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Final Report on Laboratory / Bench Scale Tests For Direct Reduction Of Zambian Raw Materials

(UNIDO PROJECT NO. DP/ZAM/88/025)

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Engineering And Projects Division

SPONGE IRON INDIA LIMITED

HYDERABAD.

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ANNEXURES

FINAL REPORT OF LABORATORY/BENCH SCALE TESTS FOR DIRECT REDUCTION OF ZAMBIAN RAW MATERIALS.

1.0 **INTRODUCTION**

1.1 United Nations Industrial Development Organisation (UNIDO) under the project No.DP/ZAM/83/025 and Contract No.89/5 awarded to Sponge Iron India Limited (SIIL), the work of conducting Laboratory/Bench Scale Tests for Direct Reduction of Zambian Iron Ores using coal as reductant. The contract was awarded in response to the proposal for undertaking such a study submitted by SIIL vide their reference No.SI/RD/SSP/7333/850/[illegible], 19.10.198[illegible].

1.2 In terms of the contract the scope of work is as follows:

a) Direct reduction tests on iron ores for determining their physical, chemical and metallurgical characteristics. In respect of coal, the tests covering proximate/ultimate analysis of coal including parameters like ash softening characteristics, reactivity etc.

b) Direct reduction tests for Sponge Iron production at laboratory scale in a laboratory rotary furnace and short rotary kiln.

c) Compilation of test results covering (a) and (b) above.

[illegible] (i) to

(a) [illegible]

[illegible]

[illegible]

[illegible] and

c) [illegible] (7) [illegible] experiments [illegible] and

[illegible] (1.[illegible] [illegible].

1.3 Test samples consisting of Iron Ore from Hambale, non-coking coal from [illegible] and Limestone from [illegible] District, totally weighing nearly 30.3 metric tonnes, were received at [illegible] Test Centre during 2nd week of April, 19[illegible].

1.4 Preliminary evaluation by way of chemical analysis and physical characteristics of iron ore samples revealed that materials could be directly tested for sponge iron production and no upgradation or beneficiation was considered necessary. Accordingly, the following programme of test work was drawn up:

i) Chemical Analysis of Iron Ore to assess its suitability for sponge iron production.

ii) To study physical properties of iron ore such as screen analysis, bulk density, tumbler and shatter strength etc.

iii) To study properties of coal like proximate analysis, ash fusion characteristics, calorific value, reactivity etc.

iv) Chemical analysis of Limestone to assess its suitability as a desulphuriser in sponge iron production.

v) Conducting Direct reduction Tests on Zambian Iron Ore with Zambian coal as reductant and Zambian limestone as desulphuriser for production of sponge iron in laboratory rotary furnace and short rotary kiln.

[illegible]. [illegible]

[illegible] The prime objective of the Laboratory and Bench Scale Tests is to determine the suitability of Zambian Iron Ore in combination with Zambian coal, for production of highly metallised sponge iron. The tests carried out and their objectives are summarised below.

2.1.1 To analyse the Zambian Iron Ore sample chemically in order to determine its suitability with regard to iron content, gangue, sulphur and phosphorus contents and other constituents.

2.1.2 To determine the physical characteristics namely screen analysis, bulk density, shatter and Tumbler Indices of as received ore sample for establishing behaviour of ore during handling, transporting, storage etc.

2.1.3 To study the decrepitation behaviour of Zambian iron ore during reduction, under standard test conditions.

2.1.4 To determine the detailed chemical analysis, physical properties and other specific properties such as ash softening characteristics, calorific value and reactivity of the Zambian coal.

2.1.5 To carry out Laboratory and Bench Scale Tests on Zambian Iron Ore in combination with Zambian coal to produce [illegible] iron.

3.0 TEST MATERIALS

[illegible] Iron ore.

[illegible] lump [illegible] (5 to [illegible]) [illegible] materials [illegible] size [illegible] of [illegible] in Table 1 [illegible].

Coal

[illegible] below 10 mm.

[illegible] Limestone

[illegible] received [illegible] (5 – [illegible]) [illegible].

4.0 **TECHNICAL REQUIREMENT OF RAW MATERIALS:**

4.1 Iron Ore, Coal and Limestone are the basic raw materials required for the production of Sponge Iron in the rotary kiln process based on 100% coal [illegible]. [illegible] Sponge Iron in rotary kiln is sensitive to the characteristics of the raw material with regard to size distribution [illegible] [illegible] [illegible] [illegible]. [illegible] of any ore, coal [illegible] [illegible] for the [illegible] [illegible] [illegible] [illegible] Electric [illegible] Furnace [illegible].

4.2 Iron Ore

[illegible] [illegible] [illegible] [illegible] [illegible] [illegible] and low levels of impurities [illegible] sulphur and phosphorus. The requirement of high iron content in ore arises from the [illegible] of the process of conversion of Sponge Iron into steel in Electric Arc Furnace. The higher iron level in the ore gives rise to higher total iron in the product and consequently higher liquid metal yield in Electric Arc Furnaces and minimum iron losses in the slag. Low level of gangue are required as there is no removal of gangue in [illegible] direct reduction process. Further gangue [illegible] additional melting power and appropriate limestone additions to remove it as slag in the steel making stage. The sulphur and Phosphorus contents are also of utmost importance while selecting the ores keeping the specification of the steels to be produced in view.

Suitable precautions are to be taken for desulphurisation in the rotary kiln, as Sponge Iron tends to pick up the sulphur from coal in the absence of desulphuriser. Phosphorus level in ore assumes importance as the Phosphorus in the ore is retained in the Sponge Iron without any change during the reduction process. Eventhough it is desirable to limit the Phosphorus below 0.06% in the ore, it has been reported that Phosphorus is in the oxide form in the gangue matrix and is absorbed by the slag at lower oxidising potential and at lower basicities in Electric Arc Furnaces. Apart from the chemical characteristics as above, the iron ore has to satisfy certain minimum requirements with [illegible], [illegible] Strength. [illegible], Tumbler and Abrasion indices give an indication of the Physical Strength.

Based on Bench Scale Tests of different ores and studies on the decrepitation behaviour in the Rotary Kiln of the SIIL Plant, it is noted that shatter index of iron ores should not be less than 95%. In addition to the physical strength, the decrepitation behaviour of the ores during reduction is of specific importance for rotary kiln operations as the fines generated during reduction form low melting compounds with the coal ash and stick to the refractory lining of the rotary kiln.

It would be desirable to have less than 5 to 7 percent -1 mm. fines in the product. The ore should also have good reducibility with coal to be suitable for use at the kiln operating temperatures. Reducibility index of the order of 94 to 96 per cent tested at a temperature of 1000°C is found to be optimum to get metallisation level of 90 to 92 per cent at the kiln operating temperature. Reducibility index lower than the above value will adversely affect the throughput of the kiln.

4.3 Coal

The main chemical characteristics of the coal which influence its suitability as the reductant are reactivity, proximate analysis comprising of fixed carbon, ash and volatile matter, melting characteristics of coal ash under reducing conditions, the total sulphur and the different forms of sulphur present. Coals of higher reactivity are preferable as they permit the operation of the kiln at lower temperatures and at high throughput rates. In general coal reactivity should be of the order of 2.2 cm^3 of CO/gC sec. The ash in coal should be as low as possible as it occupies the effective kiln volume reducing the space available for iron bearing materials. The ash content in coal can be tolerated upto a level of 25 per cent for use in rotary kilns and any increase beyond this level will reduce the throughput capacity. The volatile matter in coals should be of the order of 30 per cent so as to heat the iron ore to the reduction temperature within the shortest possible time. The fixed carbon should be of the order of 40 to 45 per cent. The melting characteristic of coal ash is of utmost importance while evaluating coals for direct reduction application. As the coal ash forms low melting compounds with sponge iron fines, it is desirable to have softening point of coal ash in excess of 1160°C under reducing conditions. The kiln operating temperature in the reduction zone is so chosen that it is lower than the ash softening point by 100 - 150°C to minimise the formation of accretions. The sulphur content in the coal, in the form of organic and inorganic compounds, also merits careful consideration.

Part of the organic sulphur gets volatilised in the pre-heating zone of the kiln and increases the sulphur load in the waste gas system. Organic sulphur tends to get released in the reduction zone along with the utilisation of carbon and gives rise to sulphur pick up in Sponge Iron in the absence of desulphuriser. In short the iron in the absence of desulphuriser. In short the total sulphur in coals should be low, preferably below 1%. However, coals having high percentage of fixed carbon like anthracite, could also be considered as reductant through blending with bituminous or sub-bituminous coal so that the reactivity of the coal blend improves. Alternatively, such coals could also be used by maintaining higher operating temperatures when the reactivity of the coal improves. The related problems of ash softening and subsequent fusion at higher operating temperatures are absent if the ash content is low.

4.4 <u>Limestone</u>

Limestone is used in the process as desulphuriser of the coal used for reduction such as dolomite. Limestone containing an average of 46 per cent CaO has been observed to be adequate for this requirement. The size distribution of limestone also needs to be considered as it is observed that the desulphurising ability of finely granulated limestone is very good. The size range of 1 to 3 mm is found to be very effective in rotary kilns.

5.0 TEST RESULTS AND EVALUATION

5.1 Chemical analysis of iron ore samples

5.1.1 The iron ore samples were analysed for the constituents such as Fe-total, FeO, SiO_2, Al_2O_3, CaO, MgO, Sulphur, Phosphorus and LOI. The chemical analysis were carried out as per BIS standard test procedures, laid down in the Bureau of Indian Standard No. IS:1493-1959.

The results of the chemical analysis of the iron ore samples are presented in Table - 1.

5.1.2 Fe-Total

The chemical analysis of the Zambian iron ore sample indicate that the average iron content is of the order of 60 to 62 percent. As per the technical requirement of Fe-total in iron ores for sponge iron application, the sample of iron ore with above percentage of iron content is considered satisfactory for the production of sponge iron.

5.1.3 Impurities

The sulphur level in the iron ore samples is observed to be 0.003%. The phosphorus level has observed to be 0.028%. These levels of sulphur and phosphorus are very much on the lower side in comparision with Indian and other ores and as such the quality of sponge iron produced from such ores could superior with very low sulphur and phosphorus levels. Such sponge iron is ideally suited for manufacture of high quality steels.

5.1.4 The loss on ignition of the iron ore samples was observed to be normal at 1.4%. The basic constituents CaO and MgO were observed to occur as traces in the ore samples.

5.2 Physical tests of iron ore

5.2.1 The physical tests like the shatter test and the tumbler tests determine the cold strength of the materials for their resistance to abrasion, impact and handling. The shatter index and the tumbling index gives the indication of probable fines generation during the operation in the kiln and in other handling methods. The results of the shatter tests and the tumbler tests are presented in Table – 2. These tests were conducted as per Bureau of Indian Standard No. IS:14[illegible]-[illegible]81 and IS:6495-1972. The description of terminology used is presented at Annexure – I

5.2.2 Shatter Index

The shatter index of the Zambian iron ore sample was 96.95% which indicates that the ore is of hard type and can withstand the normal handling operation without much generation of fines.

5.2.3 Tumbler Index

The tumbler index of Zambian iron ore sample is observed to be 91.90 percent which indicates that the ore possess good resistance to abrasion during the tumbling action inside the kiln.

5.2.4 **Abrasion Index**

The abrasion index of the ore samples is found to be of the order of 5.1% which is well within the standard norm for Iron Ores for production of sponge iron by Rotary Kiln technology.

5.2.5 **Bulk Density**

The bulk density of the Bailadilla Iron ore samples was observed to be 2.05 gm/cc.

5.3 **Properties of the Re[illegible]nt - [illegible] Coal (Haamba)**

5.3.1 **Proximate Analysis**

The proximate analysis of the coal samples for the determination of fixed carbon, volatile matter and ash was carried out as per [illegible] Indian Standard [illegible].IS:1350-1969. The average results of the analysis carried out are presented in the Table - 3. From the table it could be seen that the volatile matter is 19.80%, fixed carbon is 54.10% and ash is 26.10%. From the above, it is concluded that the coal is suitable for rotary kiln process as a reductant.

5.3.2 **Sulphur Content**

The sulphur content of the coal is one of the important characteristics for the evaluation of suitability of the coal to be used as reductant for direct reduction process using rotary kiln technology. The sulphur in coal is normally composed of inorganic/pyritic sulphur. The presence of organic sulphur contributes to the sulphur pickup in the sponge iron in the absence of desulphuriser. The total sulphur in the coal samples was analysed by gravimetric method as per Bureau of Indian Standard No.IS:1350-1969. The total sulphur in Zambian coal was 0.84 percent which is well within the normal range for reductant for direct reduction process.

5.3.3 Calorific Value

The average gross calorific value of the Zambian coal samples was observed to be of the order of 6647.02 Kcal/Kg which is considered more than adequate for the specified purpose. The calorific value of the reductant was determined in an adiabatic Bomb Calorimeter.

5.3.4 Chemical Analysis of the coal ash

The chemical composition of the coal ash influence the softening characteristics of the coal ash. Higher concentration of silica and alumina contribute to higher softening temperatures. However, higher concentration of the iron oxides in the ash lowers the softening point considerably. The analysis of the coal ash for the determination SiO_2, Al_2O_3, Fe_2O_3, CaO and MgO was carried out and the results are indicated in Table - 5. The results of the chemical analysis of the coal ash indicate that the ash is acidic in nature predominantly of Silica with a value of more than 50% and therefore ash [illegible] characteristics tend to be satisfactory.

[illegible] <u>Melting Characteristics of the coal ash</u>

In the rotary kiln process the kiln is to be operated at a temperature of [illegible]°C to achieve the desired degree of reduction and thus requires coals with relatively higher ash softening temperatures of the order of 100-[illegible]°C above the kiln operating temperature. The melting characteristics of the coal ash is determined in a LEITZ HEATING MICROSCOPE. The points of important observation are the softening or the initial deformation point, the melting or hemispherical point and the flow point. The behaviour of Zambian coal was found to be extremely good and the initial softening point itself was observed to be 1200°C. The test results or the melting behaviour of the coal ash are indicated in the Table - 3.

[illegible]6 <u>Reactivity of coal</u>

Reactivity of the coal refers to the amount and the rate of carbon monoxide generation through the well known Boudouard reaction. This is an important factor in rotary kiln operation since the generation of carbon monoxide required for the reduction of iron ore is formed insitu and is a function of the temperature in the kiln. The test results carried out on Zambian coal indicate the reactivity as 1.75 cc of carbon monoxide per gram of carbon per second. The reactivity value of Zambian coal is adequate and suitable for direct reduction process. This is also further confirmed in the reduction rates in Laboratory Rotary Furnace.

[illegible] [illegible] Limestone

The Zambian limestone chemical analysis shows that it is of Blast Furnace grade with a calcium oxide (CaO) content of 53.18%. The chemical analysis of the limestone reveals that it can be used as desulphuriser [illegible] making.

5.5 Reducibility and Decrepitation Tests.

5.5.1 The reducibility tests were carried out in order to determine the behaviour of the iron ore during reduction and to establish the behaviour of these ores in rotary kiln for commercial operation. The Laboratory Rotary Furnace and short rotary kiln reduction tests simulate the reduction conditions that actually take place in a commercial scale rotary kiln. The test results facilitate in determining the Reducibility Index and Decrepitation Index of the iron ore based on which the most suitable appropriate combination of iron ore and coal for use in rotary kiln could be established besides other factors such as operating parameters etc.

5.5.2 Laboratory Rotary Furnace

The reducibility tests are conducted in an electrically heated Laboratory Rotary Furnace and the normal reduction temperature employed for the tests is 1000°C. Based on the comparative study of bench scale testing and demonstration scale testing, the test conditions for the Laboratory Rotary Furnace tests have been developed at SIIL. A brief outline of the test conditions and evaluation is enclosed at Annexure – II.

The Laboratory Rotary Furnace test results of the Zambian iron ore samples in combination with Zambian coal are presented in Tables 9 to 25. The Laboratory Rotary Furnace tests are conducted on both the Zambian ore samples as received i.e. lump ore (size 5 to 20 mm) and chips (size 5 to 10 mm). The summary of average Laboratory Rotary Furnace Test results of Zambian lump ore and chips in combination with Zambian coal samples at standard test conditions are presented at Tables 7 & 8. Additional tests were also conducted on various size fractions of Zambian ore samples viz. 5-15 mm, 8-20 mm, 10-15 mm, 10-20 mm and 10-15 mm to study the reduction behaviour along with Zambian coal received. The results of Laboratory Rotary Furnace tests conducted on various size fractions of Zambian ore and Zambian coal are at Tables [illegible] to 26. The results [illegible], indicates the overall metallization of the range from [illegible] size [illegible] mm, reducibility [illegible], [illegible] otherwise [illegible], process degradation indices of feed ore and coal, decrepitation behaviour of the ore with respect to -1 mm, -3 mm and -5 mm fines generation during the tests and the chemical analysis of non-magnetic product (unutilised coal).

5.5.3 Average metallisation of product

In all the laboratory rotary furnace tests the average metallisation of +1 mm product achieved is above 90% which shows that Zambian ore is reducible uniformly. The degree of metallisation and the reducibility indices of Zambian iron ore sample were found to be more than 91.6%. These higher values indicate that the iron ore samples have very good reducibility property in combination with Zambian coal as a reductant and the desired degree of metallisation of the order of 90 to 92 percent can be obtained in a commercial size rotary kiln at normal operating temperatures.

Based on the demonstration tests conducted on other iron ores in SIIL Plant, it can be deduced that the Zambian ore would be suitable for sponge iron production in higher sized kilns.

5.5.4 Decrepitation behaviour of ore

The decrepitation behaviour with regard to -1 mm fines generation was found to be of the order of [illegible].71% and 6.71% for Zambian lump ore and ore chips respectively. These values are below the values of test results obtained for similar ores tested at SIIL.

The generation of 1-3 mm fraction is of the order of 16.72% and 14.87% for Zambian lump ore and chips respectively, and the generation of 3 to 5 mm fraction for the lump ore and ore chips are 5.02% and [illegible] respectively. Based on the test results of bench scale studies and the demonstration scale studies conducted with various iron ores at SIIL Test Centre the degradation behaviour of Zambian ore is considered to be good and is well suited for processing in rotary kiln.

5.5.5 Process degradation indices of ore and reductant

The process degradation index of the oxide feed was found to be 21.39% and 23.19% respectively for Zambian lump ore and chips. These values indicates satisfactory levels of degradation property of the ore. The process degradation index for the Zambian coal was found to be of the order of 22 to 26%. This value is lower compared to normal [illegible] grade coals. This is mainly due to the fact that the feed size of coal was of lower size. The marginally lower degradation property of coal did not cause any problem nor is a constraint in view of higher degree of metallization achieved during the test.

5.5.6 Grainsize Analysis

The grainsize analysis of the magnetic product i.e. Sponge Iron was analysed for Fe-total, Fe-Met, and metallization and the results are presented in Tables 9 to 25. It could be seen from the results that the degree of metallization achieved is uniform in all size fractions except -1 mm fraction where the Fe (Total) and Fe (Met) values are slightly lower from other fractions. This is due to the fact that -1 mm fraction [illegible] generally contaminated with non-magnetic fraction and also there could be a chance that the finer fraction will reoxidise as it comes out of the furnace. The uniform metallization of [illegible] achieved even for higher size fraction of +10 mm indicates that the [illegible] ore is of good reducing in nature and well suited for sponge iron making in rotary kiln.

5.6 Short rotary kiln tests

5.6.1 The short rotary kiln is an oil fired furnace, lined with high alumina refractory bricks, and is designed for batch operation. The furnace is equipped with a charging door and a sampling port through which samples can be drawn at definite intervals. It is also equipped with an oil burner whose flame is of horse shoe shape, passing over the material bed inside the furnace. In view of this the actual conditions prevailing in the rotary kiln can be simulated precisely i.e., reducing material bed and oxidizing free board gases. The waste gases are passed through the exhaust duct provided at the top of the burner stand. The rate of flow of waste gases can be controlled precisely by the damper provided in the waste gas line. The samples drawn at definite intervals, of time will be cooled in nitrogen atmosphere and are studied for decrepitation behaviour, rate of reduction and carbon consumption. The test conditions maintained for short rotary kiln test are given at annexure-III.

5.6.2 The summary of the short rotary kiln test results are presented in Tables 25 to 29. In these tables, the screen analysis of the feed material and products are incorporated. The chemical analysis of the samples drawn at various intervals of time are analysed for Fe-total, Fe-metallic, metallisation in the magnetic product and fixed carbon and volatile matter in non magnetic product.

5.6.3 As can be seen from the tables, the reducibility behaviour of Zambian iron ore was found to be good in combination with Zambian coal as reductant. The samples collected at the end of fourth hour after loading has indicated metallisation value of more than 90%. The analysis of the hourly sample indicated that the desired degree of metallisation of 90% could be obtained within four hours of retention time with a material bed temperature of 1000°C. This indicate that in the commercial size kiln the temperature can be still lowered for safe operation and the productivity of the kiln can be increased on account of good reducibility characteristics of the ore sample. Short rotary kiln test results also confirmed the good reducibility and decrepitating behaviour of the ore samples as indicated in the Laboratory Rotary Furnace.

5.7 Product quality of sponge iron

5.7.1 The chemical analysis of the sponge iron samples produced from the Zambian iron ore samples with Zambian coal as the reductant are summarised in Table-10. The results indicate the suitability of the sponge iron, produced from Zambian iron ore, for steel making in electric arc furnaces. The analysis indicates the Fe-total of more than 81%, Fe-metallic more than [illegible] and the degree of metallisation more than [illegible] for Zambian ores. The silica levels in the sponge iron is higher of the order 14%, this is due to the [illegible] ore samples having high silica content initially. The sulphur and phosphorus content in the sponge iron is 0.00[illegible]% and 0.035% respectively. The Sulphur and Phosphorus levels in the Zambian sponge iron is considered to be lower [illegible] the product [illegible] used for production of special steels.

6.0 TRAINING OF ZAMBIAN ENGINEERS

6.1 In terms of the contract two Zambian Engineers Messers A.Banda and A.M.Malama visited SIIL in April/May, 1989 for training in Direct Reduction Technology and observing the tests on Zambian raw materials.

6.2 The two engineers after arrival at Hyderabad on 21.4.89 had detailed discussions with the project Team Leader at Home Office, when the training programme was explained and a schedule was drawn up to suit the trainees. The period of training was revised at the request of Zambian engineers in such a manner that the nature, scope and extent training is not altered. The record note of discussions with trainees is enclosed at Annexure IV. The detailed schedule of training programme covering theory of Direct Reduction Technology, Zambian raw materials testing observations, inplant training at the Demonstration sponge iron plant and on the job training, is presented at Annexure-V.

7.0 CONCLUSIONS AND RECOMMENDATIONS

7.1.0 From the tests conducted and results obtained on samples of Zambian Iron Ore and Zambian Coal, it is observed that both ore and coal are suitable for production of sponge iron in rotary kiln.

7.1.1 The reducibility tests conducted on combination of Zambian ore and coal confirmed that the ore is having good reducible characteristics in combination with Zambian coal.

7.1.2 The decrepitation behaviour of ore during reduction is considered to be good since fines generation (-1 mm) is only 5 to 7%. It can be considered to briquette -3 mm fraction for better use in steel making stage.

7.2 From the extensive tests conducted on Zambian Raw Materials following operating parameters are suggested for using these combination of raw materials in a commercial rotary kiln for production of sponge iron.

Size of Ore	= 5 - 20 mm
Size of Coal	= 1 to 15 mm
Desulphuriser	= Zambian limestone in the size range of 1 to 3 mm. (feed mix 6% of ore feed)
Reduction Temperature	= 1000 - 1050°C
Retention time	= 3 to [illegible] hours.
C/Fe ratio	= 0.55

7.3 The total Iron content in the Sponge Iron produced from Zambian ore is around 83-84% with a gangue content around 14%. The total iron content is therefore slightly on the lower side as compared to Sponge Iron produced from richer iron ore where the total iron is normally around 88% in the Sponge Iron. The marginal lower iron content in the Sponge Iron associated with slightly higher percentage of gangue would mean that extra energy in the form of Electric Power would be required in Electric Arc Furnace for processing Sponge Iron into steel. Since relatively cheap power is available in Zambia the production of steel with slightly higher power consumption would not have any major impact on the Economics. Moreover the low levels of Sulphur and Phosphorus in the Sponge Iron produced from Zambian ores, makes it a very ideal feed material for producing high quality and high value steels, which would counter the disadvantage of high gangue in the sponge iron.

7.3.1 Alternatively the Sponge Iron produced from Zambian ore could be considered for smelting in a special Submerged Arc Furnace for production of low phosphorus, low sulphur, high grade pig iron. Smelting of such sponge iron with high silica content in submerged arc furnace would be considered easier as compare to iron ores. In view of the fact that the material for smelting is ; rereduced power consumption would be much low and economics for production of pig Iron by smelting in submerged arc furnace also appear to be favourable.

7.4 Taking note of above it can be concluded that a 30,000 to 40,000 Tonnes per year sponge iron plant using Zambian iron ore in combination with Zambian coal could be established at a suitable location i. Zambia. The sponge iron produced thus could be effectively used to substitute scrap to a large extent for melting in any of the existing electric arc furnace in Zambia. Alternatively, the Sponge Iron produced could be converted into low phosphorus and low sulphur pig iron in a Submerged Arc Furnace and the pig iron further processed into steel through secondary refining processes. By this route steel production could be based on 100% sponge iron feed. To begin with a 6 MVA Submerged Arc Furnace for production of 30,000-35,000 Tonnes of Pig Iron which can be converted into around 27,000-30,000 Tonnes of high quality steel could also be considered as an alternative proposal.

TABLE - 1.

CHEMICAL ANALYSIS OF [illegible] IRON ORE

Constituent	Lumps (%) (5 to 50)	Chips (%) (1 to 10)
Fe(T)	60.32	61.44
Fe^{+2}	0.40	0.33
FeO	0.51	0.43
Fe^{+3}	59.92	61.11
Fe_2O_3	85.67	87.37
L.O.I.	0.25	01.46
SiO_2	09.84	08.46
Al_2O_3	0.52	0.33
CaO	0.12	0.13
MgO	Traces	Traces
S	0.004	0.00[illegible]
P	0.0[illegible]4	0.03[illegible]

PHYSICAL PROPERTIES OF [illegible]

I [illegible] ANALYSIS ([illegible])

[illegible] ([illegible])	[illegible]	
	[illegible]	[illegible]
[illegible]	[illegible]	–
[illegible]	[illegible]	–
+15	[illegible]	–
+10	25.62	–
[illegible]	21.7[illegible]	26.[illegible]
+5	[illegible]	21.65
+3	0.[illegible]	30.22
+1	Nil	05.76
[illegible]	Nil	[illegible].47

II [illegible]

[illegible] – 96.05%

[illegible] – 91.56%

[illegible] – 5.10%

TABLE - 3

PROPERTIES OF REDUCTANT

(ZAMBIAN COAL)

CHEMICAL ANALYSIS

I Proximate analysis on air Dry Basis.

CONSTITUENT	PERCENTAGE
Volatile matter	19.80
Ash	26.10
Fixed Carbon	54.10
	100.00
Moisture	1.[illegible]0
Sulphur	[illegible].[illegible]4

II Chemical Analysis of Ash

SiO_2	[illegible]
Al_2O_3	[illegible]
Fe_2O_3	13.9[illegible]
CaO	1.[illegible]

III Ash Softening Characteristics

Softening Point	1200°C
Fusion Point	12[illegible]0°C
Flow Point	+1400°C

IV Calorific Value

Gross	6647.02 Cals/gm
Net	6245.25 Cals/gm

V Reactivity

$$\frac{cm^3 \text{ gas}}{gm.sec.} = 1.75$$

[illegible] ANALYSIS OF [illegible]

+1[illegible]	NIL
+10	[illegible]
[illegible]	17.1[illegible]
[illegible]	22.[illegible]
+3	[illegible].73
+1	14.5[illegible]
-1	13.7[illegible]

TABLE – 5

CHEMICAL ANALYSIS OF ZAMBIAN LIMESTONE USED

[illegible]

Constituent	Percentage
L.O.I.	3[illegible].36
CaO	43.1[illegible]
MgO	0[illegible].4[illegible]
Fe_2O_3	07.56
SiO_2	04.84
Al_2O_3	0.22

SCREEN ANALYSIS OF [illegible] LIMESTONE

(AS RECEIVED)

Screen (mm)	Percentage
+20-30	30.49
+15	36.59
+10	26.82
+8	06.10
+5	Nil
+3	Nil
+1	Nil

[illegible] OF [illegible] TEST [illegible] ON ZAMBIAN LUMP ORE (5 TO 20 mm SIZE) ALONG WITH ZAMBIAN COAL UNDER STANDARD CONDITIONS

1. Fe (Total) - 81.36%
2. Fe (Metallic) - [illegible]7.1[illegible]%
3. Metallization (+1 mm) - 93.32%
4. Reducibility Index - 95.31%
5. Process degradation Index
   - Oxide Feed - 21.[illegible]%
   - Reductant - 22.63%
6. Decrepitation behaviour
   - 1 mm fines generation - 4.71%
   - 3 mm fines generation - 21.43%
   - 5 mm fines generation - 26.45%
7. Chemical analysis of non-magnetic product
   - Fixed Carbon - 46.42%
   - Ash - 4[illegible].20%
   - Volatile matter - 5.[illegible]%

SUMMARY OF LABORATORY ROTARY FURNACE TEST RESULTS

ON [illegible] ORE CHIPS (5 TO 10 mm SIZE) ALONG WITH

[illegible] CONDITIONS

1. Fe (Total) (+ 1 mm)	- 82.10%
2. Fe (Met) (+ 1 mm)	- 69.33%
3. Metallization (+ 1 mm)	- 91.91%
4. Reducibility Index	- 94.32%
5. Process degradation Index	
- Oxide feed	- 28.19%
- Reductant	- 22.26%
6. Decrepitation Behaviour	
- 1 mm fines generation	- 6.71%
- 3 mm fines generation	- 21.58%
- 5 mm fines generation	- 37.16%
7. Chemical analysis of non-magnetic product	
- Fixed Carbon	- 43.95%
- Ash	- 49.95%
- Volatile matter	- 6.10%

LABORATORY ROTARY FURNACE TEST RESULTS

Test No.1

I. Input Raw Materials

Iron Ore	: Zambia (5 to 20 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.50
Reduction Temp. °C	: 1000
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 92.29
Reducibility Index	: 94.50
Process Degradation Index	
- Oxide feed	: 23.14
- Reductant	: 13.85

Decrepitation Behaviour (%)

-1 mm	: 4.38
-3 mm	: 21.05
-5 mm	: 28.07

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	79.36	67.74	[illegible]
1 - 3 mm	83.65	76.20	[illegible]
3 - 5 mm	82.32	76.13	[illegible]
5 -10 mm	82.32	75.45	91.[illegible]
10 -15 mm	83.55	76.33	[illegible]
+15 mm	84.12	79.36	[illegible]

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 48.00
Ash	: 46.[illegible]0
Volatile Matter	: 5.10

LABORATORY ROTARY FURNACE TEST RESULTS

Test No.2

I. Input Raw Materials

Iron Ore : Zambia (5 to 20 mm)

Reductant : Coal, Zambia

Desulphuriser : Limestone, Zambia

II. Test Conditions

C/Fe : 0.55

Reduction Temp. °C : 1000

Retention Time Hrs. : 3

III Test Results

Average Metallization (+1 mm) % : 92.03

Reducibility Index : 94.41

Process Degradation Index

- Oxide feed : 24.80
- Reductant : 13.42

Decrepitation Behaviour (%)

-1 mm : 5.56

-3 mm : 23.10

-5 mm : 30.51

IV Crainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	78.98	68.21	86.36
1 - 3 mm	80.33	71.69	89.24
3 - 5 mm	81.36	74.33	91.36
5 -10 mm	83.60	78.24	93.52
10 -15 mm	83.40	76.99	92.31
+15 mm	84.33	77.91	92.39

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon : 43.00

Ash : 52.90

Volatile Matter : 4.10

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 3

I. Innut Raw Materials

Iron Ore	: Zambia (5 to 20 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reluction Temp. °C	: 1000 °C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 93.12
Reducibility Index	: [illegible]
Process Degradation Index	
- Oxide feed	: 26.05
- Reductant	: 26.19

Decrepitation Behaviour (%)

-1 mm	: 5.21
-3 mm	: 9.56
-5 mm	: 25.21

IV Crainsizewise Analysis of Maonetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	72.05	67.02	93.01
1 - 3 mm	79.31	72.61	91.54
3 - 5 mm	80.98	74.64	92.41
5 -10 mm	75.40	71.95	95.42
10 -15 mm	79.05	71.44	90.37
+15 mm	80.19	74.46	92.85

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 49.60
Ash	: 41.20
Volatile Matter	: 9.20

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 4

I. **Input Raw Materials**

Iron Ore	:	[illegible] (5 to 20 mm)
Reductant	:	Coal, [illegible]
Desulphuriser	:	Limestone, [illegible]

II. **Test Conditions**

C/Fe	:	0.[illegible]
Reduction Temp. °C	:	10[illegible]
Retention Time Hrs.	:	3

III **Test Results**

Average Metallization (+1 mm) %	:	95.85
Reducibility Index	:	97.06
Process Degradation Index		
- Oxide feed	:	13.57
- Reductant	:	37.07

Decrepitation Behaviour (%)

-1 mm	:	3.67
-3 mm	:	14.69
-5 mm	:	22.02

IV **Grainsizewise Analysis of Magnetics (%)**

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	81.28	76.34	93.93
1 - 3 mm	81.36	75.32	92.58
3 - 5 mm	82.46	77.87	94.44
5 -10 mm	83.33	78.12	93.75
10 -15 mm	81.36	79.64	97.91
+15 mm	78.37	76.11	97.22

V **Proximate Analysis of Non-magnetic Product (Char)%**

Fixed Carbon	:	45.10
Ash	:	51.80
Volatile Matter	:	3.10

TABLE - 13

LABORATORY ROTARY FURNACE TEST RESULTS

Test No.5

I. Input Raw Materials

Iron Ore	:	[illegible] (5 to 15 mm)
Reductant	:	[illegible]
Desulphuriser	:	[illegible]

II. Test Conditions

C/Fe	:	[illegible]
Reduction Temp. °C	:	1[illegible]
Retention Time Hrs.	:	3

III Test Results

Average Metallization (+1 mm) %	:	91.75
Reducibility Index	:	94.20
Process Degradation Index		
- Oxide feed	:	19.91
- Reductant	:	29.35

Decrepitation Behaviour (%)

-1 mm	:	5.17
-3 mm	:	18.96
-5 mm	:	25.86

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	75.40	53.61	71.11
1 - 3 mm	80.42	75.68	94.02
3 - 5 mm	82.66	76.19	94.5[illegible]
5 -10 mm	80.98	73.60	90.80
10 -15 mm	81.80	74.68	91.30
+15 mm	82.50	74.86	90.50

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	:	48.10
Ash	:	44.80
Volatile Matter	:	7.10

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 6

I. Input Raw Materials

Iron Ore	: Zambia (5 to 15 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 1000°C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 92.52
Reducibility Index	: 94.75
Process Degradation Index	
- Oxide feed	: 13.77
- Reductant	: 31.68

Decrepitation Behaviour (%)

-1 mm	: 4.38
-3 mm	: 12.27
-5 mm	: 20.16

IV Crainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	73.72	69.25	93.94
1 - 3 mm	81.80	77.07	94.21
3 - 5 mm	82.50	77.63	94.10
5 -10 mm	82.10	77.07	93.87
10 -15 mm	82.00	74.49	90.84
+15 mm	87.13	79.30	91.01

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 47.80
Ash	: 46.30
Volatile Matter	: 5.90

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 7

I. Input Raw Materials

Iron Ore	:	[illegible] ([illegible] to [illegible])
Reductant	:	Coal, [illegible]
Desulphuriser	:	L[illegible], [illegible]

II. Test Conditions

C/Fe	:	0.55
Reduction Temp. °C	:	1000°C
Retention Time Hrs.	:	3

III Test Results

Average Metallization (+1 mm) %	:	92.78
Reducibility Index	:	94.43
Process Degradation Index		
- Oxide feed	:	2[illegible].30
- Reductant	:	32.81

Decrepitation Behaviour (%)

-1 mm	:	4.33
-3 mm	:	14.51
-5 mm	:	20.16

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	72.60	63.95	88.08
1 - 3 mm	81.54	76.51	93.80
3 - 5 mm	79.87	77.63	97.19
5 -10 mm	77.50	68.03	87.78
10 -15 mm	79.75	75.19	94.28
+15 mm	81.80	77.23	94.41

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	:	47.20
Ash	:	45.90
Volatile Matter	:	47.20

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 8

I. Input Raw Materials

Iron Ore	: Zambia (8 to 20 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.60
Reduction Temp. °C	: 1000 °C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 91.74
Reducibility Index	: 94.20
Process Degradation Index	
- Oxide feed	: 19.70
- Reductant	: 28.20

Decrepitation Behaviour (%)

-1 mm	: 3.36
-3 mm	:14.29
-5 mm	:19.33

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe (Met)	Metallization
-1 mm	73.72	69.25	93.94
1 - 3 mm	83.78	76.24	91.00
3 - 5 mm	85.45	78.19	91.50
5 -10 mm	82.10	76.51	93.19
10 -15 mm	86.57	78.19	90.31
+15 mm	91.59	84.89	92.68

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 45.70
Ash	: 46.90
Volatile Matter	: 7.40

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 9

I. Input Raw Materials

Iron Ore	:	Zambia (4 to 20 mm)
Reductant	:	Coal, Zambia
Desulphuriser	:	Limestone, Zambia

II. Test Conditions

C/Fe	:	0.66
Reduction Temp. °C	:	1000 °C
Retention Time Hrs.	:	3

III Test Results

Average Metallization (+1 mm) %	:	95.04
Reducibility Index	:	96.[illegible]
Process Degradation Index		
- Oxide feed	:	19.70
- Reductant	:	36.09

Decrepitation Behaviour (%)

-1 mm	:	3.39
-3 mm	:	15.[illegible]
-5 mm	:	19.49

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	75.40	68.14	90.3[illegible]
1 - 3 mm	83.22	78.75	94.62
3 - 5 mm	86.57	82.65	95.48
5 -10 mm	82.80	78.20	94.44
10 -15 mm	88.80	84.33	94.97
+15 mm	91.59	87.68	95.74

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	:	53.10
Ash	:	40.60
Volatile Matter	:	6.1

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 10

I. Input Raw Materials

Iron Ore	: Zambia (10 to 15 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 100[illegible]°C
Retention Time Hrs.	: [illegible]

III Test Results

Average Metallization (+1 mm) %	: 87.65
Reducibility Index	: [illegible]1.48
Process Degradation Index	
- Oxide feed	: [illegible]9.52
- Reductant	: 3[illegible].62

Decrepitation Behaviour (%)

-1 mm	: 2.73
-3 mm	: 10.18
-5 mm	: 15.74

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	79.32	69.40	87.50
1 - 3 mm	82.73	77.80	94.04
3 - 5 mm	83.43	76.09	91.10
5 -10 mm	83.52	73.23	87.68
8 -10 mm	82.65	74.84	90.54
10 -15 mm	82.43	71.30	86.50

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 43.80
Ash	: 50.10
Volatile Matter	: 6.10

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 11

I. Input Raw Materials

Iron Ore	: Zambia ([illegible] mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 1050
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 92.63
Reducibility Index	: 94.86
Process Degradation Index	
- Oxide feed	: 21.49
- Reductant	: 37.79

Decrepitation Behaviour (%)

-1 mm	: 2.52
-3 mm	: 11.74
-5 mm	: 15.97

IV Crainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	72.61	61.99	85.38
1 - 3 mm	78.75	72.33	91.84
3 - 5 mm	80.98	74.84	92.42
5 -10 mm	77.63	72.25	93.07
10 -15 mm	86.01	80.42	93.50
15 -20 mm	83.77	78.75	94.00
20 -25 mm	89.36	82.66	92.50

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 51.80
Ash	: 43.10
Volatile Matter	: 5.10

LABORATORY ROTARY FURNACE TEST RESULTS

Test No.12

I. Input Raw Materials

Iron Ore	: Zambia (10 to 25 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 1050°C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 91.82
Reducibility Index	: 94.26
Process Degradation Index	
- Oxide feed	: 27.95
- Reductant	: 41.37

Decrepitation Behaviour (%)

-1 mm	: 2.59
-3 mm	: 9.49
-5 mm	: 12.9[illegible]

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe (Met)	Metallization
-1 mm	82.15	72.55	88.30
1 - 3 mm	82.26	73.52	89.38
3 - 5 mm	84.13	77.68	92.32
5 -10 mm	83.38	77.65	93.13
10 -15 mm	83.16	79.48	92.29
15 -20 mm	82.45	75.33	73.53
+20 mm	81.36	73.53	90.38

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 43.1
Ash	: 51.8
Volatile Matter	: 5.1

TABLE - 21

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 13

I. Input Raw Materials

Iron Ore	: Zambia (5 to 10 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 1000°C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 92.68
Reducibility Index	: 94.86
Process Degradation Index	
- Oxide feed	: 32.12
- Reductant	: 14.01

Decrepitation Behaviour (%)

-1 mm	: 7.93
-3 mm	: 13.87
-5 mm	: 41.59

IV Crainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	72.60	68.14	93.85
1 - 3 mm	77.84	72.31	92.90
3 - 5 mm	79.07	73.62	93.11
5 -10 mm	80.75	74.16	91.84
8 -10 mm	81.20	77.09	94.64

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 46.80
Ash	: 44.80
Volatile Matter	: 8.40

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 14

I. **Input Raw Materials**

Iron Ore	: Zambia (5 to 10 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Lime stone, Zambia

II. **Test Conditions**

C/Fe	: [illegible].55
Reduction Temp. °C	: 1000 °C
Retention Time Hrs.	: 3

III **Test Results**

Average Metallization (+1 mm) %	: 92.40
Reducibility Index	: 94.67
Process Degradation Index	
- Oxide feed	: 29.82
- Reductant	: 21.10

Decrepitation Behaviour (%)

-1 mm	: 7.14
-3 mm	: 23.22
-5 mm	: 30.[illegible]

IV **Grainsizewise Analysis of Magnetics (%)**

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	72.61	65.90	90.76
1 - 3 mm	83.78	76.73	91.66
3 - 5 mm	84.33	79.31	94.03
5 -10 mm	83.22	76.23	91.60
8 -10 mm	80.98	75.40	93.10

V **Proximate Analysis of Non-magnetic Product (Char)%**

Fixed Carbon	: 45.10
Ash	: 46.80
Volatile Matter	: 8.10

TABLE - 23

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 15

I. Input Raw Materials

Iron Ore	: Zambia (5 to 10 mm)
Reductant	: Coal, Zambia
Desulphuriser	: Limestone, Zambia

II. Test Conditions

C/Fe	: 0.55
Reduction Temp. °C	: 1050°C
Retention Time Hrs.	: 3

III Test Results

Average Metallization (+1 mm) %	: 92.28
Reducibility Index	: 94.58
Process Degradation Index	
- Oxide feed	: 22.84
- Reductant	: 25.86

Decrepitation Behaviour (%)

-1 mm	: 5.94
-3 mm	: 17.82
-5 mm	: 33.66

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	79.38	75.62	95.26
1 - 3 mm	80.38	77.56	96.49
3 - 5 mm	81.23	75.85	93.38
5 - 8 mm	81.16	77.19	95.11
8 -15 mm	78.43	67.80	86.59

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	: 38.40
Ash	: 58.10
Volatile Matter	: 3.50

LABORATORY ROTARY FURNACE TEST RESULTS

Test No. 16

I. Input Raw Materials

Iron Ore	:	Zambia (3 to 10 mm)
Reductant	:	Coal, Zambia
Desulphuriser	:	Limestone, Zambia

II. Test Conditions

C/Fe	:	0.50
Reduction Temp. °C	:	1000
Retention Time Hrs.	:	3

III Test Results

Average Metallization (+1 mm) %	:	90.29
Reducibility Index	:	93.18
Process Degradation Index		
- Oxide feed	:	27.98
- Reductant	:	28.09

Decrepitation Behaviour (%)

-1 mm	:	5.82
-3 mm	:	31.40
-5 mm	:	43.03

IV Grainsizewise Analysis of Magnetics (%)

Size Range	Fe (Total)	Fe(Met)	Metallization
-1 mm	70.93	64.79	91.34
1 - 3 mm	75.40	67.02	88.35
3 - 5 mm	74.28	66.74	89.05
5 -18 mm	73.84	67.58	91.52
8 -10 mm	73.16	66.46	90.84
+15 mm	-	-	-

V Proximate Analysis of Non-magnetic Product (Char)%

Fixed Carbon	:	45.50
Ash	:	50.10
Volatile Matter	:	4.40

TABLE-25

[illegible]

TEST No. 1

Ore : Nambala Lumps (+3-20mm) Coal : Maamba

Temp : 1000°C C/Fe : 0.55

Screen Size	Feed Ore	Feed Coal	Magnetics	Non-Magnetics
+ 20 mm	27.44	Nil	3.91	Nil
+ 15-20 mm	16.29	Nil	15.61	Nil
+ 10	[illegible]	0.52	39.06	Nil
+ 8	21.72	17.15	11.72	17.14
+ 5	04.44	12.30	11.72	14.29
+ 3	06.49	31.70	10.16	50.00
+ 1	Nil	14.58	03.91	11.43
- 1	Nil	13.72	03.91	07.14

[illegible] :

Sl.No.	Sample reference	Temp °C	Fe(T)	Fe(M)	Metn
(1)	After two hrs.	985	75.35	37.41	75.35
(2)	After Three hrs.	[illegible]	[illegible]	71.05	[illegible]
(3)	After Four hrs.	985°C	82.36	75.33	91.46

[illegible] :

	Sample No. (1)	(2)	(3)
VM =	02.80	[illegible]	01.40
[illegible] =	[illegible]	[illegible]	[illegible]
FC =	37.40	[illegible]	10.60

SHORT ROTARY KILN TEST RESULTS

TEST NO. 2

Ore : Nambala (+8-25mm) **Coal** : Maamba

Temp : 1000°C **C/Fe** : 0.6

Screen Size	Feed Ore	Feed Coal	Magnetics	Non-Magnetics
+ 20-25mm	15.00	Nil	2.80	-
+ 15-20mm	25.00	Nil	15.65	-
+ 10	35.00	Nil	21.31	-
+ 8	25.00	30.00	16.86	12.64
+ 5	Nil	40.00	16.68	24.62
+ 3	Nil	20.00	15.62	41.55
+ 1	Nil	10.00	6.68	12.68
- 1	Nil	--	4.40	8.51

CHEMICAL ANALYSIS OF PRODUCT (MAGS) :

Sl.No.	Sample reference	Temp°C	Fe(T)	Fe(M)	Metn
(1)	After two hrs.	980°C	70.32	52.60	74.36
(2)	After three hrs.	990°C	80.46	69.56	86.45
(3)	After four hrs.	1005°C	83.10	75.09	90.36

CHEMICAL ANALYSIS OF NON-MAGNETICS :

Sample No.		(1)	(2)	(3)
VM	=	03.10	02.80	02.10
Ash	=	56.40	62.10	66.30
FC	=	42.50	35.10	31.60

SHORT ROTARY KILN TEST RESULTS

TEST NO. 3

Ore : Nambala (+8–20mm) **Coal** : Maamba

Temp : 1000°C **C/Fe** : 0.62

Screen Size	Feed Ore	Feed Coal	Magnetics	Non-Magnetics
+ 15–20 mm	35.00	Nil	4.83	-
+ 10	40.00	Nil	17.54	-
+ 8	25.00	30.00	25.42	13.56
+ 5	Nil	45.00	23.36	26.48
+ 3	Nil	25.00	20.44	38.15
+ 1	Nil	Nil	4.56	11.68
- 1	Nil	Nil	3.85	5.13

CHEMICAL ANALYSIS OF PRODUCT (MAGS) :

Sl.No.	Sample reference	Temp°C	Fe(T)	Fe(M)	Metn
(1)	After two hrs.	[illegible]0°C	72.36	53.78	74.32
(2)	After three hrs.	9[illegible]5°C	76.32	62.85	82.35
(3)	After four hrs.	1005°C	83.15	76.05	91.45

CHEMICAL ANALYSIS OF NON-MAGNETICS :

Sample No.		(1)	(2)	(3)
VM	=	01.40	01.10	0.90
Ash	=	46.[illegible]	51.[illegible]	62.90
FC	=	51.80	47.10	36.20

SHORT ROTARY KILN TEST RESULTS

TEST NO.4

Ore : Nambala (+10-20mm) Coal : Maamba

Temp : 1020 C/Fe : 0.60

Screen Size	Feed Ore	Feed Coal	Magnetics	Non-Magnetics
+ 15-20 mm	40.00	Nil	7.5	-
+ 10	60.00	Nil	20.64	-
+ [illegible]	Nil	30.[illegible]	23.56	10.56
+ 5		45.[illegible]	22.64	18.89
+ 3		25.[illegible]	17.85	50.67
+ 1		Nil	5.66	12.86
- 1		Nil	2.15	7.02

CHEMICAL ANALYSIS OF PRODUCT (MAGS) :

Sl.No.	Sample reference	Temp°C	Fe(T)	Fe(M)	Metn
(1)	After two hrs.	[illegible]°C	[illegible].36	53.34	73.7[illegible]
(2)	After three hrs.	1005°C	[illegible].57	6[illegible].36	[illegible]
(3)	After four hrs.	1020°C	[illegible].43	76.29	92.55

CHEMICAL ANALYSIS OF NON-MAGNETICS :

	Sample No. (1)	(2)	(3)
VM =	03.10	02.20	01.10
Ash =	39.80	45.80	51.90
FC =	57.10	52.00	47.00

SHORT ROTARY KILN TEST RESULTS

TEST NO. 5

Ore : Nambala (+8-20mm) Coal : Maamba

Temp : 1030°C C/Fe : 0.60

Screen Size	Feed Ore	Feed Coal	Magnetics	Non-Magnetics
+ 15-20mm	35.00	Nil	5.24	-
+ 10	40.00	Nil	19.65	-
+ 8	25.00	30.00	24.51	16.81
+ 5	Nil	45.00	18.48	24.35
+ 3		25.00	21.34	42.20
+ 1		Nil	6.64	11.35
- 1			4.14	5.29

CHEMICAL ANALYSIS OF PRODUCT (MAGS) :

Sl.No.	Sample reference	Temp°C	Fe(T)	Fe(M)	Metn
(1)	After two hrs.	1030°C	75.34	57.19	75.92
(2)	After three hrs.	1030°C	7[illegible].36	64.[illegible]	81.7[illegible]
(3)	After four hrs.	1030°C	83.15	75.97	91.36

CHEMICAL ANALYSIS OF NON-MAGNETICS :

Sample No.	(1)	(2)	(3)
VM =	01.80	[illegible]	0.80
Ash =	42.80	4[illegible].30	51.80
FC =	55.40	[illegible]	47.40

TABLE – [illegible]

CHEMICAL ANALYSIS OF SPONGE IRON PRODUCED FROM INDIAN ORE

Fe(T)	:	83.77
Fe^{+2}	:	3.08
FeO	:	3.96
Fe^{+3}	:	1.67
Fe_2O_3	:	2.39
Fe(M)	:	79.02
Metn.	:	94.33
SiO_2	:	13.14
Al_2O_3	:	0.87
CaO	:	0.05
MnO	:	Traces
Phosphorus	:	0.055
Sulphur	:	0.006
Carbon	:	0.15

LIST OF TERMINOLOGY, ABBREVIATIONS AND MEASUREMENT UNITS USED

1. **Metallisation:** (Metn.):- The ratio of metallic iron to total iron in sponge iron expressed as percentage i.e.,

$$\text{Percent Metallisation} = \frac{\text{Fe metallid + Fe in Fe3C}}{\text{Fe total}} \times 100$$

2. **Metn + 1 mm:**- Metallisation of sponge iron of size above one millimetre expressed as percentage.

3. **Reducibility:**- The property of iron ore that measures the ease with which it parts with its oxygen under action of reductant.

4. **Reducibility Index (R.I):**- The extent of reduction taken place expressed as a percentage. The reported values are the reduction achieved at the test period, calculated from metallisation obtained by chemical analysis of sponge iron.

5. **Degradation:**- It is the fragmentation and breaking up, giving rise to fines which the material undergoes due to abrasion, handling, transportation etc.

6. **Thermal Degradation:**- It is fragmentation and breaking up, giving rise to fines which the material undergoes when subjected to heating and cooling cycles in the presence of air and at temperature upto 700°C.

7. **Process Degradation:**- It is the degradation which the material may suffer due to reduction process.

...

8. **Process Degradation of Oxide Feed:-** It is the degradation of iron ore during the reduction process. Process degradation of iron ore is expressed as a ratio of change in mean particle size of iron ore after reduction to the initial mean particle size before reduction expressed as percentage i.e. process Degradation of Oxide Feed

$$= \frac{\text{Mean Particle size of Iron Ore before reduction} - \text{Mean particle size of Sponge Iron after reduction}}{\text{Mean particle size of Iron Ore before Redn.}} \times 100$$

9. **Process Degradation of Reductant:-** It is the degradation of coal during the reduction process. Process Degradation of coal is expressed as a ratio of change in mean particle size of coal after reduction to the initial mean particle size before reduction expressed as percentage i.e.

i.e. Process Degradation of Reductant

$$= \frac{\text{Mean Particle Size of coal before Reduction} - \text{Mean particle size of coal after reduction}}{\text{Mean Particle size of Coal before Reduction}} \times 100$$

10. **C/Fe Ratio:-** It is the ratio of weight of Fixed Carbon content in coal used for reduction test to the weight of Iron content in ore used for reduction test.

11. **Tumbler Strength:** It measures the relative resistance of the material to degradation by impact and abrasion.

...

12. **Tumbler Index:-** It is expressed as the weight percentage iron ore of size above 6.3 mm after subjecting to Tumbling Test.

13. **Abrasion Index:-** It is expressed as the weight percentage of iron ore of size below 0.5 mm after subjecting to Tumbling Test.

14. **Shatter Strength:-** The test to determine the shatter index stimulates the effect dropping iron ore and measures the impact hardness (the abradability of iron ore) as distinct from surface hardness.

15. **Shatter Index:-** It is expressed as the weight percentage of iron ore of size above 5 mm after subjecting iron ore to drop test.

16. **F.C. or C-Fix:-** Fixed Carbon Content of Coal in weight percentage.

17. **V.M.;-** Volatile Matter Content of Coal in weight percentage.

18. **I.D.T.:-** Initial Deformation Temperature of Coal Ash °C.

19. **K-Cal/Kg** - Calorific value of coal expressed on Kilo Calories per Kilogram of the sample.

20. CM^3/of CO/g C see. Reactivity of coal expressed as volume of carbon monoxide generated in cubic centimeters per gram carbon per second.

...

21. L.O.I.:- Loss on Ignition for Iron Ore or Limestone.

22. Fe(T):- Total Iron Content of Iron Ore or Sponge Iron %

23. Fe(M): Metallic Iron content of Sponge Iron %

ANNEXURE-II

LABORATORY ROTARY FURNACE TEST CONDITIONS

Furnace Feed Charge

Iron Ore	: [illegible] ore (Standard size 5-20 mm)
Reductant	: As per test requirements
C/Fe ratio	: [illegible]
Desulphurizer	: As per requirement (% of ore feed)

Furnace Conditions

Temperature of Furnace on feeding	: Room Temperature 35°C
Heat up time reduction temperature	: 120 minutes
Reduction temperature	: 1000°C
Reduction time	: [illegible] minutes
Furnace rotation speed	: 8 rpm
Furnace atmosphere	: Inert atmosphere

SHORT ROTARY KILN TEST CONDITIONS

KILN CHARGE

Iron Ore	:	Sized Ore (Standard Size 5-20 mm)
Reductant	:	Sized coal as per requirement (Standard size 1 to 15 mm)
C/Fe ratio	:	0.55
Desulphurizer	:	As per test requirements

KILN CONDITIONS

Temperature of kiln upon feeding	:	700°C
Heat up time to reduction temperature	:	100 Minutes
Reduction temperature	:	975 to 1050°C
Reduction time	:	140 to 160 Minutes
Kiln speed	:	2 rpm
Kiln atmosphere	:	As per requirement.

ANNEXURE-IV

FELLOWSHIP TRAINING PROGRAMME OF ZAMBIAN ENGINEERS UNDER CONTRACT NO.DP/ZAM/88/025.

Messers A.M.Malama and A.Banda from Republic of Zambia arrived at Hyderabad on 21.4.89. The training programme drawn up by SIIL was made available to them and the same was discussed at SIIL Office in Hyderabad on 22.4.89.

The Zambian Engineers were informed that the Raw Materials from Zambia were received during the Second week of April'89, and preliminary tests have been carried out, the results of which are encouraging. Detailed test work in accordance with the contract with UNIDO, would be undertaken and the same would be witnessed by Zambian Engineers. The test results to the extent that would be completed during their stay at Paloncha would be made available so that the same could be carried for evaluation and interaction with the Metallurgical Expert already posted to Lusaka.

The Zambian Engineers suggested that the test work be expedited so that they return to Lusaka with the results for discussion with the Metallurgical Expert. Accordingly, the training programme has been revised. By this arrangement there will be no change in the scope and magnitude of work and the training programme.

The Zambian Engineers would leave Paloncha on 17.5.1989 after the test work has been completed.

A.M.Malama

K.P.Patnaik 22/4/89

A.Banda

[illegible] AT SITE

21.4.89 - Arrival at Hyderabad

22.4.89 - Discussion with project Team Leader at Hyderabad on the schedule of training programme.

[illegible] - [illegible]

[illegible] -

Forenoon - Introduction to plant personnel and plant general layout.

Afternoon - [illegible]

[illegible]

Forenoon - Test work observation at R&D Centre

Afternoon - Technical discussions with [illegible]

[illegible]

Forenoon - Observation of Test Work on [illegible] raw material

Afternoon - Discussions

27.4.89

Forenoon - Raw materials for direct reduction and requirements

Afternoon - Chemical analysis of raw materials and final product.

28.4.89

Forenoon - Laboratory equipment and R&D facility and test procedures

Afternoon - Equipment flow-sheet in raw material preparation plant.

29.4-89

Forenoon - Equipment flow-sheet in Reduction Plant

Afternoon - Equipment flow-sheet in Briquetting Plant.

02.5.89

Forenoon - Process flow-sheet Explanation

Afternoon - Refractory for Direct Reduction Plant.

03.5.89

Forenoon - Electrical equipments in Raw Material preparation plant and their interlocking and controls.

Afternoon - Description of electrical equipment in Reduction Plant.

04.5.89

Forenoon - Instrumentation and Controls.

Afternoon - Mechanical equipment maintenance and shut down planning in DRP

[illegible]

05.05.1989 to 06.05.1989	- RMP Plant
08.05.1989	- Briquetting plant
09.05.1989 to 11.05.1989	- R&D observations of Test Work
12.05.1989 to 15.05.1989	- Reduction Plants - I and II
16.05.1989	- Discussions, Clarifications and concluding.
17.05.1989	- Leave for Hyderabad.
18.05.1989	- Review meeting with Project Team Leader at Hyderabad.