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FINAL REPORT ON TESTS ON IRON ORE SAMPLES RECEIVED FROM GOVERNMENT OF NEPAL THROUGH UNIDO.

17268

November 1988

ENGINEERING AND PROJECTS DIVISION
Sponge Iron India Ltd.
HYDERABAD-ANDHRA PRADESH

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INTERIM REPORT ON TESTS ON IRON ORE SAMPLES RECEIVED FROM GOVERNMENT OF NEPAL THROUGH UNIDO.

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1.0 INTRODUCTION

1.1 United Nations Industrial Development Organisation (UNIDO) under the Project No.DP/RAS/81/063 and Contract No. 86/33 awarded to Sponge Iron India Limited (SIIL), the work on testing of the Iron Ores of Nepal for ascertaining their suitability for production of Sponge Iron suitable for steel making in Electric Arc Furnace. The Contract was awarded in response to the proposal for undertaking such a study submitted by SIIL vide their reference No.SI/RO/E&P/7681/677/57, dated 14.4.1986.

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

(a) Undertake raw material processing, beneficiation, agglomeration, etc. of iron ores for direct reduction tests and of coal as the reductant, covering their physical, chemical and metallurgical analysis and test work;

(b) Carry out direct reductions tests for sponge production on laboratory scale;

(c) Compile test results achieved through the above measures;

(d) Prepare a detailed report on the work performed under sub-paragraphs (a) to (c) above, including an analysis of the techno-economic data/results/ recommendations for Sponge Iron production.

1.3 Iron Ore samples of two types from Phulchoki region, each of 5000 kg were received from Department of Mines and Geology, Government of Nepal for undertaking the above tests, at SIIL Test Centre in the second week of January, 1987. The physical characteristics of the samples and the Petrological studies revealed that the Ores are of Hematite type associated with quartz and meta basic rocks as gangue materials. The size of the as received samples ranged from 25 mm to 100 mm. The results of the preliminary chemical analysis of the two ore samples revealed that the Ores are of low grade type and require beneficiation for upgradation.

Accordingly, the following programme of test work was drawn up:

i) Preliminary investigations on Iron Ores of Nepal to asses their quality.

ii) Beneficiation tests on Nepal Iron Ores to improve the quality of the Ore.

iii) Determination of chemical analysis and physical properties of beneficiated Nepal ore samples.

iv) Study of physical properties like reactivity, ash fusion characteristics, calorific value, etc., and chemical analysis of the reductant used for reduction tests.

v) Conducting of Laboratory and Bench Scale Tests on Nepal Ores along with Indian non coking coal as reductant, for production of Sponge Iron.

2.0 TEST OBJECTIVES:

2.1 The prime objective of the Laboratory and Bench Scale Tests is to determine the suitability of Nepal Ores in combination with Manuguru Coal of Singareni Collieries, for production of highly metallised sponge iron suitable for steel making in Electric Arc Furnaces (EAF). The tests carried out and their objectives are summarised below.

2.1.1 To analyse the Nepal Iron Ore samples chemically in order to determine their suitability with regard to Fe total, gangue and other constituents.

2.1.2 To determine the physical characteristics viz., screen analysis, shatter and tumbler index and to carry out Petrological study of the, as received ore samples, for establishing beneficiation work to be undertaken for upgrading the ores.

2.1.3 Beneficiation of the Nepal iron ore samples to improve the iron content and to produce sized ore samples for carrying out further reduction tests, 2.1.4 To determine the cold strength of the Nepal iron ores and its resistance to abrasion, impact using the shatter test apparatus.

2.1.5 To determine the decrepitation behaviour of the Nepal iron ores during reduction, under standard test conditions.

2.1.6 To determine the detailed chemical analysis and physical properties of the reductant (Indian non-coking coal) used in the reduction tests.

2.1.7 To carry out Laboratory and Bench Scale Tests on Nepal Iron Ores along with Indian non-coking coal (Manuguru) to produce highly metallised sponge iron.

3.0 TEST MATERIAL

3.1 Iron Ores:

Two samples of Nepal Iron Ores from Phulchoki region were received from the Department of Mines and Geology, Government of Nepal, in the size range of 25 to 100 mm. The quantity of each sample is 5000 Kg. The physical characteristics (Screen analysis) and chemical analysis of as received samples are given at Tables 1 & 2.

3.2 Reductant (Coal):

Indian non-coking coal (Manuguru) being used in SIIL Plant has been considered as a reductant for the test work. The properties of the Manuguru coal is presented in Table - 3.

3.3 Desulphurizer (Limestone used):

The Limestone used in the SIIL Plant has been considered as a desulphuriser for the tests. The screen analysis and chemical analysis of the Limestone is given at Table - 4.

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 operation. As the manufacture of Sponge Iron in rotary kiln is sensitive to the characteristics of the raw materials with regard to size distribution and other chemical parameters, bench scale testing forms the first essential step in determining the suitability of any ore, coal and limestone combination for the production of Sponge Iron suitable for Electric Arc Furnace steel making.

4.2 Iron Ore

Iron Ore should have as high iron content as possible, preferably above 62% with low gangue components and low levels of impurities such as sulphur and phosphorus. The requirement of high iron content in ore arises from the needs 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 the direct reduction process. Further gangue requires additional melting power and appropriate limestone additions to remove it as slag in the steel making stage. Based on the operating experience, total gangue below 6% would be desirable in the iron ore with silica being less than 3%. 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 observed that Phosphorus levels could be tolerated upto 0.12% in Sponge Iron, 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 regard to physical strength. Shatter, 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 1150°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 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 a desulphurizer as the coal used for reduction contains sulphur. Limestone containing as average of 45 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 BENEFICIATION OF ORES:

5.1.0 Preliminary Tests on the Iron Ores from Nepal:

5.1.1 The Preliminary chemical analysis carried out on the as received ore samples indicated that both the ores are of a relatively low grade with average total Fe content of 52.80% and 48.03% in sample-1 and sample-2 respectively. The total gangue content in the two ore samples are of the order 17.50% and 23.47% respectively. As it is seen from the chemical analysis of the ores the Silica and Aluminium content is as high as 17.5 to 24% from which it could be infered that the ores should be beneficiated for eliminating or minimising the gangue portion.

5.1.2 The sizewise chemical analysis of as received ore samples indicates that -25 mm fraction was bearing low iron content as compared to +25 mm fraction. Also it was observed that ore sample was having some contaminants (Green Pieces) with very low iron content of the order 10 to 15 per cent and which could be identified physically and seperated. Such inclusions could be segregated during mining operations without any difficulty.

5.1.3 The Petrological studies on the ore samples shows that Hematite and Goethite were the main iron ore minerals while quartz and meta basic rocks were present as gangue materials in both the samples. Based on this preliminary study, beneficiation process for improving the iron content was drawn up.

5.2.0 BENEFICIATION STUDIES ON NEPAL ORES:

5.2.1 The beneficiation tests for improving the iron content in the iron ore samples of Nepal was conducted at Research and Development Laboratories of National Mineral Development Corporation (NMDC), Hyderabad. The tests were aimed to establish the feasibility to produce high iron content of calibrated product in the size range of 6 to 20 mm, which is the normal feed size of ore for sponge iron production by the Rotary Kiln process. Keeping this in view a flow sheet was developed for carrying out beneficiation studies.

5.2.2 Two samples of Iron Ore received from Nepal marked as Sample-1 and Sample-2 were supplied to NMDC for undertaking the beneficiation tests. Petrological examination and study of the sizewise chemical analysis was conducted on the ore samples. On the basis of such preliminary studies the beneficiation tests were carried out. The detailed report on the beneficiation tests is given at Annexure-I. The beneficiation tests have shown that the iron content of the ores could be improved from 53.4% to 56.14% and 48.41% to 53.99% for Sample-1 and Sample-2 respectively. The beneficiation tests were carried out in bench scale and pilot plant scale levels. The results of the beneficiation tests are summarised below:

	At Bench Scale Test Level.		At Pilot Plant Scale Test Level.	
	Sample-1	Sample-2	Sample-1	Sample-2
Fe(T) % in the as received samples	53.40	48.41	53.40	48.41
Size of products after beneficiation-mm	6 to 20	6 to 20	6 to 20	6 to 20
Fe(t) in the beneficiated product %	56.52	54.22	57.50	55.69
Weight recovery %	68.50	64.40	58.90	54.80
Iron Unit recovery	72.07	73.51	63.42	63.04

5.2.3 Beneficiation tests were also conducted on Nepal Ores by wet jigging operation. For these studies, the two samples of ore received from Nepal were blended in equal proportion and experiments were conducted on composite samples. The main objective of this beneficiation tests is to study the effect of jigging operation for improving the iron content in the ore. Harz type of jigs were used for the experiments. The jigging tests were conducted at a recognised mineral dressing and benefication laboratory of the Government of India, as such beneficiation facility of jigging was not available with SIIL. The detailed report as proposed by the above laboratory is enclosed at Annexure - II. From the jigging tests conducted on different size fractions of the ore sample, it is established that the total iron content in the ore has not shown any improvement as compared to the results obtained from the previous test of crushing, screening and washing conducted at National Mineral Development Corporation, Hyderabad. As such the jigging operation is considered not suitable particularly on account of high density of the ore.

The results of the beneficiation studies by jigging operation are summerised below:

Assay %	Composit ore sample as fed to the jig	BENEFICIATED PRODUCT -15 +10 mm	-10 +[illegible]mm	-10.0 +4.75mm	-4.75 +3.3mm	-3.2 +0.85 mm
Fe (T)	51.9	52.06	53.50	55.25	53.00	56.24
SiO_2	18.11	17.27	14.07	14.40	11.68	6.91

6.0 LABORATORY AND BENCH SCALE TESTS ON NEPAL ORES

6.1.0 Chemical analysis of Ore Samples:

6.1.1 The Beneficiated Iron Ore samples of Nepal were analysed for the constituents such as Fe (Total), FeO, SiO_2, Al_2O_3, CaO, MgO, Sulphur and Phosphorus. The results of the chemical analysis of two beneficiated ore samples used for further testing (reduction tests) are given in Table-5.

6.1.2 Fe (Total):

The chemical analysis of two ore samples shows that the total Iron content is 58.64% in Sample-1 and 57.80% in Sample-2. The Iron content is still considered to be low as compared to normally occuring ores suitable for sponge iron production. Low Iron content in the ore tends to lower Fe (total) in Sponge Iron. In view of the lower Fe content in the sponge iron, the liquid metal yield would be lower as compared to the yield when scrap or sponge iron with high total Fe manufactured from better grade ores are used.

6.1.3 Gangue:

The gangue content in the two ore samples is about 15.79% and 16.84% in sample-1 and sample-2 respectively. The gangue could be separated during steel making stage as slag.

6.1.4 Impurities:

The impurities normally present in the Iron Ores are sulphur and phosphorus. As can be seen from the chemical analysis both the Nepal Ores contain low phosphorus and sulphur and hence could be considered superior as compared to normally occurring ores for sponge iron making. Special steel can be produced from both the Ores due to low Sulphur and Phosphorus in the sponge iron.

6.2.0 **Physical Tests on the Iron Ores:**

6.2.1 The physical tests like the Shatter test and the Tumbler test determine the cold strength of the material for their resistance to abrasion, impact handling. The Shatter, Tumbler and the abrasion indices give an indication of probable extent of fines likely to be generated during the reduction process in the kiln and while handling the product. These tests have been carried out as per relevant standards IS: 9963-1981 and IS: 6495-1972 respectively. The results of the shatter tests and tumbler tests are shown in the Table-6.

6.2.2 **Shatter Index:**

The Shatter Index of both the Nepal Ore samples is 97.00%. The test results indicate that the ores can withstand very well to normal handling and such high shatter index indicated that the Ores are suitable for direct reduction process using rotary kiln technology.

6.2.3 **Tumbler Index:**

The Tumbler Index of the Ore samples is observed to be 91.30% for sample-1 and 88.70% for sample-2. The test results indicate that the two ores could be classified as hard and dense and considered to be suitable for the Direct Reduction process using rotary kiln technology.

6.2.4 Abrasion Index:

The abrasion index of the two ore samples are 4.70% and 7.59% for sample-1 and sample-2 respectively. The abrasion index of both the ores are well within the acceptable limits for Direct Reduction process.

6.2.5 Bulk Density:

The bulk density of the two ore samples is 2.13 and 2.06 tons/M^3 for sample-1 and sample-2 respectively. The bulk density is less compared to normally occurring iron ores which could be on account of low iron content.

6.3.0 Properties of Reductant used (Manuguru, Singareni Coal - India):

6.3.1 Proximate Analysis:

The proximate analysis of the coal samples for the determination of fixed carbon, volatile matter and ash was carried out as per the procedure outlined in Indian Standards IS: 1350 (Part-I) 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 24.14%, fixed carbon is 46.02% and ash is 29.04%.

6.3.2 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 of iron ores. The sulphur in coal is normally composed of inorganic/pyritic sulphur, sulphate sulphur and organic 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 sample was analysed by gravimetric method as per procedure outlined in the Indian Standard IS: 1350 (Part-III) 19[illegible]. The different forms of the sulphur in Manuguru coal were also analysed and the results of these chemical analysis are presented in the Table-3. The total sulphur in the coal was 1.05 per cent. With the organic sulphur of the order of 0.58 per cent, it could be observed that the sulphur content in sponge iron could be controlled well below acceptable limit with usage of limestone (Blast Furnace grade) as desulphuriser.

The average gross calorific value of the Manuguru coal sample was observed to be of the order of 5000 Kcal/Kg which is considered optimum for the specified purpose. The calorific value of the reductant was determined in an adiabatic Bomb Calorimeter.

6.3.3 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 are generally in line with higher softening temperature. 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, CaO and MgO was carried out and the results are tabulated in the Table-3. The results of the chemical analysis of the coal ash indicate that the ash is acidic in nature and predominately of Silica with a value of morethan 50%.

6.3.4 Melting Characteristics of the coal ash

In the rotary kiln process the kiln is to be operated at a temperature of 1050°C to get the desired degree of reduction and this requires coals with relatively higher ash softening temperatures of the order of 100 - 150°C above the kiln operating temperatures. The melting characteristics of the coal ash is determined in a LEITZ HEATING MICROSCOPE and 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 Manuguru coal was found to be extremely good and the initial softening point itself was observed to be 1200°C. It is felt that this could be attributed to lower concentration of sulpate sulphur in the coal ash. The test results of the melting behaviour of the coal ash are indicated in the Table-3.

6.3.5 Reactivity of coal

Reactivity of the coal refers to the amount and the rates of carbon monoxide generation through the well known Boudourd 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 in situ and is a function of the temperature in the kiln. The reactivity of the coal is determined by the weightloss method. The test results carried out on Manuguru coal indicate the reactivity as 2.07 cc of carbon monoxide per gram of carbon per second.

6.4.0 Reducibility and Decrepitation Tests at Laboratory Scale Level

6.4.1 Reducibility tests are carried out in order to determine the behaviour of the iron ore during reduction and to predict the behaviour of the ores in rotary kiln for commercial operation. In the Laboratory rotary furnace and Short Rotary Kiln reduction tests operating conditions of the rotary kiln are simulated. The test results determine the Reducibility and Decrepitation Index of the ore based on which thesuitability of the particular combination of iron ore and coal for us in rotary kilns could be determined.

6.4.2 Laboratory Rotary Furnace Tests

The reducibility tests were conducted in an electrically heated Laboratory rotary furnace at a reduction temperature of 1000°C. Based on the comparitive study of Bench and Demonstration Scale Tests on known iron ore and coals, the test parametres/conditions for the Laboratory Rotary Furnace have been developed by SIIL. A brief outline of the test conditions is enclosed at Annexure-III.

The Laboratory Rotary Furnace test results on the Nepal Ore samples in combination with Manuguru coal are presented in Table-7 & 8.

6.4.3 The degree of metallisation and reducibility index

The degree of metallisation and reducibility index of Nepal Ore samples were found to be 88.78% and 92.13% respectively for sample-1 and for sample-2 they were 83.28% and 88.26%. The results indicate that both the ore samples have satisfactory reducible properties and are reducible with Manuguru Coal.

6.4.4 Decrepitation behaviour of ores

The decrepitation behaviour of Nepal ores with regard to generation of -1mm fines for both the ores is less than 5%. The generation of -3mm for ore sample-1 is 10.49% and for Ore Sample-2 it is 10.06%. The decrepitation behaviour of both the ores is very good compared to the various other ores sofar tested by SIIL.

6.4.5 Process degradation indices of ores and reductant

The process degradation index of Nepal Ore sample-1 and sample-2 are [illegible]% and [illegible] respectively and they are comparable with the [illegible] of local iron ores which are being used by [illegible] in their regular plant operations and as such they are well within acceptable limits.

6.4.6 Grain size wise analysis

The grain size wise analysis of magnetic product presented in table--, shows that -5mm fraction has achieved higher metallisation on compared to +5mm fraction.

6.5 SHORT ROTARY KILN TESTS:

6.5.1 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 are 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 inside a commercial Kiln can be simulated precisely i.e., reducing material bed and oxidizing free board gases. The waste gases pass through the exhaust duct provided at the top of the burner stand. The rate of flow of waste gases and the kiln pressures are controlled by the damper provided in the waste gas line. The samples drawn at definite intervals are cooled in inert

(Nitrogen) atmosphere and analysed for decrepitation behaviour, rate of reduction and carbon consumption, etc. The test conditions for short rotary kiln test are given at Annexure -

6.5.2 The summary of the short rotary kiln test results are presented in Table 10 & 11. In these tables, the screen analysis of the feed materials viz., Nepal Ores and Manuguru coal and the grainsize analysis of magnetic and non-magnetic products fractions are indicated. The chemical analysis of the samples drawn at various intervals have been analysed for Fe (total), Fe-metallic, metallisation, Carbon and Sulphur. Fixed carbon in non magnetics are also analysed.

6.5.3 As can be seen from the results the reducibility behaviour of Nepal Iron Ores was found to be satisfactory in combination with Manuguru coal as reductant. The samples collected at the end of fourth hour after loading has indicated a metallisation value of the order 87% for both ore samples. Short Rotary Kiln test results also confirmed the similarity in the reducibility behaviour of theore samples as indicated in the Laboratory Rotary Furnace Tests.

6.5.4 The decrepitation behaviour of the Ore samples was observed to be more or less same as indicated in the Laboratory Rotary Furnace Tests. The -1mm fines generation was observed to be 2.85% and the 1 to 3 mm fines generation was observed to be 7.32%. The total -3 mm fraction [illegible] 1. The decrepitation behavi[illegible] [illegible] lie in the same line as sam[illegible] [illegible] the fines generation was well within [illegible]. The fixed carbon analyses in [illegible] the hourly samples indicate [illegible] of the carbon with respect to degree [illegible].

7.0 CONCLUSI[illegible]

From the te[illegible] [illegible] obtained on both the sample of [illegible] observed th t the samples of ore [illegible] with relatively high gan[illegible] [illegible] analysis and petrolo[illegible] samples reveal that the Iron [illegible] of low grade Hematite type asso[illegible].

A the sampl[illegible] with Silicious matter, the feasibilit[illegible] the ore sample was examined and it [illegible] desirable to undertake the beneficiation tests consisting of crushing and washing the ore.

7.1 BENEFICIATION TESTS

7.1.1 The beneficiation tests have indicated that the Iron content could be improved by 10% with a recovery of around 68% to 72% by crushing, screening and washing techniques. The beneficiation was carried out on the samples crushed to the size range of 6 to 20 mm which is the [illegible] used for production of Sponge Iron [illegible]. The sized bene-ficiated ore [illegible] contained 58.64% and 57.80% of Fe [illegible].

7.1.2 From the Shatter [illegible] tests conducted on the beneficiation ores, [illegible] that the ore is hard and [illegible] on. On account of its good [illegible] property the ore is highly suitable for [illegible] Kiln as the generation of fines in the process would be very minimum.

7.1.3 Further beneficiation [illegible] conducted by wet jigging method is [illegible] much advantage as the Fe content of the [illegible] operation has not shown any improvement. [illegible] view of this conducting jigging for further [illegible] at commercial level of operation is not [illegible] from economics point of view. [illegible] one more stage of operation without much benefit.

7.1.4 Benefication by grinding and pelletization for such low grade hematitie ores would involve deployment of grinding to a very fine size fraction and subjecting the material to high intensity magnetic separation. such a process involves high investment and consequently higher operating costs with very low yields of the order 20-25% only. This technique would make the overall proposition totally uneconomical.

7.1.5 As reported ... tests carried out at Research ... of National Mineral ... distinguishable ... The ... at the ... itself. ... mines is practicable as the ... is not very large for sponge Iron ... from 30000 TPA to 60000 TPA ... such kind of practice is being ... obtaining their ores from some of its ...

7.2 REDUCTION TESTS

7.2.1 The chemical ... reveals that sulphur and phosphorous ... low and ... they are ... sponge iron suitable for making ...

7.2.2 The reducibility ... that the ore is reasonably ... with normal non-coking coal. ... the reduction has been achieved ... within the ash softening temperature of ...

However, due to ... content in the feed material the total Fe ... sponge Iron is of the order of 77% to ... comparitively lower than that of ... by iron ores with Fe content above 62%. While the sponge iron produced from Nepal ores as such could be considered suitable for steel making, on account of higher gangue inherent in the ores the yield in steel making would tend to be comparitively lower. In view of this and on account of very low levels of Sulphur and Phosphorus and sponge iron from Nepal ores could be considered as a blend with normal scrap for producing quality steels. On account of low Sulphur and Phosphorus levels and the known chemistry on the sponge iron a blend in the order of 20 to 30% would give optimum results in the steel making process. Such proportion of blend would not have much adverse effect on the yield.

7.2.3 Alternatively the sponge iron produced 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 in submerged arc furnace would be considerably easier as compared to Iron Ore. In view of the fact that the material for smelting is pre-reduced, the power consumption would be much lower and economics for production of Pig Iron by smelting in Submerged Arc Furnace appear to be extremely favourable.

7.2.4 Taking note of the above it can be concluded that a 32,000 to 40,000 tonnes per annum Sponge Iron Plant using beneficiated Lump Iron Ores of Nepal in combination with Indian non-coking coals could be established in Nepal. The Sponge Iron of comparitively lower grade (on account of low Fe in Iron Ore) thus produced could be effectively used in combination with scrap to an extent of 20% to 30% for melting in any of the existing Electric Arc Furances in Nepal However, taking note of the difficult availability of scrap in Nepal, it is considered desirable to set up a Submerged Arc Furance facility designed for smelting sponge iron for production of low phosphorus, low sulphur pig iron. The Submerged Arc Furance facility could be of a capacity of about 6 MW capable of producing 30,000 to 35,000 tonnes of hot metal. On successful implementation of the above scheme further development could be considered by setting up a steel making facility consisting of a MRP Convertor with continuous casting and rolling mill facilities.

Table -1

SCREEN ANALYSIS OF AS RECEIVED IRON ORE SAMPLES

Screen mm	Sample - 1 Pulchoke %	Sample - 2 Pulchoke %
+ 15	04.60	06.30
+ 10	50.00	61.76
+ 8	26.34	22.83
+ 5	14.09	09.40
+ 3	02.97	00.71

Table - 2

CHEMICAL ANALYSIS OF AS RECEIVED ORE SAMPLES

Constituent	Sample - 1 %	Sample - 2 %
Fe(T)	[illegible]	48.03
Fe^{+3}	[illegible]	46.35
Fe_2O_3	[illegible]	66.28
Fe^{++}	[illegible]	1.67
FeO	[illegible]	2.15
SiO_2	[illegible]	13.78
Al_2O_3	[illegible]	4.69
CaO	[illegible]	0.42
MgO	[illegible]	2.40
LOI	[illegible]	1.39
Phosphorus	[illegible]	0.028
Sulphur	[illegible]	0.016

PROPERTIES OF [illegible]

SINGARENI - [illegible]

Sample Mark	Singareni / Manuguru PK 1
Proximate Analysis (On Dry Basis)	
Ash %	24.14
Volatile Matter %	29.04
Fixed Carbon %	46.82
Total	100.00
Sulphur (On Dry Basis) %	
Organic Sulphur	0.582
Pyritic Sulphur	0.45
Sulphate Sulphur	0.018
Total	1.05
Gross Calorific Value Kcal/Kg	5820
Melting Behaviour of Coal Ash	
Softening (Initial Deformation) Point °C	1200
Melting (Hemispherical) Point °C	1320
Flow Point °C	1360
Chemical Analysis of Coal Ash %	
SiO_2	56.50
Al_2O_3	26.50
Fe_2O_3	11.20
CaO	1.40
MgO	0.45
Reactivity $\frac{cm^3 \text{ of } CO}{gm \text{ of carbon-Sec}}$	2.07

Table - 4

CHEMICAL ANALYSIS OF DESULPHURIZING (LIMESTONE)

USED IN THE TEST WORK

Fe (T)	:	0.84
Fe_2O_3	:	1.20
SiO_2	:	6.80
Al_2O_3	:	1.78
Sulphur	:	0.058
CaO	:	48.76
MgO	:	0.28
LOI	:	39.96

Table - 5

CHEMICAL ANALYSIS OF IRON ORE SAMPLES AFTER BENEFICIATION

Constituent	Sample - 1 %	Sample - 2 %
Fe(T)	[illegible]	57.80
Fe^{+3}	52.16	53.90
Fe_2O_3	[illegible]	77.07
Fe^{+2}	[illegible]	3.90
[illegible]	[illegible]	5.08
LOI	0.37	0.45
SiO_2	[illegible]	13.74
Al_2O_3	[illegible]	3.10
CaO	[illegible]	0.32
MgO	[illegible]	0.97
Sulphur	[illegible]	0.017
Phosphorus	0.038	0.030

Table - 6

PHYSICAL PROPERTIES OF IRON ORE SAMPLES

		Sample - 1 %	Sample - 2 %
I.	**SHATTER TEST:**		
	Shatter Index	97.0	97.0
II.	**TUMBLER TEST:**		
	Tumbler Index	91.30	8[illegible].70
	Abrasion Index	4.70	7.59
III.	**BULK DENSITY:**		
	Tons/M^3	2.13	2.06

Table - 7

SUMMARY OF LABORATORY ROTARY FURNACE TEST RESULTS

Ore: **NEPAL ORE**
Sample - 1

Reductant: **Manuguru Coal**

Reduction Temp.-1000°C

Retention Time - 3 hrs.

C/Fe = 0.50

Exp. No.	Metalisation %	R.I. %	Decrepitation Behaviour %			Process Degradation Index %	
			-1mm	-3mm	-5mm	Oxide feed	Reductant
1.	88.78	92.13	4.84	10.49	14.52	21.96	23.95

SUMMARY OF LABORATORY ROTARY FURNACE TEST RESULTS

Ore: NEPAL ORE Sample - 2 | Reductant: Manuguru Coal | Reduction Temp-1000°C | Retention Time - 3 hrs. C/Fe = 0.50

Exp. No.	Metalisation %	R.I. %	Decrepitation Behaviour %			Process Degradation Index %	
			-1mm	-3mm	-5mm	Oxide feed	Reductant
1.	83.28	88.26	3.77	10.06	15.72	18.55	44.71

Table - 9

GRAIN SIZEWISE CHEMICAL ANALYSIS OF LABORATORY ROTARY FURNACE TESTS

MAGNETIC PRODUCT

Size Range m.m.	Sample - 1 %			Sample - 2 %		
	Fe(T)	Fe(M)	Met.	Fe(T)	Fe(M)	Met.
+15 - 20	-	-	-	71.76	57.80	80.55
+10 - 15	77.07	67.30	87.32	72.61	64.51	71.76
+ 5 - 10	77.07	68.97	89.49	73.16	66.74	91.22
+ 3 - 5	76.51	70.65	92.34	76.51	69.25	90.52
+ 1 - 3	80.14	73.44	91.64	78.75	71.21	90.42
- 1	84.61	76.70	90.65	81.54	69.53	85.27

NON-MAGNETIC PRODUCT

Constituent	Sample - 1 %	Sample - 2 %
Volatile Matter	6.00	11.00
Ash	59.50	58.00
Fixed Carbon	34.50	31.00
Fe (T)	6.56	6.98

TABLE - 10

SHORT ROTARY KILN TEST RESULTS

ORE: NEPAL ORE SAMPLE - 7

REDUCTANT : MANUGURU COAL

REDUCTION TEMP. = 980°C

C/Fe = 0.50

SCREEN ANALYSIS WEIGHT %

Screen mm	Feed Material		Products	
	Ore	Coal	Magc.	Non-Magc.
+ 15	7.00	-	-	-
+ 10	57.75	26.95	21.30	15.36
+ 6	22.75	28.13	23.35	14.35
+ 5	12.50	30.86	29.36	18.87
+ 3	-	14.05	15.82	10.32
+ 1	-	-	7.32	33.38
- 1	-	-	2.85	7.69

CHEMICAL ANALYSIS OF MAGNETIC PRODUCT %

S.No.	Sample Reference	Fe (t)	Fe (m)	Met	C.	S.	F.C. in Non-Magc.
1.	after 2 Hrs.	78.32	59.13	75.50	0.14	0.018	46.09
2.	after 3 Hrs.	82.32	68.64	83.36	0.15	0.016	36.73
3.	after 4 Hrs.	85.63	75.20	87.78	0.18	0.016	22.51

TABLE - 11

SHORT ROTARY KILN TEST RESULTS

ORE: NEPAL ORE SAMPLE - 2

REDUCTANT: MANUGURU COAL

REDUCTION TEMP. 960°C

C/Fe = 0.50

SCREEN ANALYSIS WEIGHT %

Screen mm	Feed Material Ore	Feed Material Coal	Products Magc.	Products Non-Magc.
+ 15	5.35	-	0.23	-
+ 10	59.82	25.00	24.36	11.33
+ 8	19.53	30.00	25.7[illegible]	11.35
+ 5	15.19	33.00	33.3[illegible]	2[illegible]
+ 3	-	12.00	16.83	12.33
+ 1	-	-	6.38	35.63
- 1	-	-	2.13	6.78

CHEMICAL ANALYSIS OF PRODUCT %

S.No.	Sample	Fe (t)	Fe (m)	Met	C.	S.	F.C. in Non-magc.
1.	after 2 hrs.	76.34	56.73	74.52	0.13	0.017	47.87
2.	after 3 hrs.	80.36	65.24	81.15	0.16	0.016	35.69
3.	after 4 hrs.	84.73	73.99	87.32	0.14	0.015	2[illegible].75

ANNEXURE - I

R&D/[illegible]

CONFIDENTIAL
NOT FOR PUBLICATION

REPORT ON BENEFICIATION TEST

CARRIED OUT ON LOW GRADE

NEPAL ORE

FOR M/S [illegible] LIMITED

RESEARCH AND DEVELOPMENT LABORATORIES,

NATIONAL MINERAL DEVELOPMENT CORPORATION

HYDERABAD [illegible]

I N D E X

ABBREVIATIONS

Al_2O_3	- Alumina
(Calc)	- (Calculated)
CaO	- Calcium Oxide
Dist.	- Distribution
Fe	- Iron
LOI	- Loss on ignition
mm	- millimetre
Mn	- Manganese
MgO	- Magnesium Oxide
NMDC	- National Mineral Development Corporation Limited
%	- Percentage
P	- Phosphorus
R&D	- Research and Development
SiO_2	- Silica
S	- Sulphur
wt.%	- weight percentage
w.r.o.	- With respect to original

BENEFICIATION OF LOW GRADE IRON ORE SAMPLES RECEIVED FROM M/S. SPONGE IRON INDIA LIMITED

1. INTRODUCTION

Two low grade iron ore samples of quantities, Sample No. I-2.5 tonnes and Sample No. II-3.5 tonnes were received from the Sponge Iron India Ltd. for conducting beneficiation studies.

The maximum size of the lumps was upto 100 mm.

2. OBJECTIVE

Sponge Iron India Ltd desired NMDC to conduct beneficiation of these samples suitably to produce minus 20+6 mm lumps.

3. SCOPE OF WORK

The scope of work for beneficiating these samples involved the following steps :

i) Chemical analysis of as received samples.

ii) Size analysis of as received samples.

iii) Petrological studies of the samples.

iv) Processing of ore samples as per the flow sheet worked out to produce 6 to 20 mm product.

v) Chemical analysis of final lumps product for Fe, FeO, SiO_2, Al_2O_3, LOI, S, P, Mn, CaO and MgO.

4. CHARACTERISTICS OF THE SAMPLE

4.1 Chemical Analysis

The as received representative samples were analysed. The chemical analysis of the samples is given in table I.

4.2 Size and Chemical Analysis

The as received samples were screened at 75 mm, 50 mm, 25 mm, 10 mm and 6 mm. The size analysis and the chemical analysis of the fractions are given in table II.

As can be seen in table II the -25 mm fraction contained 3.94 iron only with a wt.% of 4.60 in case of sample no. I. In case of sample No. II the iron content of -25 mm is only 1.53 with a wt.% of 2.5. This indicates the -25 mm fraction of both the samples can be rejected.

On visual observation of +25 mm fraction of both the samples, it was observed, green coloured lumps which are distinct in colour from the rest of the iron ore lumps. Petrological examination indicated that these green lumps are only silicates with very low iron values. Keeping this in view, it was decided to pick these green lumps manually and separate from the other iron ore lumps, presuming that this would be possible in the mine when the magnitude of mining the quantity of ore is not going to be very large as indicated by Sponge Iron India Ltd.

Table I

CHEMICAL ANALYSIS OF AS RECEIVED SAMPLES

Constituent	Assay %	
	Sample I	Sample II
Fe	53.40	48.41
FeO	0.38	1.02
SiO_2	14.20	18.04
Al_2O_3	3.80	4.80
LOI	1.60	1.74
MnO	0.065	0.13
CaO	1.42	1.80
MgO	1.80	2.70
S	Traces	Traces
P	0.042	0.031

Table II

SIZE AND CHEMICAL ANALYSIS OF 'AS RECEIVED' SAMPLE

Size	Sample I Wt. %	Sample I Assay % Fe	Sample I Dist. % Fe	Sample II Wt. %	Sample II Assay % Fe	Sample II Dist. % Fe
+ 75 mm	29.1	55.80	30.08	29.8	52.40	32.24
+ 50 "	43.9	54.80	44.57	43.9	50.20	45.50
+ 25 "	22.4	51.60	21.41	23.8	42.20	20.73
Head (Calc)	95.4	54.35	96.06	97.5	48.92	98.47
+ 10 mm	3.8	47.40	3.34	1.9	29.40	1.14
+ 6 "	0.3	44.00	0.24	0.2	30.80	0.13
Minus 6 mm	0.5	39.00	0.36	0.4	31.60	0.26
Head (Calc)	100.0	53.98	100.0	100.0	48.44	100.0

4.3 Petrological Studies

The samples ranged in size from 1" to 4" and quite hard and compact. Hematite and Goethite were the major iron ore minerals and quartz and meta basic rocks were present as gangue minerals. Hematite exhibits lamellar twinning as well as colloform banding occassionally. Goethite was associated with quartz. The apparent specific gravity of iron ore pieces ranged from 3.72 to 4.50 of sample No. I and 4.11 to 4.6 of sample No. II.

The detailed petrological report is given in Annexure I.

5. BATCH SCALE TESTING (DRY BASIS)

After separating the green lumps (silicate minerals) from the +25 mm fraction the iron ore lumps and the green rock lumps were analysed separately.

The results obtained of sample No. I and sample No, II are given in table No. III-A and table No. III-B respectively.

As can be seen from the above tables the grade of the +25 mm was improved from 54.35% Fe to 56.14% Fe in case of sample No. I and the grade of +25 mm lump was improved from 48.92% Fe to 53.98% Fe in case of sample No. II after separating the green rock lumps manually.

The +25 mm iron ore lumps were crushed to -20 mm and screened at 20 mm, 10 mm and 6 mm. The results obtained are given in table No. IV-A and IV-B for samples I and II respectively.

Table III-A

SAMPLE NO. I

Product	Wt. %	Wt. % W.R.O.	Assay % Fe	Assay % SiO_2
Iron ore lumps + 25 mm	95.5	91.1	56.14	12.45
Green rock lumps + 25 mm	4.5	4.3	10.60	43.24
Head (Calc)	100.0	95.4	54.08	13.84

Table III-B

SAMPLE NO. II

Product	Wt. %	Wt. %	Assay % Fe	Assay % SiO_2
Iron ore lumps + 25 mm	86.5	84.3	53.98	13.99
Green rock lumps + 25 mm	13.5	13.2	9.42	43.68
Head (Calc)	100.0	97.5	47.96	18.01

Table IV-A

SAMPLE I

Size	Wt. %	Wt. % W.T.C.	Assay % Fe	Assay % SiO_2
+ 20 mm	3.8	3.5	56.82	11.72
+ 10 "	57.0	51.9	56.65	12.09
+ 6 "	14.4	13.1	55.95	12.82
- 6 "	24.8	22.6	54.97	13.19
Head (Calc)	100.0	91.1	56.14	12.45

Table IV-B

SAMPLE II

Size	Wt. %	Wt. % W.T.C.	Assay % Fe	Assay % SiO_2
+ 20 mm	3.3	2.8	56.54	11.98
+ 10 "	50.4	42.5	54.29	13.44
+ 6 "	22.7	19.1	53.74	14.49
- 6 "	23.6	19.9	53.22	14.97
Head (Calc)	100.0	84.3	53.99	13.99

Table V

OVER-ALL RESULTS ON BATCH TESTING OF SAMPLE NO. I

Product	Wt. % w.r.c.	Assay % Fe	Assay % SiO_2	Dist. % Fe
-20 + 6 mm lumps	68.5	56.52	12.59	72.07
-25 mm (Reject)	4.6	46.27	15.59	3.96
Green rock lumps reject (+25 mm)	4.3	10.60	43.24	0.85
-6 mm generated fines	22.6	54.97	13.19	23.12
Head (Calc)	100.0	53.72	14.2	100.00

Table VI

OVER-ALL RESULTS ON BATCH TESTING OF SAMPLE NO. II

Product	Wt. % W.R.O.	Assay % Fe	Assay % SiO_2	Dist. % Fe
-20+6 mm lumps	64.4	54.22	13.69	73.51
-25 mm reject	2.5	29.86	19.16	1.57
Green rock lumps reject (+25 mm)	13.2	9.42	43.68	2.62
-6 mm Generated fines	19.9	53.22	14.97	22.30
Head (Calc)	100.0	47.50	18.04	100.00

On batch testing the lumps (-20+6 mm) assayed 56.52% Fe with a weight recovery of 68.5% and iron unit recovery of 72.07% in case of sample No. I.

In case of sample No. II -20+6 mm lumps assayed 54.22% Fe with a weight recovery of 64.40% and iron unit recovery of 73.51%.

5. PILOT PLANT TESTING

In order to find out the recoveries and the grades obtainable on pilot scale testing, representative samples of about 1.5 to 2.00 tonnes were drawn from each of the samples and subjected to pilot scale testing. The flow sheet adopted for the pilot scale testing is given as fig. no. 1.

The details of equipment used in the pilot plant are as follows :

1. Crusher

   Type - Single toggle Jaw Crusher
   size - 400 mm x 250 mm

2. Opening

   a) O.S.S - 50 mm
   b) O.S.S - 20 mm

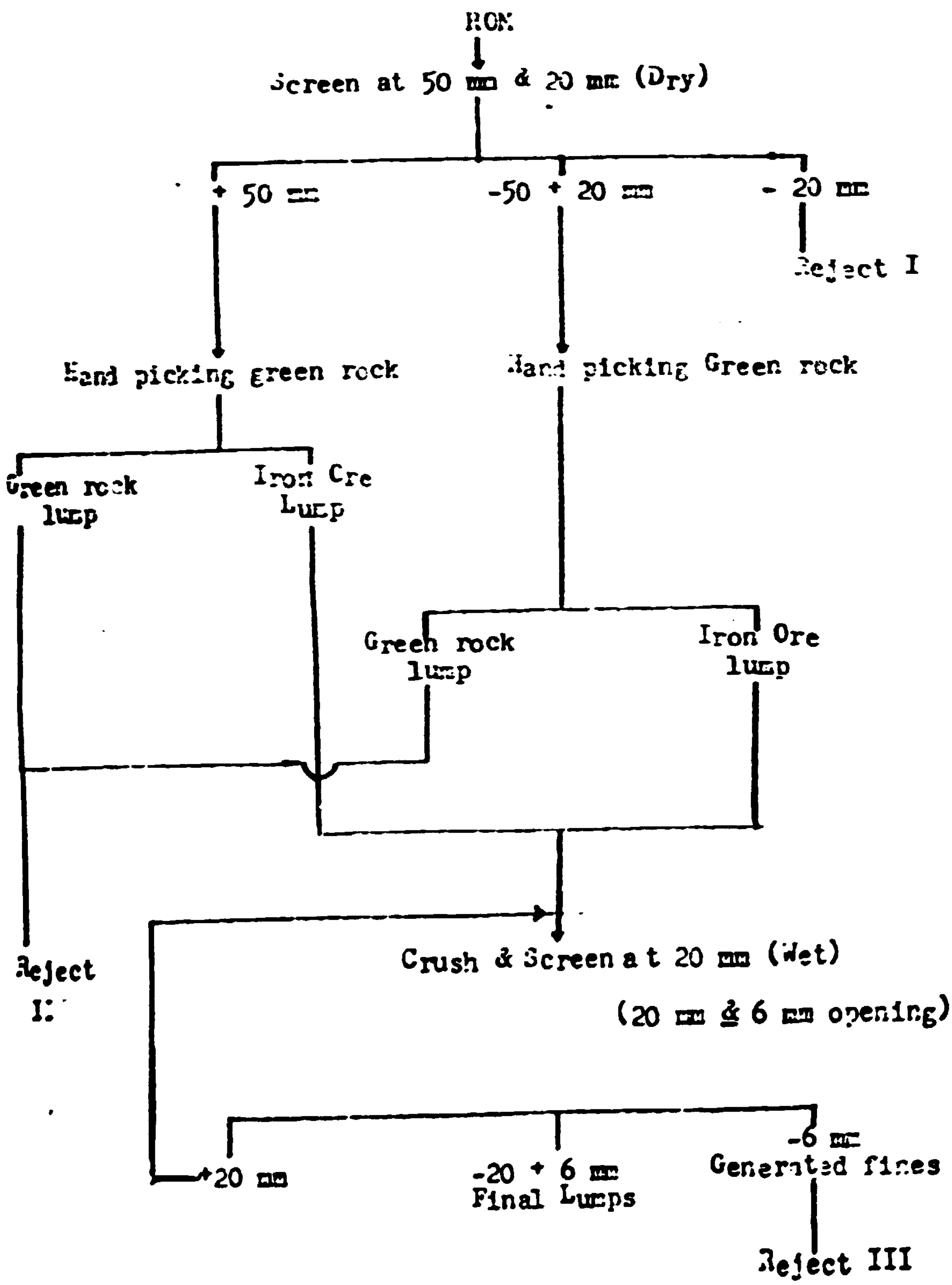
3. Vibratory Screen (Double Deck)

   a) Size - 90 mm x 45 mm (3' x 1½')
   b) Screen openings - 20 mm and 6 mm
   c) Type of Screening - Wet

Water consumption for testing the samples by wet screening found to be 1.22 m^3/Tonne in case of sample I and 1.15 m^3/Tonne in case of sample II.

Figure-I

FLOW SHEET ADOPTED FOR PILOT PLANT TESTING



The as received samples were screened at 50 mm & 20 mm (dry). From the +20 mm material. The green lumps were manually picked up and rejected. The -20 mm screened fraction was also rejected. The +20 mm iron ore lumps were crushed to 50 mm by close circuit crushing and screened at 50 mm.

The -50 mm material was fed to a double deck screen with openings 20 mm and 6 mm and wet screened. The -50 + 20 mm material was fed to the crusher and the crusher product was fed to the same double deck screen. After crushing and wet screening the products obtained were -20 + 6 mm lumps, -6 mm fines and the slimes.

The results obtained on the pilot plant scale testing are given in tables VII AND VIII.

The over-all results of pilot plant testing in respect of Sample No. I involving the following steps are given in table VII.

i) Removal of -20 mm fraction of ROM.

ii) Picking and rejecting of +20 mm gangue pieces from the +20 mm ROM.

iii) Stage crushing of +20 mm ROM to minus 20 mm and wet screening at 20 mm and 6 mm.

The over-all results of pilot plant testing in respect of Sample No. II involving the following steps are given in Table VIII.

i) Removal of -20 mm fraction of ROM.

ii) Picking and rejecting of +20 mm gangue pieces from the +20 mm ROM.

iii) Stage crushing of +20 mm ROM to minus 20 mm and wet screening at 20 mm and 6 mm.

Table VII

SAMPLE NO. I

Sl.	Product	Wt. %	Assay % Fe	Dist. %
1.	Minus 20 mm Fraction of ROM	1.8	45.18	1.52
2.	+20 mm Gangue of ROM	5.2	9.53	0.93
3.	Crushing, Washing and Screening:			
	a) Minus 20+6 mm lumps	58.9	57.50	63.42
	b) Minus 6 mm fines and slimes	34.1	53.44	34.13
	Head (Calc)	100.0	53.40	100.00

Table VIII

SAMPLE NO. II

Sl. No.	Product	Wt. %	Assay % Fe	Dist. % Fe
1.	Minus 20 mm Fraction of ROM	1.4	28.03	0.81
2.	+20 mm Gangue of ROM	11.9	9.52	2.34
3.	Crushing, Washing and Screening			
	a) Minus 20+6 mm lumps	54.8	55.69	63.04
	b) Minus 6 mm fines and slimes	31.9	51.31	33.81
	Head (Calc)	100.0	48.41	100.00

The lumps of Sample No. I (-20 + 6 mm) assayed 57.5% Fe with weight recovery 58.9% with iron unit recovery of 63.4%.

The lumps of sample No. II (-20 + 6 mm) assayed 55.69% Fe with weight per cent of 54.8 and iron unit recovery of 63.04%.

The complete chemical analysis of the lumps are as given below :

Constituent	Assay %	
	Sample No. I	Sample No. II
Fe	57.50	55.69
FeO	1.99	1.55
SiO_2	12.00	13.75
Al_2O_3	2.87	3.34
LOI	1.06	1.08
Mn	0.10	0.08
CaO	0.43	0.43
MgO	1.02	1.00
S	0.016	0.058
P	0.043	0.028

7. CONCLUSION

7.1 Two low grade iron ore samples received from Sponge Iron India Ltd. assayed [illegible] Fe, 14.2% SiO_2, 3.80% Al_2O_3, 1.60% LOI and [illegible] Fe, 1[illegible].04% SiO_2, 4.[illegible]% Al_2O_3, 1.74% LOI respectively.

7.2 Micrological examination revealed that the samples contained lumps of meta basic rocks which are green in colour and can be manually picked from the remaining iron ore lumps. These meta basic rocks assayed 9.42% to [illegible] Fe and 43.2% to 43.60% SiO_2.

7.3 Batch Scale beneficiation tests improved the iron grade of the lumps from [illegible].72% Fe to 56.5[illegible]% Fe in case of sample No. I and [illegible].50% Fe to 54.[illegible]% Fe in case of sample No. II.

7.4 The lumps of -[illegible] + 6 mm produced after pilot scale beneficiation tests assayed 57.5% Fe with iron unit recovery of [illegible] and a weight recovery of [illegible] in case of sample No. I. Similarly, the lumps produced from sample No. II assayed 55.69% Fe with iron unit recovery of 6[illegible]% and weight recovery of [illegible].

ANNEXURE-I

PETROLOGICAL REPORT ON IRON ORE SAMPLES RECEIVED FROM M/S. SPONGE IRON INDIA LIMITED

SAMPLE I

Megascopic Description: The lumps ranged in size from 1" to 4" and were quite hard and compact. Most of the pieces were massive but some showed laminations ranging in thickness from 1 to 5 mm. The sample contained invariably waste material like meta basic rocks and B.H.Q. in addition to iron ore (their description is given separately).

The iron ore was greyish brown in colour. It showed mostly dull lusture. It gave cherry-red streak. Its apparent specific gravity ranged from 3.72 to 4.50.

Microscopic Description: The principal ore minerals observed under the microscope were hematite and goethite. Quartz occurred as gangue mineral. Hematite, goethite and quartz are mentioned in order of abundance.

Hematite was mostly cryptocrystalline but occasionally some crystals were observed and few of them showed lameller twinning. Most of the hematite was anhedral. The colloform banding was also observed though it was not so common.

Goethite was mostly amorphous. It was mostly in the form of haphasard bands. Goethite was associated with quartz. The size of the bands varied from 100 to 1000 microns.

Quartz was present as individual crystals and also as an aggregate. Quartz was quite common in goethite as compared to hematite. Its size varied from 5 to 300 microns. The aggregates of quartz had a size upto 800 microns.

Conclusion: The iron ore contains hematite and goethite as ore minerals and quartz and meta basic rocks were present as gangue minerals. Hematite exhibits lamellor twinning as well as colloform banding occassionally.

SAMPLE II

Megascopic Characters: The lumps were of the size 4" to 5" and were hard and compact. They were mostly massive and some showed laminations ranging in thickness from 1 to 5 mm. This sample also contained waste material like meta basic rocks and B.H.Q. in addition to iron ore which has been described separately.

Most of the iron ore was greyish brown in colour and showed dull lusture. Its streak was cherry-red. The apparent specific gravity of iron ore pieces ranged from 4.11 to 4.60.

Microscopic Characters: The sample mainly consisted of hematite and goethite as ore minerals and quartz as gangue mineral. The section showed that it contained considerable amount of quartz, it was second abundant mineral after hematite, whereas goethite was third abundant.

Hematite occurred in crystalline as well as in crypto-crystalline form. Most of hematite was anhedral with few exceptions. Some of the hematite crystals showed lamellar twinning and few places hematite exhibited colloform banding. Its size varied upto 600 microns.

Goethite was mostly cryptocrystalline. Quartz was invariably seen to be associated with the Goethite.

Quartz was mostly anhedral. It occurred as individual crystals in hematite as well as in goethite. Most of the quartz was associated with goethite. Quartz also occurred as aggregates. Some of the sections of iron ore showed substantial amount of quartz. The size of quartz varied from 5 to 350 microns.

Conclusion: The ore sample was hard and massive. Hematite and goethite were identified as ore minerals with quartz and meta basic rocks were present as gangue minerals. Lamellar twinning and colloform banding could also be observed in hematite.

DESCRIPTION OF METABASIC ROCK AND B.H.Q.

Both the samples, namely, sample I and sample II invariably contained pieces of metabasic rock and B.H.Q. Petrological description of these materials is as follows :

METABASIC ROCK

Megascopic Description: The metabasic rock was greyish green in colour. It was comparatively hard and compact. It was medium grained. Its apparent specific gravity ranged from 2.65 to 2.77.

Microscopic Characters: Under microscope it showed presence of chlorite, pyroxene and plagioclase. The thin section showed lot of alterations and signs of metamorphism. Taking into consideration its mineral assemblage, uralitisation and alterations it could aptly be termed as meta-dolerite.

B. H. Q.

Megascopic Characters: The samples were greyish brown in colour but contained some whitish bands of silica, ranging in thickness from 1 to 2 mm. The samples were quite hard and compact. They gave cherry red streak.

Microscopic Characters: Its polished section showed alternate bands of hematite, quartz and goethite and quartz.

Hematite was major ore mineral and was present as cryptocrystalline as well as in crystalline form. The crystalline hematite was mostly anhedral. Its size ranged from 5 to 700 microns.

Goethite was mostly amorphous and was associated mostly with quartz.

Quartz was mostly anhedral and its size varied from 5 to 350 microns.

Conclusion: The sample I and II contained waste material such as metabasic rock and B.H.Q. The metabasic rock was identified as metadolerite under microscope. The B.H.Q. showed distinct alternate bands of hematite, quartz and goethite and quartz under the microscope.

FEASIBILITY OF BENEFICIATION BY JIGGING OF LOW GRADE IRON ORE SAMPLE FROM SPONGE IRON INDIA LIMITED

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CONTENTS

ABSTRACT

Jigging experiments were carried out on a low grade iron ore sample received from Sponge Iron India Limited, to determine the technical feasibility of upgrading the ore to the required grade of 60 % Fe. Tests were carried out at different size fractions. Because of the heavy nature of iron mineral hematite, the dilation in jigging machine was inadequate to cause stratification of minerals according to density. Further the mineralogical characteristics, particularly the non-liberation of quartzite intergrowths, also restrict the grade of the jig concentrate. The results are presented and discussed in detail.

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I INTRODUCTION

Experiments on the gravity beneficiation of a low grade iron ore sample received from M/s Sponge Iron India Limited (SIIL), Hyderabad were carried out. This iron ore sample was found to assay [illegible]1.9 % Fe, the iron values occurring mainly as hematite. The minimum iron content specification of the iron ore for charging into SIIL's rotary kiln for production of sponge iron is [illegible]0 % Fe(1) The low grade iron ore, therefore, needs to be upgraded before being processed and, the beneficiation has to be done at the coarsest size possible since rotary kiln takes in only lumpy ores, and at present no facility exists at SIIL for pelletising and sintering the fines. A simple procedure involving crushing and screening of the ore followed by hand-picking of the "green" gangue pieces has been reported[2] to yield a hematite concentrate assaying 55.5 - 57.5 % Fe with a recovery of 63 %. By a suitable mechanical means of separation, it should therefore be possible to improve upon the earlier results, both in terms of grade of the concentrate and total iron recovery. With this view SIIL requested the Ore Dressing Section to carry out studies on upgradation of the ore by jigging, at a size as coarse as possible preferably in the range 20 - 5 mm.

Experiments were carried out in the Ore Dressing Section using "Harz" type laboratory jigs and this report presents and discusses the experimental results in detail.

II JIGS FOR IRON ORE BENEFICIATION

The jig is one of the most widely applied gravity concentrating devices. Jigging is the process of sorting different minerals in a fluid by stratification, based upon the movement of a bed of particles which are intermittently fluidized by the pulsation of the fluid in a vertical plane. The stratification causes particles to be arranged in layers with increasing density from top to bottom. This particle arrangement is developed by several continuously varying forces acting on the particles and, is more related to particle density than most other gravity concentrating devices.

A number of different types of jigs are available in the market. This laboratory has Harz type mineral jigs of different [illegible]. A Harz type mineral jig consists of a rectangular hopper shaped compartment, divided at the top into two parts plunger section and separation chamber. The separation chamber [illegible] the main tank by a replaceable wire mesh or trapezoidal bar-screen and, has provisions for feeding and tailings disposal by overflow. The plunger is actuated by an eccentric, driven at the top by a motor. This jig incorporates a rotating water valve synchronised with the diaphragm in such a way that water is introduced into the jig only during the diaphragm up-stroke or suction stroke and this arrangement neutralises the drawing in of the bed during suction(3).

The major modern applications of jigs are essentially in

(a) coal washing

(b) primary treatment of alluvials,

(c) coarse lode tin ore processing,

(d) free metal recovery in gold and other mills, and

(e) cleaning of sand.

In coal washing jigs are used to process relatively coarse particles upto sizes 150 - 200 mm (4). But in the case of beneficiation of heavy minerals, finer sizes are used in jigs. Ores of wolframite(5), cassiterite, columbite, tantalite etc., have been successfully treated in jigs upto a size of 6 mm. In all these cases the heavy mineral fraction constitutes a very small percentage of the ore. The use of jigs for beneficiation of iron ore, in which the heavy mineral constitutes the larger fraction, is however not widespread, although one or two sporadic occurrence of use of jigs for processing iron ore is reported in United States and Canada(6,7). A special type of jig, known as Wemco-Remer jig is claimed to have been developed primarily for the treatment of iron ores. This jig has a unique mechanism to keep the bed mobile and prevents complete closure during the interstitial trickling phase. A medium stroke and frequency harmonic motion is superimposed by a high frequency short stroke motion, achieved by dual eccentrics operating in parallel and linked to the outer compartment by pivoted cross-arms. The whole hutch oscillates vertically and is connected to the jig by a rubber diaphragm[8]. This laboratory, not having worked on the Wemco-Remer jig is not in a position to comment upon the performance of this jig. A careful inquiry into the available literature has not revealed any plant practice, wherein jigs are used for beneficiation of iron ore lumps, except one mill at Ontario.

III BENEFICIATION STUDIES

The ore sample as supplied by SIIL, weighing about 100 kg was in the form of lumps measuring about 75 to 125 mm in size. Crushing of the lumps was carried out in jaw crusher followed by roll crushers in stages so as to minimize generation of fines. The crushed material was screened into various size fractions, as required for different experiments, and were processed in "Harz" type mineral jigs, available in this laboratory. Most of the experiments were carried out on 100 x 150 mm "Harz" jig.

3.1 Chemical and Mineralogical Characteristics

Chemical analysis of a representative sample gave 51.9 % Fe and 18.11 % SiO_2. The iron values were essentially contributed by hematite. Megascopic examination of the sample showed the presence of greenish coloured metabasic rock fragments mixed with hematite-quartzite lumps. The gangue constituents to be discarded are the metabasic rocks (greenish coloured gangue pieces) and the interbanded quartzite. Whi[illegible] the [illegible] rock are not composite with hematite, the [illegible] show a close intergrowth relationship with hematite.

Besides [illegible] wide bands [illegible] quartzite visible megascopically, [illegible] examination under the ore microscope has [illegible] the presence of closely intergrown quartzite with [illegible] in the form [illegible] broad [illegible] narrow bands (Figures 1, [illegible] angular fragments (Figure 4) and fine disseminations [illegible] 5). Fragments of quartzite with interstitial [illegible] (Figure 6) [illegible] composite hematite -quartzite with [illegible] containing disseminations of the other (Fi[illegible] are [illegible] common. Even the relatively pure hematite [illegible] contain micro[illegible]opic disseminations of quartz (Figure [illegible]). Presence of these closely intergrown quartz (quartz[illegible]) [illegible] hematite sets a limit for the maximum attainable gra[illegible] recovery by beneficiation at a given particle size.

3.2 Jigging of [illegible] mm Lumps

From the crushed ore, about 25 kg of -15 + 10 mm sized material was [illegible] off and processed in the laboratory jigs. The feeding was done through a hopper and vibratory feeder assembly. It was observed that dilation of the bed during the pulsion stroke, very essential for the stratification of the feed material according to density, was completely missing. This was due to the greater weight of the feed ore lumps and also to the predominant heavy mineral content of the feed. Attempts to increase the thrust during pulsion by manipulating the control variables like stroke lengths and frequency also failed to lift up the material. Tests were also conducted with various jig screens of different sized openings. Finally by multiple passes through the jig and by allowing for at least re adjustment of the bed by giving more time in the separation chamber, slightly better results were obtained, which are shown in Figure 9. The back calculated feed assay of this size fraction (-15 + 10 mm) was found to be 46.8 % Fe. The hutch product assayed 52.56 % Fe, while the bed material assayed 49.72 % Fe. The combined hutch and bed products constituted 79% of the weight of the feed material, assayed 52.06 % Fe and contained 88 % of the total iron values. The tailings assayed less of iron and more of silica indicating that some separation has indeed taken place during jigging even with improper and insufficient bed dilation. This experiment indicated that if only proper dilation could be induced by suitable arrangement, it might be possible to upgrade the feed material to the required grade.

3.3 Jigging of -10 mm Material

From the total -10 mm crushed ore, about 20 kg of the material was screened to remove -3 mm material and the -10 + 3 mm fraction was processed in the jig, and the details of the experiment along with the results are shown in Figure 10. In this case the back calculated feed grade was found to be 50.73 % Fe, which is greater than that of +10 mm size fraction, but still less than the overall tenor of 51.9 % Fe.

better compared to the earlier experiment. The rougher concentrate (combined hutch and bed products) constituted 62.8 % by weight, assayed 53.5 % Fe and contained 66 % of iron values. If scavenger hutch is also included in the concentrate, then the combined concentrate constituted 79.5 % by weight, assayed [illegible] % Fe and iron distribution of 83 %

Comparison of these results with those of earlier experiment reveals that there is only marginal if any, improvement. This negates the earlier assumption that a better dilation of the bed would give improved performance and, indicates the operation of a factor other than the poor performance of the machine. This factor, perhaps, is the physical characteristics of the ore sample, particularly the extent and the fineness of the interlayered quartzite bands and disseminated quartz grains in hematite, which will determine whether it is possible at all to get the required grade by jigging at a coarser size.

In order to confirm this observation, further jigging experiments were carried out after classifying the -10 mm material into four size fractions, namely, -10 +4.75 mm, -4.75 + 3.2 mm, -3.2 + 0.85 mm and -0.85 mm fractions. The-0.85 mm size fraction was not treated, and as such it was discarded.

3.4 Jigging of Closely Sized Fine Material

About 15 kg of each of the size fractions -10 + 4.75 mm,

-4.75 + 3.2 mm [illegible] + 0.85 mm were prepared by crushing and screening the remaining ore sample and these were separately treated in the laboratory jig. The jig screens were appropriately changed for different size fractions. The results of these experiments are shown in Figures 11, 12 and 13 respectively and are discussed below.

3.4.1 Jigging [illegible] + 4.75 mm Fraction

In this case [illegible] mm screen was used and, there was no proper dilation of the bed though it was slightly better than in the earlier experiments. The back calculated feed grade of this fraction was 51.67 % Fe, the value being very close to the average grade of the ore sample. The hutch product assayed [illegible] % Fe and, the bed 54.55 % Fe. The hutch and the bed products combined, constituted 76.1 % by weight, assaying 55.25% Fe and having an iron distribution of 81%.

3.4.2 Jigging [illegible] 4.75 + 3.2 mm Fraction

In this case, [illegible] mm screen was used in the jig. The back calculated feed grade was found to be 46.76 % Fe and, the hutch product and the bed assayed 53.25 and 52.60 % Fe respectively. Both these fractions mixed together accounted for 67.7 % of the total weight and [illegible] % of the total iron values, with an average assay of [illegible] % Fe. Here also, the jig performance was not any better even though better dilation was obtained.

3.4.3 Jigging of -3.2 + 0.85 mm Fraction

In this case [illegible] mesh screen was usedin the jig. The hutch product assayed 58.45 % Fe, but the iron distribution in this fraction was rather less (only 26.5 %). The bed material assayed 55 % Fe (Figure 13). However, silica content of these two fractions were low. Both hutch and the bed material weighing 42 % of the total feed, assayed 56.24 % Fe, but the total iron recovery was only 59 %. The back calculated feed grade was computed to be 49.44 % Fe.

IV DISCUSSION

It was not possible to process +10 mm size material in this laboratory since no proper jig which can dilate such a heavy ore, was available. However, the poorer results are not due to only machine operation, but also due to the ore characteristics. This became evident by experimental results of jigging finer fractions. Essentially, two phenomena are responsible for the results obtained. They are :

(i) Absence of bed dilation due to equipment limitations - this prevented proper stratification of minerals and trapped the "green" gangue pieces in between the heavier hematite pieces. A better dilation would have definitely freed these "green" pieces which would have eventually escaped in the tailings overflow. This explains the presence of a number of "green pieces" i.e., pure gangue pieces in the jig concentrate. Probably a better operating jig would have given improved results.

(ii) Ore Characteristics - though jigging of the -3.2 + 0.85 mm size fraction gave the highest grade of 58.4 % Fe, in the other two c[illegible] sizes there w[illegible] no improvement in the performance [illegible] t[illegible]se obtained [illegible] jigging [illegible] 10 mm size material. It [illegible] from the mic[illegible]scopic examination of the sample that t[illegible] ach[illegible] the require[illegible] grade of concentrate, the jigging oper[illegible]ion [illegible]ould be abl[illegible] reject not only the "green" gang[illegible], but al[illegible] the hematite-quartzite composites. W[illegible]ile the specific gr[illegible]vity of gangue pieces is about 3, that [illegible] h[illegible]tite-quartzite composites varied between 3.1 and 5, d[illegible]pen[illegible]g upon the quartzite content, 3.1 being the specific gra[illegible]y of composite containing about 80 % of quartzite by vol[illegible] and, 5.0 being that of pure compacted hematite. The re[illegible]ive abundance of particles of different specific grav[illegible]ty w[illegible] depend on the extent of liberation. It is obvious th[illegible] i[illegible] [illegible]arser sizes there will be particles of all densities in t[illegible] range 3.1 to [illegible] due to poor liberation, and in such [illegible]ondition it is dif[illegible]ult to obtain a clean separation by [illegible] operation, ev[illegible] with proper dilation of the bed. On t[illegible] oth[illegible]r hand it may b[illegible] possible to reject the bulk of the gre[illegible] pieces (all [illegible] which have a specific gravity of [illegible] if proper [illegible]ation of the bed is achieved, but [illegible] alone will not give the required grade of the concentra[illegible]

By commi[illegible] [illegible] about -3 mm [illegible]ze it may be possible to liberate most of the wide bands of quartzite. Thus a considerable im[illegible]rovement in the grad[illegible], to 58.4 % Fe, could be achieved by jiggi[illegible] in the size range -3.2 +0.85 mm. For further improvement in the grade, the fine bands as well as disseminated [illegible] need to be liberated, which is possible only at much finer grind of about all passing through 100 mesh (0.15 mm). Determination of the exact size at which optimum liberation of quartz from hematite takes place, needs further detailed petrographic study.

V CONCLUSIONS

On the basis of a few jigging experiments carried out on the low grade iron ore sample, received from SIIL, following conclusions are drawn :

5.1 Beneficiation of low grade iron ore by jigging at very coarse sizes is not a common practice and, is difficult due to the absence of dilation of the bed of heavy minerals. Special type of jigs are needed.

5.2 Jigging of [illegible] +10 mm size material in "Harz" jigs did not give good results due to the dense nature of the bed.

5.3 In finer size, jigging performance is slightly better, with improved separation. It seems possible to improve the grade by giving adequate time in the separation chamber for stratification of the minerals to take place, at least by re-adjustment of the bed, if not by full bed dilation.

5.4 However, the presence of intergrowths of quartz in hematite in [illegible] varying dimensions, which are not liberated, prevents achieving the required grade of the concentrate even by jigging in finer sizes (i.e., -3 +0.85 mm).

5.5 Determination of the grind at which these intergrown quartz can be optimally liberated, requires detailed mineralogical and petrographical study, which is beyond the scope of the present study.

Acknowledgements

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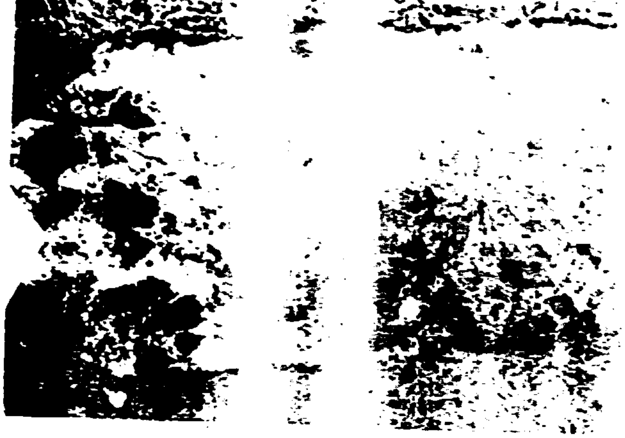
Figure 1. A typical banded hematite(white)-quartzite(dark) x215

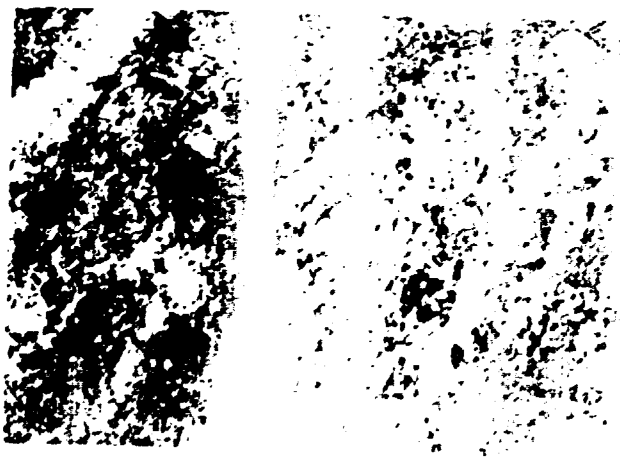
Figure 2. A particle showing banding with layers of predominant quartzite (dark band-A), mixture of hematite and quartz (band B) and nearly pure hematite (white band C) x11[illegible]

Figure 3. Hematite-quartzite with broad and narrow bands of quartzite (dark) x50

Figure 4. Hematite (white) containing angular fragments of quartz (dark) x275



F IG



F IG 3

FIG

Figure 5. Hematite (white) with fine dissemination of quartz (dark) x[illegible]

Figure 6. Fragment quartzite (dark) with interstitial hematite (white) x[illegible]

Figure 7. Composite hematite (white)-quartzite (dark grey) with each constituent containing very fine disseminations of the other.

Figure 8. Nearly pure fragment of hematite, but containing microscopic inclusions of quartz (dark) x215

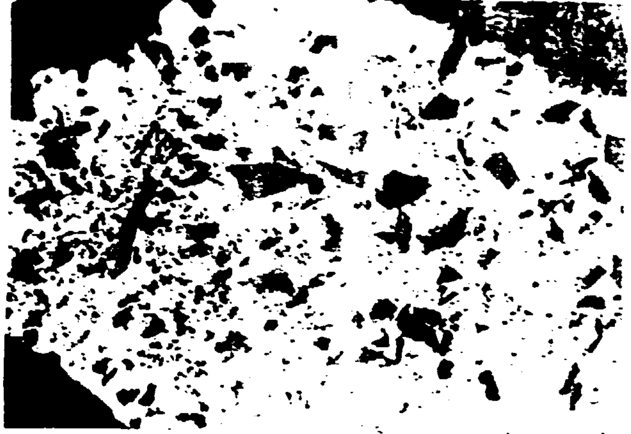


FIG 5

FIG

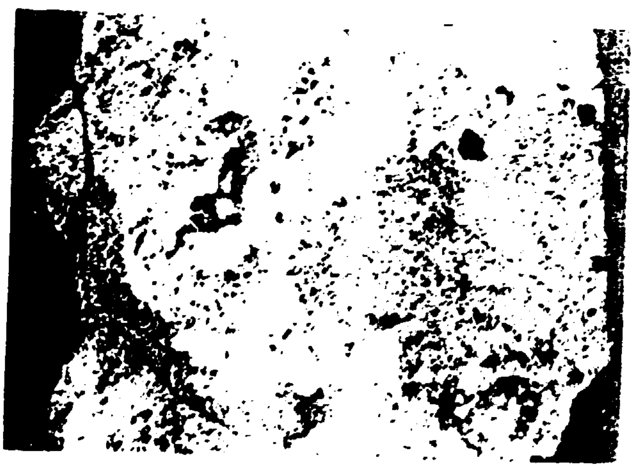
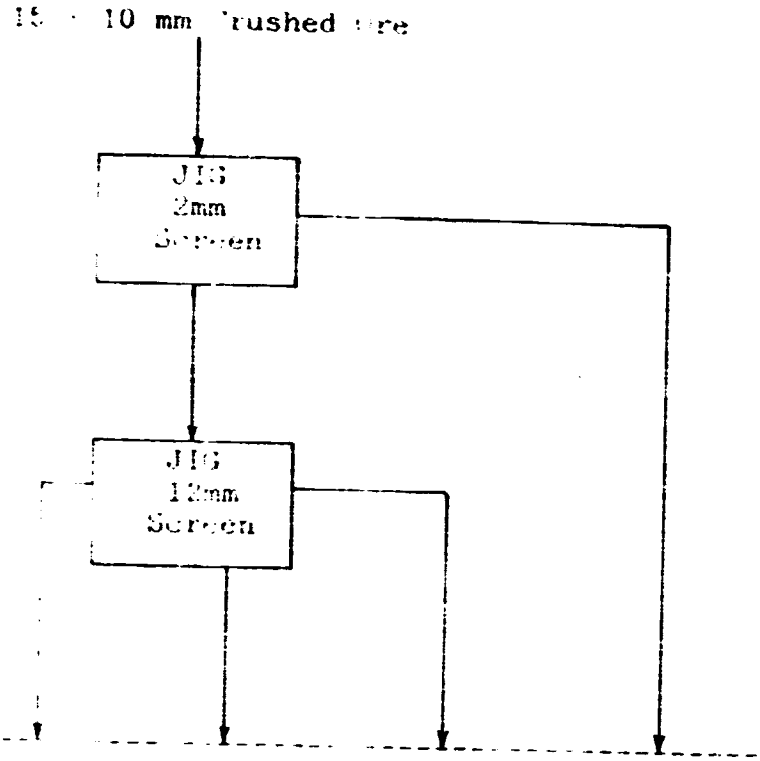


FIG. 7

FIG. 8

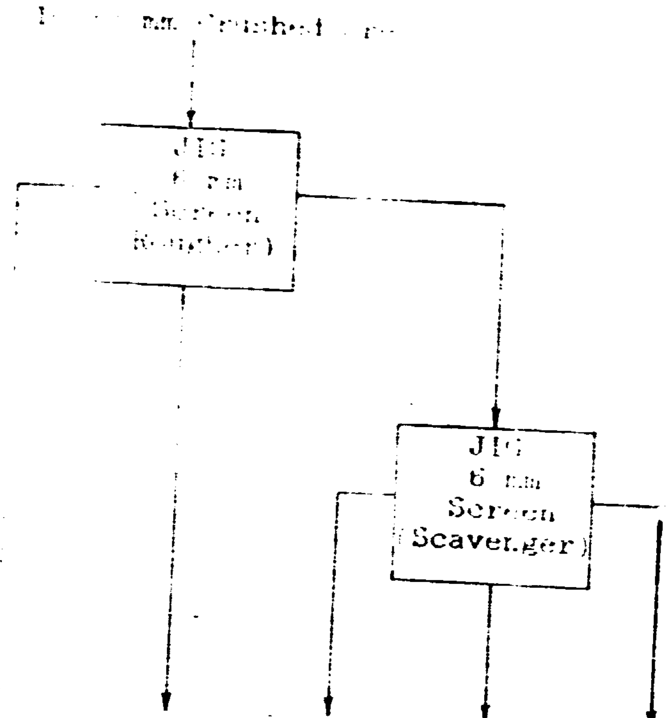


	Hut[illegible]	Bed	Tails 2	Tails 1
Weight, %	65.[illegible]	14.00	5.86	15.14
Assay, % Fe	52.[illegible]	49.72	22.03	28.96
Assay, % SiO2	16.[illegible]	19.25	35.32	32.83
Fe Distn., %	73.[illegible]	14.87	2.76	9.37

Back Calc[illegible]late[illegible] Feed Assay : 46.80 % Fe

Hu[illegible]ch + [illegible]ed Weight :	79.0
[illegible]ssay, % Fe :	52.06
[illegible]ssay, % SiO_2 :	17.27
Fe [illegible]ecovery, % :	87.87

Figure 9. R[illegible]sult[illegible] of Jigging -15 +10 mm Material



	Rghr. Hutch	Rghr Bed	Scav. Hutch	Scav. Bed	Scav. Tails
Weight, %	[illegible]	12.80	16.7[illegible]	8.90	11.60
Assay, % Fe	[illegible]	53.5[illegible]	50.0[illegible]	44.6[illegible]	41.22
Assay, %SiO2	[illegible]4	14.[illegible]	15.84	19.47	26.74
Fe Distn., %	[illegible]5	13.50	16.4[illegible]	7.8[illegible]	9.43

Back Calculated Feed Assay : [illegible]0.73 % Fe

	Rougher Hutch + Rougher Bed	Rougher Hutch + Rougher Bed + Scavenger Hutch
Weight, %	[illegible].8	79.5
Assay, % Fe	[illegible]3.50	5[illegible].70
Assay, % SiO_2	[illegible]4.07	14.45
Fe Distn., %	[illegible]6.25	82.70

Figure 10. Results of Jigging -10 +3 mm Material

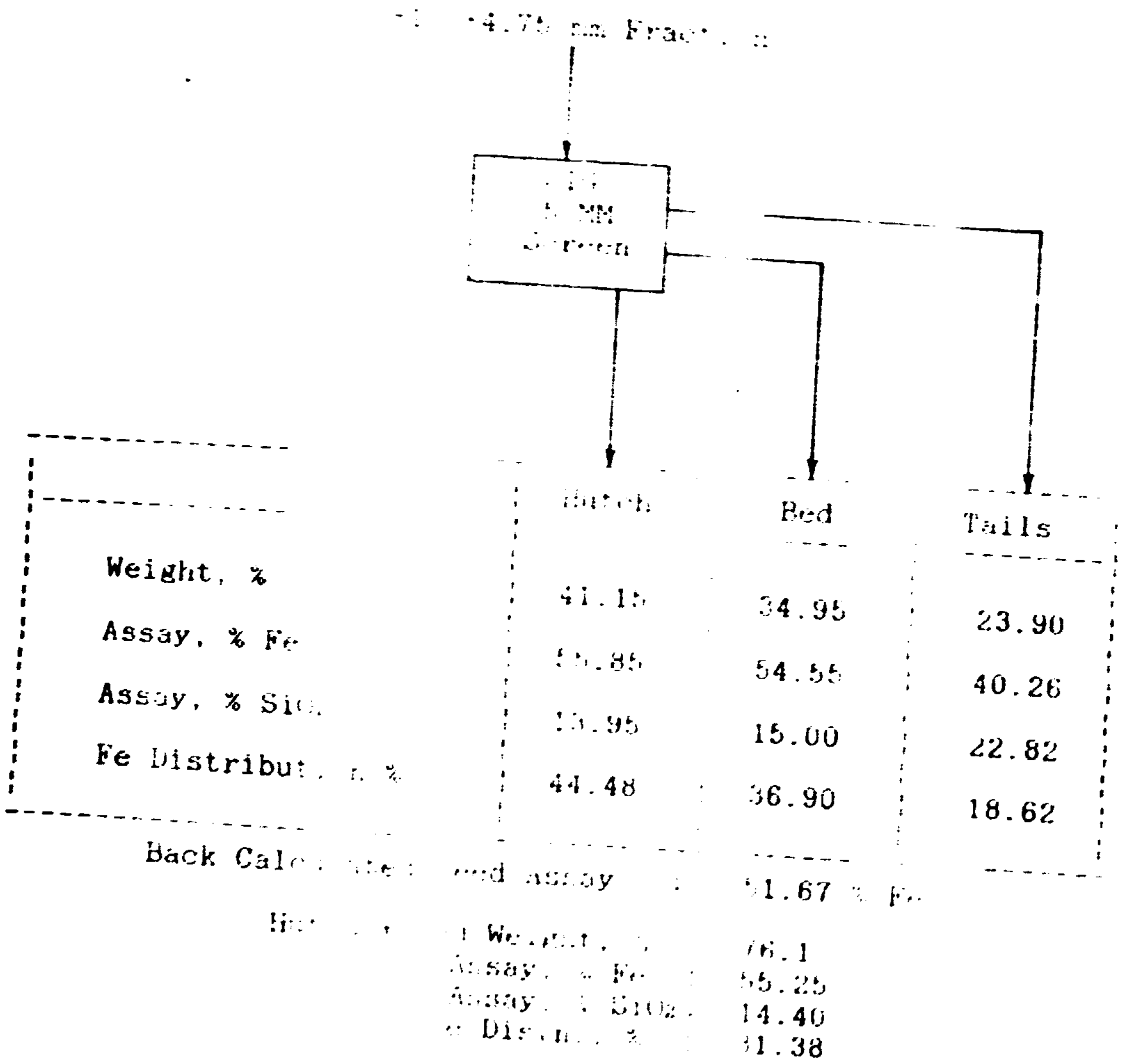
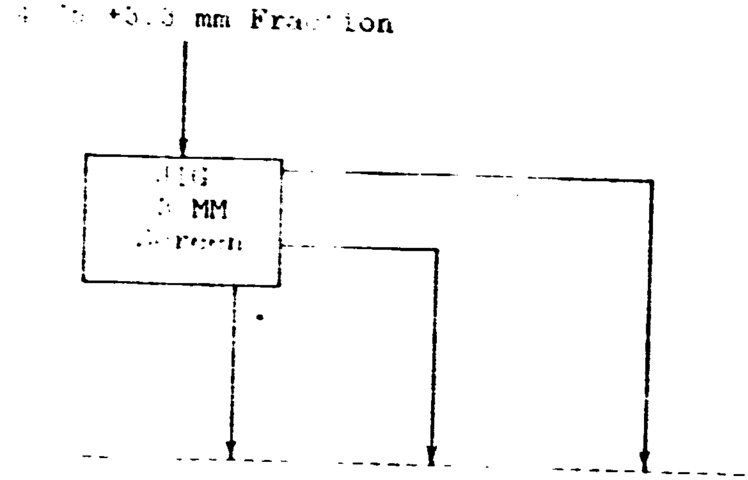


Figure 11. Res... ...of ... 75 mm Fraction

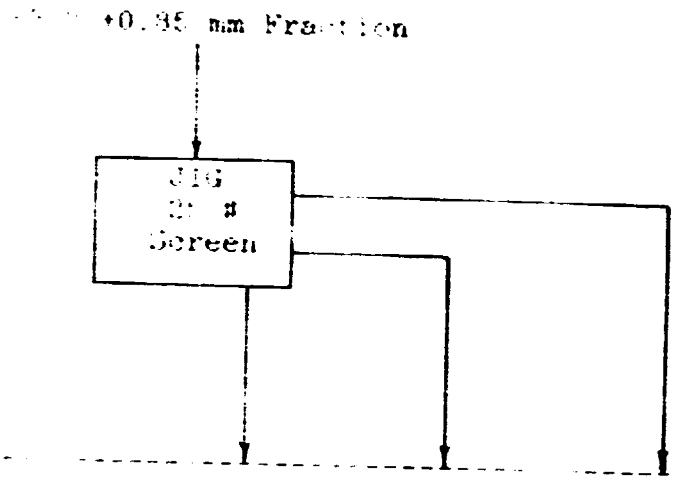


	Hutch	Bed	Tails
Weight, %	45.16	22.58	32.26
Assay, % Fe	53.25	52.60	44.16
Assay, % SiO2	11.32	12.40	19.00
Fe Distribution, %	47.93	23.67	28.40

Back Calculated Feed Assay 46.76 % Fe

Hutch + Bed Weight, %	67.74
Assay, % Fe	53.03
Assay, % SiO2	11.68
Fe Distn, %	71.66

Figure 12. Results of Jigging of -4.75 +3.2mm Fraction



	Hutch	Bed	Tails
Weight, %	22.44	29.14	48.42
Assay, % Fe	53.43	54.55	42.21
Assay, % SiO_2	6.80	7.00	19.00
Fe Distribution, %	26.52	32.15	41.33

Back Calculated Feed Assay 49.44 % Fe

Hutch + Bed Weight, %	51.58
Assay, % Fe	56.24
Assay, % SiO_2	6.91
Fe Distn., %	58.67

Figure 13. Results of Jigging of [illegible] +0.85mm Fraction

REDUCIBILIT[illegible] [illegible] [illegible] [illegible] IN [illegible]RATLRY [illegible] FURNACE

Test Condit[illegible] :

Furnace Char[illegible]

Weight of Or[illegible]	:	[illegible] g.
Size	:	6 [illegible] mm
Reductant us[illegible]	:	As [illegible] test requirement
C.Fix/Size Ra[illegible]	:	0.[illegible]
Limestone	:	As [illegible] requirement (6%)

Kiln Condit[illegible] :

Temperature [illegible] feeding	:	R[illegible] temperat[illegible] °C
Heat up time [illegible] temperature	:	1[illegible] minutes
Reduction te[illegible]	:	1[illegible]
Reduction tim[illegible]	:	1[illegible] minutes
Kiln speed	:	[illegible]
Kiln atmosphe[illegible]	:	Nitr[illegible]en

ANNEXURE - IV

REDUCIBILI... IRON ORE IN ... ROTARY KILN

Test Conditi...:

Kiln Charge:

Weight of O:	: ...
Size	: ... - 20 mm
Reductant	: ... per test requirement
C.Fix/Size ...	: 0....
Limestone/...	: As per test ...irement

Kiln Conditi...:

Temperature ... i... bon feeding:	: 7... °C
Heat up ti... ... temp.	: 1... minutes
Reduction tem...	: ...°C to 98...°C
Reduction ti...	: 1... to 180 minutes
Kiln speed	: 2 ...
Kiln atmosphe...	: as ... requirements