4.50	0.62	4.47	0.61
3.35	5.20	34.01	3.68	0.19	3.66	0.19
2.00	21.47	55.48	2.68	0.57	2.59	0.56
1.00	16.47	71.95	1.50	0.25	1.41	0.23
0.50	9.71	81.66	0.75	0.07	0.71	0.07
0.25	7.25	88.91	0.38	0.03	0.35	0.03
0.13	6.37	95.28	0.19	0.01	0.18	0.01
0.11	1.60	96.88	0.12	0.00	0.12	0.00
0.08	1.50	98.38	0.09	0.00	0.09	0.00
0.05	0.62	99.00	0.06	0.00	0.06	0.00
0.05	0.64	99.64	0.05	0.00	0.05	0.00
-0.05	0.36	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.73		2.68

APPENDIX I

Sieves analysis of the mixture 80% Thabazimbi iron ore, 20% Sishen iron ore without fluxes.

Fraction	Mass (g)	%Mass	Cum.Mass (%)
12.50	7.60	0.08	0.08
10.00	36.82	0.37	0.44
8.00	69.72	0.70	1.14
6.30	624.96	6.25	7.39
5.00	1065.14	10.66	18.05
4.00	1041.36	10.42	28.47
3.35	770.98	7.71	36.18
2.00	2010.78	20.11	56.29
1.00	1543.82	15.44	71.74
-1.00	2825.32	28.26	100.00
Total	9996.50	100.00	

Second input (-1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	196.72	28.45	28.45
0.25	160.90	23.27	51.72
0.13	149.52	21.62	73.34
0.11	20.14	2.91	76.25
0.08	66.92	9.68	85.93
0.05	50.44	7.29	93.23
0.05	28.02	4.05	97.28
-0.05	18.82	2.72	100.00
Total	691.48	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.08	0.08	14.25	0.01		
10.00	0.37	0.44	11.25	0.04	11.18	0.04
8.00	0.70	1.14	9.00	0.06	8.94	0.06
6.30	6.25	7.39	7.15	0.45	7.10	0.44
5.00	10.66	18.05	5.65	0.60	5.61	0.60
4.00	10.42	28.47	4.50	0.47	4.47	0.47
3.35	7.71	36.18	3.68	0.28	3.66	0.28
2.00	20.11	56.29	2.68	0.54	2.59	0.52
1.00	15.44	71.74	1.50	0.23	1.41	0.22
0.50	8.04	79.78	0.75	0.06	0.71	0.06
0.25	6.58	86.35	0.38	0.02	0.35	0.02
0.13	6.11	92.47	0.19	0.01	0.18	0.01
0.11	0.82	93.29	0.12	0.00	0.12	0.00
0.08	2.74	96.02	0.09	0.00	0.09	0.00
0.05	2.06	98.09	0.06	0.00	0.06	0.00
0.05	1.15	99.23	0.05	0.00	0.05	0.00
-0.05	0.77	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.79		2.73

APPENDIX I

Sieves analysis of the mixture 50% Thabazimbi iron ore, 50% Sishen iron ore with fluxes not sized.

Fraction (mm)	Mass (g)	%Mass	Cum.Mass (%)
12.50	21.80	0.22	0.22
10.00	18.00	0.18	0.40
8.00	22.10	0.22	0.62
6.30	212.20	2.12	2.74
5.00	767.20	7.67	10.42
4.00	1374.20	13.75	24.16
3.35	1080.90	10.81	34.98
2.00	1712.50	17.13	52.11
1.00	2197.10	21.98	74.09
-1.00	2590.30	25.91	100.00
Total	9996.30	100.00	

Second input (1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	180.30	43.23	43.23
0.25	142.30	34.12	77.34
0.13	78.00	18.70	96.04
0.11	12.00	2.88	98.92
0.08	3.20	0.77	99.69
0.05	1.00	0.24	99.93
0.05	0.20	0.05	99.98
-0.05	0.10	0.02	100.00
Total	417.10	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.22	0.22	14.25	0.03		
10.00	0.18	0.40	11.25	0.02	11.18	0.02
8.00	0.22	0.62	9.00	0.02	8.94	0.02
6.30	2.12	2.74	7.15	0.15	7.10	0.15
5.00	7.67	10.42	5.65	0.43	5.61	0.43
4.00	13.75	24.16	4.50	0.62	4.47	0.61
3.35	10.81	34.98	3.68	0.40	3.66	0.40
2.00	17.13	52.11	2.68	0.46	2.59	0.44
1.00	21.98	74.09	1.50	0.33	1.41	0.31
0.50	11.20	85.29	0.75	0.08	0.71	0.08
0.25	8.84	94.13	0.38	0.03	0.35	0.03
0.13	4.85	98.97	0.19	0.01	0.18	0.01
0.11	0.75	99.72	0.12	0.00	0.12	0.00
0.08	0.20	99.92	0.09	0.00	0.09	0.00
0.05	0.06	99.98	0.06	0.00	0.06	0.00
0.05	0.01	99.99	0.05	0.00	0.05	0.00
-0.05	0.01	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.59		2.51

APPENDIX I

Sieves analysis of the mixture 50% Thabazimbi iron ore, 50% Sishen iron ore with fluxes where only coke and lime were sized.

Fraction (mm)	Mass (g)	%Mass	Cum. Mass (%)
12.50	12.00	0.12	0.12
10.00	10.40	0.10	0.22
8.00	21.50	0.22	0.44
6.30	247.30	2.47	2.91
5.00	712.30	7.13	10.04
4.00	823.60	8.24	18.28
3.35	1112.90	11.13	29.41
2.00	2500.00	25.01	54.42
1.00	1680.00	16.81	71.23
-1.00	2876.20	28.77	100.00
Total	9996.20		

Second input(1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	187.50	37.14	37.14
0.25	130.80	25.91	63.04
0.13	161.20	31.93	94.97
0.11	13.00	2.57	97.54
0.08	9.00	1.78	99.33
0.05	2.80	0.55	99.88
0.05	0.60	0.12	100.00
-0.05	0.00	0.00	100.00
Total			

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.12	0.12	14.25	0.02		
10.00	0.10	0.22	11.25	0.01	11.18	0.01
8.00	0.22	0.44	9.00	0.02	8.94	0.02
6.30	2.47	2.91	7.15	0.18	7.10	0.18
5.00	7.13	10.04	5.65	0.40	5.61	0.40
4.00	8.24	18.28	4.50	0.37	4.47	0.37
3.35	11.13	29.41	3.68	0.41	3.36	0.41
2.00	25.01	54.42	2.68	0.67	2.59	0.65
1.00	16.81	71.23	1.50	0.25	1.41	0.24
0.50	10.69	81.91	0.75	0.08	0.71	0.08
0.25	7.45	89.37	0.38	0.03	0.35	0.03
0.13	9.19	98.55	0.19	0.02	0.18	0.02
0.11	0.74	99.29	0.12	0.00	0.12	0.00
0.08	0.51	99.81	0.09	0.00	0.09	0.00
0.05	0.16	99.97	0.06	0.00	0.06	0.00
0.05	0.03	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.46		2.39

APPENDIX I

Sieves analysis of the mixture 50% Thabazimbi iron ore, 50% Sishen iron ore with fluxes where only coke, lime and return fines were sized.

Fraction (mm)	Mass (g)	%Mass	Cum. Mass (%)
12.50	12.00	0.12	0.12
10.00	8.40	0.08	0.20
8.00	19.40	0.19	0.40
6.30	121.10	1.21	1.61
5.00	1327.40	13.28	14.89
4.00	1087.30	10.88	25.76
3.35	1243.70	12.44	38.20
2.00	2698.70	26.99	65.20
1.00	1965.30	19.66	84.85
-1.00	1514.20	15.15	100.00
Total	9997.50	100.00	

Second input(1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	192.00	43.29	43.29
0.25	167.50	37.77	81.06
0.13	53.90	12.15	93.21
0.11	17.00	3.83	97.05
0.08	9.60	2.16	99.21
0.05	3.20	0.72	99.93
0.05	0.20	0.05	99.98
-0.05	0.10	0.00	100.00
Total			

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.12	0.12	14.25	0.02		
10.00	0.08	0.20	11.25	0.01	11.18	0.01
8.00	0.19	0.40	9.00	0.02	8.94	0.02
6.30	1.21	1.61	7.15	0.09	7.10	0.09
5.00	13.28	14.89	5.65	0.75	5.61	0.75
4.00	10.88	25.76	4.50	0.49	4.47	0.49
3.35	12.44	38.20	3.68	0.46	3.66	0.46
2.00	26.99	65.20	2.68	0.72	2.59	0.70
1.00	19.66	84.85	1.50	0.29	1.41	0.28
0.50	6.56	91.41	0.75	0.05	0.71	0.05
0.25	5.72	97.13	0.38	0.02	0.35	0.02
0.13	1.84	98.97	0.19	0.00	0.18	0.00
0.11	0.58	99.55	0.12	0.00	0.12	0.00
0.08	0.33	99.88	0.09	0.00	0.09	0.00
0.05	0.11	99.99	0.06	0.00	0.06	0.00
0.05	0.01	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.92		2.85

APPENDIX I

Sieves analysis of the mixture 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes not sized.

Fraction (mm)	Mass (g)	%Mass	Cum. Mass (%)
12.50	12.00	0.12	0.12
10.00	7.60	0.08	0.20
8.00	17.80	0.18	0.37
6.30	114.20	1.14	1.52
5.00	1000.20	10.00	11.52
4.00	905.00	9.05	20.57
3.35	1092.60	10.93	31.50
2.00	2804.60	28.05	59.55
1.00	1928.30	19.29	78.84
-1.00	2115.60	21.16	100.00
Total	9997.90	100.00	

Second input(1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	205.40	39.39	39.39
0.25	178.60	34.25	73.65
0.13	94.00	18.03	91.68
0.11	21.60	4.14	95.82
0.08	18.30	3.51	99.33
0.05	2.70	0.52	99.85
0.05	0.80	0.15	100.00
-0.05	0.00	0.00	100.00
Total	521.40	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.12	0.12	14.25	0.02		
10.00	0.08	0.20	11.25	0.01	11.18	0.01
8.00	0.18	0.37	9.00	0.02	8.94	0.02
6.30	1.14	1.52	7.15	0.08	7.10	0.08
5.00	10.00	11.52	5.65	0.57	5.61	0.56
4.00	9.05	20.57	4.50	0.41	4.47	0.40
3.35	10.93	31.50	3.68	0.40	3.66	0.40
2.00	28.05	59.55	2..68	0.75	2.59	0.73
1.00	19.29	78.84	1.50	0.29	1.41	0.27
0.50	8.34	87.18	0.75	0.06	0.71	0.06
0.25	7.25	94.42	0.38	0.03	0.35	0.03
0.13	3.81	98.24	0.19	0.01	0.18	0.01
0.11	0.88	99.12	0.12	0.00	0.12	0.00
0.08	0.74	99.86	0.09	0.00	0.09	0.00
0.05	0.11	99.97	0.06	0.00	0.06	0.00
0.05	0.03	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.030	0.00
Total	100.00			2.64		2.56

APPENDIX I

Sieves analysis of the mixture 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes where only coke and lime were sized.

Fraction (mm)	Mass (g)	%Mass	Cum. Mass (%)
12.50	4.00	0.04	0.04
10.00	8.10	0.08	0.12
8.00	6.60	0.07	0.19
6.30	112.30	1.12	1.31
5.00	658.20	6.59	7.90
4.00	890.30	8.91	16.81
3.35	1060.20	10.61	27.42
2.00	2417.40	24.19	51.61
1.00	1995.50	19.97	71.58
-1.00	2839.50	28.42	100.00
Total	9992.10	100.00	

Second input(1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	169.00	41.14	41.14
0.25	140.20	34.13	75.27
0.13	81.00	19.72	94.99
0.11	12.20	2.97	97.96
0.08	6.80	1.66	99.61
0.05	1.30	0.32	99.93
0.05	0.30	0.07	100.00
-0.05	0.00	0.00	100.00
Total	410.80	100.00	

Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.04	0.04	14.25	0.01		0.01
10.00	0.08	0.12	11.25	0.01	11.18	0.01
8.00	0.07	0.19	9.00	0.01	8.94	0.08
6.30	1.12	1.31	7.15	0.08	7.10	0.37
5.00	6.59	7.90	5.65	0.37	5.61	0.40
4.00	8.91	16.81	4.50	0.40	4.47	0.39
3.35	10.61	27.42	3.68	0.39	3.66	0.63
2.00	24.19	51.61	2.68	0.65	2.59	0.28
1.00	19.97	71.58	1.50	0.30	1.41	0.08
0.50	11.69	83.27	0.75	0.09	0.71	0.03
0.25	9.70	92.97	0.38	0.04	0.35	0.01
0.13	5.60	98.57	0.19	0.01	0.18	0.00
0.11	0.84	99.42	0.12	0.00	0.12	0.00
0.08	0.47	99.89	0.09	0.00	0.09	0.00
0.05	0.09	99.98	0.06	0.00	0.06	0.00
0.05	0.02	100.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00			2.35		2.29

APPENDIX I

Sieves analysis of the mixture 20% Thabazimbi iron ore, 80% Sishen iron ore with fluxes where coke, lime and return fines were sized.

Fraction (mm)	Mass (g)	%Mass	Cum. Mass (%)
12.50	8.00	0.08	0.08
10.00	14.80	0.15	0.23
8.00	22.10	0.22	0.45
6.30	290.40	2.9	3.35
5.00	1402.00	14.02	17.38
4.00	1308.00	13.08	30.46
3.35	1188.50	11.89	42.35
2.00	2225.50	22.26	64.61
1.00	2179.50	21.80	86.41
-1.00	1359.10	13.59	100.00
Total	9997.90		

Second input(1mm)			
Fraction	Mass (g)	%Mass	Cum. Mass
0.50	146.40	40.76	40.76
0.25	113.20	31.51	72.27
0.13	86.90	24.19	96.46
0.11	7.30	2.03	98.50
0.08	3.30	0.92	99.42
0.05	2.00	0.56	99.97
0.05	0.10	0.03	100.00
-0.05	0.00	0.00	100.00
Total	359.20		

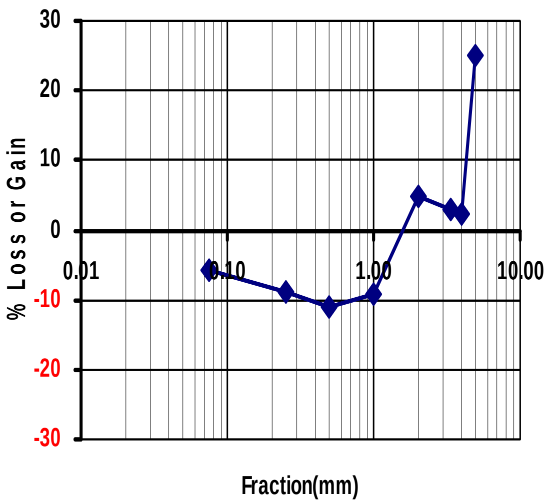
Sieve analysis			Linear		Geometric	
Fraction	%Mass	Cum. Mass	Dp	Calc	Dp	Calc
12.50	0.08	0.08	14.25	0.01		
10.00	0.15	0.23	11.25	0.02	11.18	0.02
8.00	0.22	0.45	9.00	0.02	8.94	0.02
6.30	2.90	3.35	7.15	0.21	7.10	0.21
5.00	14.02	17.38	5.65	0.79	5.61	0.79
4.00	13.08	30.46	4.50	0.59	4.47	0.59
3.35	11.89	42.35	3.68	0.44	3.66	0.44
2.00	22.26	64.61	2.68	0.60	2.59	0.58
1.00	21.80	86.41	1.50	0.33	1.41	0.31
0.50	5.54	91.95	0.75	0.04	0.71	0.04
0.25	4.28	96.23	0.38	0.02	0.35	0.02
0.13	3.29	99.52	0.19	0.01	0.18	0.01
0.11	0.28	99.80	0.12	0.00	0.12	0.00
0.08	0.12	99.92	0.09	0.00	0.09	0.00
0.05	0.08	100.00	0.06	0.00	0.06	0.00
0.05	0.00	10.00	0.05	0.00	0.05	0.00
-0.05	0.00	100.00	0.02	0.00	0.03	0.00
Total	100.00		3.06			2.99

APPENDIX II

Sieve analysis before and after granulation

	Before granulation			After granulation		
Fraction (mm)	Mass (g)	% Mass	Cum.mass (%)	Mass (g)	% Mass	Cum.mass (%)
5.00	1041.30	10.42	10.42	191.60	35.55	35.55
4.00	1374.20	13.75	24.16	86.00	15.95	51.50
3.35	1080.90	10.81	34.98	73.80	13.69	65.19
2.00	1712.50	17.13	52.11	118.60	22.00	87.20
1.00	2197.10	21.98	74.09	68.70	12.75	99.94
0.50	1119.71	11.20	85.29	0.32	0.06	100.00
0.25	883.72	8.84	94.13	0.00	0.00	100.00
-0.25	586.87	5.87	100.00	0.00	0.00	100.00
Tot	9996.30			539.02		

Fraction	% Diff.	%Transferred
5.000	25.129	52.471
4.000	2.208	4.610
2.000	4.872	10.172
1.000	-9.234	-19.281
0.500	-11.142	-23.265
0.250	-8.840	-18.459
0.075	-5.871	-12.259



X (mm)
1.6

S = $(\%<x_{mm})_{BG} - (\%<x_{mm})_{AG}$
= $(\%>x_{mm})_{AG} - (\%>x_{mm})_{BF}$
= $(\%<2_{mm})_{BG} - (\%<2_{mm})_{AG}$
= 35.087

Ex = 100 * S/S’
= 73.26

APPENDIX III

XRF analysis of sinter samples.

%	GSNcert	GSN	Mixture 1	Mixture 2	Mixture 3	Mixture 4
SiO_2	**65.80**	65.44	5.04	4.78	5.02	4.70
TiO_2	**0.68**	0.64	0.10	0.10	0.11	0.11
Al_2O_3	**14.67**	14.63	1.31	1.52	1.39	1.51
Fe_2O_3	**3.75**	3.67	80.99	81.04	81.90	81.25
MnO	**0.06**	0.05	0.38	0.28	0.37	0.28
MgO	**2.30**	2.21	2.89	2.89	2.88	2.86
CaO	**2.50**	2.99	9.35	9.32	9.60	9.28
Na_2O	**3.77**	3.81	0.01	0.01	0.01	0.01
K_2O	**4.63**	4.70	0.06	0.05	0.06	0.06
P_2O_5	**0.28**	0.29	0.10	0.12	0.10	0.12
Cr_2O_3	**0.008**	0.008	0.03	0.03	0.02	0.03
NiO	**0.0043**	0.006	0.00	0.00	0.00	0.00
V_2O_5	**0.01**	0.01	0.01	0.01	0.01	0.01
ZrO_2	**0.03**	0.03	0.00	0.00	0.00	0.00
LOI	**1.32**	1.29	-0.82	-0.88	-0.84	-0.84
TOTAL	**99.82**	99.78	99.44	99.26	100.63	99.39
ppm	**GSNcert**	**GSN**	**Mixture 1**	**Mixture 2**	**Mixture 3**	**Mixture 4**
As	**1.6**	3	18	34	29	44
Cu	**20**	26	24	13	18	13
Ga	**22**	20	6	4	7	5
Mo	**1.2**	1	38	38	37	39
Nb	**21**	22	29	30	29	29
Ni	**34**	37	72	59	27	38
Pb	**53**	46	26	23	32	31
Rb	**185**	182	27	30	28	29
Sr	**570**	579	215	311	225	317
Th	**42**	41	64	65	61	63
U	**8**	5	62	66	61	66
W*	**450**	458	100	119	147	160
Y	**19**	11	38	37	36	36
Zn	**48**	50	34	24	34	22
Zr	**235**	227	81	72	80	72
Cl*	**450**	499	115	144	113	125
Co	**65**	57	2	2	2	2
Cr	**55**	45	115	118	72	84
F*	**1050**	1177	874	723	636	663
S*	**140**	556	81	72	73	73
Sc	**7**	6	1	3	1	2
V	**65**	63	20	19	17	19
Cs	**5**	6	9	9	9	9
Ba	**1400**	1417	127	167	133	173
La	**75**	60	30	29	31	28
Ce	**135**	138	5	5	5	5

APPENDIX IV

Sieve analysis of the granulated mixture Phoenix iron ore-Sishen iron ore with as-received fluxes1

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5	50.800	84.385								
4	6.600	10.963	64.700	84.575						
3.35	0.000	0.000	7.500	9.804	31.900	48.260				
2	0.000	0.000	0.300	0.392	24.200	36.611	84.200	59.759		
1	0.000	0.000	0.100	0.131	0.600	0.908	30.400	21.576	79.000	64.542
0.5	0.400	0.664	0.500	0.654	0.500	0.756	3.300	2.342	18.400	15.033
0.25	0.500	0.831	0.800	1.046	1.400	2.118	5.000	3.549	8.100	6.618
-0.25	1.900	3.156	2.600	3.399	7.500	11.346	18.000	12.775	16.900	13.807
Total	60.200	100.000	76.500	100.000	66.100	100.000	140.900	100.000	122.400	100.000

Sieve analysis of the granulated mixture Phoenix iron ore-Sishen iron ore with as-received fluxes1'

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5	58.500	84.783								
4	7.300	10.580	58.800	82.238						
3.35	0.000	0.000	8.200	11.469	34.000	49.347				
2	0.000	0.000	0.300	0.420	25.800	37.446	78.100	57.216		
1	0.000	0.000	0.100	0.140	0.200	0.290	33.200	24.322	78.000	63.260
0.5	0.400	0.580	0.600	0.839	0.700	1.016	2.800	2.051	21.300	17.275
0.25	0.700	1.014	0.900	1.259	1.300	1.887	5.600	4.103	9.000	7.299
-0.25	2.100	3.043	2.600	3.636	6.900	10.015	16.800	12.308	15.000	12.165
Total	69.000	100.000	71.500	100.000	68.900	100.000	136.500	100.000	123.300	100.000

APPENDIX IV

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore with as-received fluxes 2

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	100.50	55.04								
4.00	27.10	14.84	89.10	44.44						
3.35	6.60	3.61	45.60	22.74	50.40	45.16				
2.00	11.70	6.41	26.00	12.97	35.70	31.99	117.40	58.94		
1.00	10.30	5.64	10.80	5.39	8.90	7.97	44.50	22.34	113.30	74.64
0.50	8.20	4.49	6.70	3.34	4.20	3.76	10.10	5.07	16.90	11.13
0.25	7.20	3.94	7.40	3.69	3.70	3.32	9.30	4.67	6.30	4.15
-0.25	11.00	6.02	14.90	7.43	8.70	7.80	17.90	8.99	15.30	10.08
Total	182.60	100.00	200.50	100.00	111.60	100.00	199.20	100.00	151.80	100.00

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore 2'

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	90.20	54.87								
4.00	18.90	11.50	89.10	44.57						
3.35	7.80	4.74	45.60	22.81	56.70	47.05				
2.00	14.00	8.52	26.00	13.01	36.02	29.89	101.40	57.42		
1.00	8.30	5.05	10.80	5.40	9.20	7.63	36.00	20.39	97.30	73.10
0.50	8.70	5.29	7.60	3.80	5.00	4.15	9.60	5.44	13.80	10.37
0.25	6.50	3.95	7.20	3.60	4.40	3.65	11.20	6.34	7.20	5.41
-0.25	10.00	6.08	13.60	6.80	9.20	7.63	18.40	10.42	14.80	11.12
Total	164.40	100.00	199.90	100.00	120.52	100.00	176.60	100.00	133.10	100.00

APPENDIX IV

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore 3

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	157.20	54.02								
4.00	48.70	16.74	68.40	41.86						
3.35	11.70	4.02	42.30	25.89	36.40	44.34				
2.00	16.50	5.67	20.20	12.36	28.90	35.20	77.50	71.49		
1.00	18.70	6.43	11.30	6.92	7.40	9.01	19.50	17.99	50.70	80.09
0.50	12.50	4.30	6.50	3.98	3.00	3.65	4.40	4.06	6.70	10.58
0.25	10.30	3.54	6.10	3.73	2.30	2.80	2.50	2.31	2.70	4.27
-0.25	15.40	5.29	8.60	5.26	4.10	4.99	4.50	4.15	3.20	5.06
Total	291.00	100.00	163.40	100.00	82.10	100.00	108.40	100.00	63.30	100.00

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore 3’

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	115.20	44.82								
4.00	50.20	19.53	82.00	48.09						
3.35	13.80	5.37	35.50	20.82	35.80	42.42				
2.00	21.00	8.17	19.40	11.38	29.90	35.43	84.90	64.46		
1.00	20.50	7.98	12.80	7.51	7.70	9.12	28.40	21.56	46.60	75.77
0.50	11.30	4.40	6.10	3.58	3.10	3.67	5.50	4.18	8.30	13.50
0.25	10.00	3.89	5.90	3.46	2.60	3.08	4.20	3.19	2.50	4.07
-0.25	15.00	5.84	8.80	5.16	5.30	6.28	8.70	6.61	4.10	6.67
Total	257.00	100.00	170.50	100.00	84.40	100.00	131.70	100.00	61.50	100.00

APPENDIX IV

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore 4

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	90.20	36.37								
4.00	45.70	18.43	68.90	41.58						
3.35	18.10	7.30	37.60	22.69	38.00	40.86				
2.00	22.60	9.11	24.20	14.60	31.40	33.76	73.90	72.03		
1.00	24.00	9.68	9.80	5.91	6.70	7.20	11.40	11.11	62.80	82.74
0.50	12.30	4.96	5.00	3.02	2.80	3.01	6.60	6.43	6.70	8.83
0.25	16.50	6.65	7.00	4.22	3.10	3.33	3.40	3.31	2.40	3.16
-0.25	18.60	7.50	13.20	7.97	11.00	11.83	7.30	7.12	4.00	5.27
Total	248.00	100.00	165.70	100.00	93.00	100.00	102.60	100.00	75.90	100.00

Sieves analysis of the granulated mixture Phoenix iron ore-Sishen iron ore 4’

	Granule('+ 5mm)		Granule('+ 4mm)		Granule('+ 3,35mm)		Granule('+ 2mm)		Granule('+ 1mm)	
Fraction	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)	Mass(g)	Mass(%)
5.00	96.50	37.78								
4.00	46.20	18.09	73.00	40.76						
3.35	16.80	6.58	40.60	22.67	35.50	41.86				
2.00	23.70	9.28	29.10	16.25	28.90	34.08	80.70	74.31		
1.00	24.00	9.40	11.30	6.31	5.10	6.01	12.20	11.23	61.00	85.315
0.50	13.80	5.40	5.30	2.96	2.80	3.30	6.20	5.71	4.90	6.853
0.25	15.00	5.87	6.80	3.80	2.30	2.71	3.00	2.76	2.80	3.916
-0.25	19.40	7.60	13.00	7.26	10.20	12.03	6.50	5.99	2.80	3.916
Total	255.40	100.00	179.10	100.00	84.80	100.00	108.60	100.00	71.50	100.000