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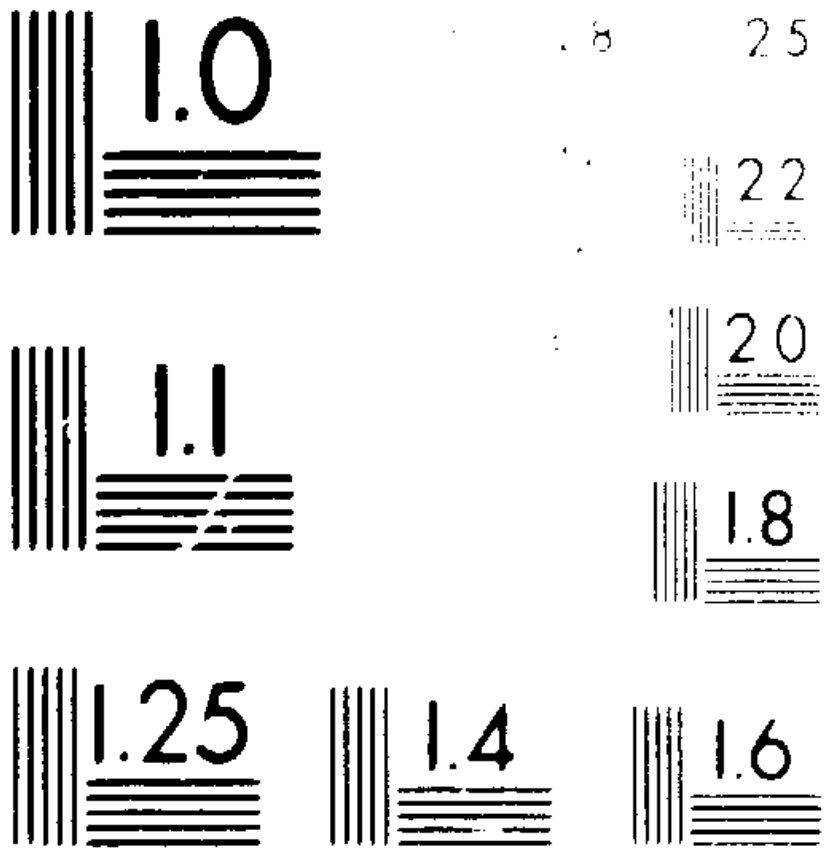
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~~DRAFT~~ FINAL REPORT

on

Investigation on the Production of Sponge Iron Suitable for Steel-making with Iron Ores and Coals from Hungary.

SI/HUN/82/802

SIIL

ENGINEERING AND PROJECTS DIVISION

SPONGE IRON INDIA LTD.

HYDERABAD - A. P.

DRAFT FINAL REPORT ON INVESTIGATION ON THE PRODUCTION OF SPONGE IRON SUITABLE FOR STEELMAKING WITH IRON ORES AND COALS FROM HUNGARY

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SIIL

DRAFT FINAL REPORT ON INVESTIGATION ON THE PRODUCTION OF SPONGE IRON SUITABLE FOR STEELMAKING WITH IRON ORES AND COALS FROM HUNGARY

1.0 INTRODUCTION:

1.1 United Nations Industrial Development Organisation (UNIDO) vide their Contract No.83/12, Project No.SI/HUN/82/802, awarded the work relating to carrying out investigations on the feasibility of production of sponge iron, suitable for steelmaking, with iron ore and coals from Hungary.

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

a) Beneficiation and upgrading of low grade iron ores to high grade green concentrates consistent with optimum recovery/yield figures.

b) Pelletization of the green concentrates to yield high quality heat hardened pellets.

c) Investigation work using pellets (vide 'b' above) and Hungarian non-coking coals to produce highly metallized sponge iron through direct reduction in rotary kiln operations.

d) Melting trials of highly metallised sponge (vide 'c' above) to produce acceptable grades of steel in Electric Arc Furnace.

e) Detailed techno-economic analysis of all operations (vide 'a to d' above) for commercial scale operations.

f) Preparation of a comprehensive self-contained detail report covering "a to e" above.

1.3 Insofar as testing of raw materials are concerned the following programme was drawn up.

STAGE-I : Preliminary investigations on Hungarian Iron Ore and Coal by conducting laboratory tests to assess their quality and suitability.

STAGE-II : Beneficiation tests on Hungarian ores for production of high grade concentrates.

STAGE-III: Production of high grade heat hardened pellets from ore concentrates.

STAGE-IV : Reduction of heat hardened pellets with Hungarian Coals to produce highly metallised sponge iron for steelmaking.

STAGE-V : Melting trials of sponge iron produced.

2.0 STAGE-I: PRELIMINARY TEST WORK ON HUNGARIAN RAW MATERIALS:

2.1.0 Coal

2.1.1 The Coal sample received from Hungary was tested for following:

1. Proximate analysis of coal
2. Ash softening characteristics
3. Tests on suitability as a reductant in laboratory rotary furnace.

2.1.2 The preliminary tests have shown that the coal sample received consisted of contaminants of wood like fibrous material. In view of this two sets of proximate analysis were carried one without seggregation of contaminants and other with seggregation of contaminants. The tests have shown that the volatile matter in the coal is reasonably high, above 55% average, and ash content 17% average. However the fixed carbon in both seggregated and unseggregated samples appear to be on the lower side.

2.1.3 Insofar as ash softening tests are concerned they very between 1160^{o} to 1180^{o} which is reasonably satisfactory.

2.1.4 The preliminary reduction tests with the coal samples with Indian ores revealed that 1.65 Kg of coal is required for reducing 1 Kg of ore. The high consumption of coal is mainly due to low content of fixed carbon. High consumption of coal also resulted in high sulphur pick up in the sponge iron produced. The details of test results are placed at Annexure-I.

2.1.5 On the basis of preliminary test, it is apparent that the coal does not appear to be representative as has been confirmed by the Hungarian representatives who were present during the test programme. As the tests had to be repeated with the right type of coal it was agreed that UNIDO would supply additional quantities of representative coal samples.

2.1.6 Fresh coal samples were received in September 1983. Preliminary inspection and investigation has shown that these samples appear more like char with less volatile matter. This aspect was brought to the notice of UNIDO before taking up the tests.

2.1.7 The proximate analysis of the fresh coal samole is given below:

Ash	15.10%
Volatile Matter	11.20%
Fixed Carbon	73.70%

2.1.8 As the volatile matter appears to be on lower side it was decided to carryout ultimate analysis of these coal samples the results of which are given below:

Ultimate Analysis:

Moisture	9.09%
Ash	13.47%
Carbon	69.71%
Hydrogen	1.2 %
Nitrogen	1.03%
Sulphur	2.43%
Oxygen	3.07%
Total	100.00%

2.2 Iron Ore

Insofar as iron ore samples are concerned the chemical and physical analysis of samples as received were carried out and the details of the analysis are given below:

2.2.1 Chemical Analysis:

a) As received Fe-total 55.85%

b) -1mm fraction, Fe-total 56.41%

c) -3mm +1mm fraction, Fe-total 53.62%

2.2.2 Screen Analysis (As received)

	Wt. %
IS + 280 (2.8 mm)	1.34
IS + 200 (2.0 mm)	9.77
IS + 120 (1.2 mm)	14.18
IS + 100 (1.0 mm)	2.49
ASTM + 60 (250 micros)	29.69
ASTM + 80 (180 micros)	5.36
ASTM - 80 (177 micros)	37.17
Total	100.00

3.0 STAGE-II: BENEFICATION OF IRON ORE:

3.1 The beneficiation tests for producing high grade ore concentrates from iron ore samples of Hungary was conducted at National Mineral Development Corporation (NMDC) Laboratory, Hyderabad, after seeking the approval of UNIDO. The tests were carried out on the basis of the flow-sheet approved by the Hungarian Engineers, who were present at that time.

3.2 1250 Kg of iron ore sample was supplied to NMDC by Sponge Iron India Limited (SIIL) for carrying out the beneficiation tests. Petrological examination and study on the behaviour of ore sample for gravity concentration was conducted on a sample of 150 Kg. On the basis of the preliminary studies, the actual beneficiation work was carried in the presence of the Hungarian engineers. The details of tests are given at Annexure-II. The beneficiation tests have shown that it is feasible to produce concentrates with average Fe total 66.5% and with an yield of 32.8%. The tests also established that 80% of these concentrates is of 30-60 microns size which is considered suitable for pellatization. The total quantity of such concentrates produced is 265 Kg.

4.0 STAGE - III: PREPARATION OF HEAT HARDENED PELLETS:

4.1 The ore concentrates at NMDC Laboratory were sent to Indian Bureau of Mines, Nagpur (IBM), who have the requisite facilities for preparation of pellets at laboratory scale.

4.2 Before taking up preparation of pellets, tests for optimisation of parameters of pellets were carried and the following broad parameters were arrived at:

4.2.1 Ore Concentrate:

Size analysis of concentrates:

Size Microns	Wt. %
+ 104	-
- 104 + 74	1.0
- 74 + 53	4.3
- 53 + 44	7.0
- 44	87.7
Total	100.0

Blain Number 2140 Cm^2/gm

4.2.2 Green pellet making:

Moisture	6%
% Binder-Bantonite used: (weight basis)	0.75%

Properties of Green Pellets:

a) Drop Index No. (from 450 mm) — 6 to 7

b) Green strength — 2 Kg

c) Size of Pellets — 12 to 15 mm

d) Heat Sensibility — $130^{o}C \pm 10^{o}C$

4.2.3 Conditions for various stages in induration of Green Pellets.

Type of pot used : Gratepot

Bed thickness of green pellets: 175 to 200 mm

S.No.	Stages of Induration	Test Conditions		
		Pressure differential mm water gauge	Temperature $0^{o}C$	Time minutes
1.	Drying	300	130 ± 10	8
2.	Pre-heating			
	i)	300	700 - 750	8
	ii)	400	1000	3
3.	Firing	500	1220+20	12

4.3 Based on the above optimum parameters, preparation of pellets was carried out on the available concentrate, by IBM, Nagpur. The detailed test report is at Annexure-III.

4.4 In view of the need to carry out a number of preliminary tests for optimisation of parameters the quantity of pellets that could be finally produced was slightly on the lower side than expected. It was possible to produce only 150 Kg of pellets against 265 Kg of concentrates supplied.

5.0 STAGE-IV: REDUCTION TESTS

The reducibility tests on pellets produced from Hungarian Iron Ore concentrate were carried out in the laboratory rotary furnace at SIIL Test Centre Kothagudem. Hungarian Coal was used as reductant during above test. Singareni Coal was also used for a comparitive study of the test results.

The detailed physical and chemical analysis of Hungarian pellets and the reductants used namely Hungarian Coal and Singareni Coal are given at Annexure-IV. The results of the reducibility tests including decrepitative behaviour of the pellets during reducibility tests are given at Annexure-V.

5.1 Review of the Test Results:

5.1.1 Chemical Analysis:

i) The results of the physical and chemical analysis of Hungary iron ore pellets and the coal revealed that the raw materials are suitable for the production of Sponge Iron by Direct Reduction and that the Sponge Iron could be effectively melted in Electric Arc Furnace for steel making. The pellet size as well as the tumbler test results indicate satisfactory abrasion resistance. Also the crushing strength of the pellets is found to be about 120 Kg per sq.cm. which is satisfactory.

ii) The physical appearance of the coal received and the proximate analysis carried out, indicate that the coal may be of char type with less volatile matter. The other properties of the coal such as reactivity, ash softening temperature were found to be within acceptable limits.

III) Sulphur in coal is found to be higher than acceptable limit of one percent maximum. However it has been observed that sulphur is of organic type and in the reduction tests, Sulphur level could be brought down to 0.033 percent with the addition of about six percent of limestone.

5.1.2 Reduction Tests:

The analysis results of the reduction tests on the pellets with Hungarian Coal and Singareni Coal indicate the following:

i) The reducibility characteristics of the pellets is found to be good. The degree of metallisation levels achieved with both Hungarian and Singareni Coals was well above 92% average. The degree of reduction was also found to be well above 90%.

ii) The results showed that the pellets are not decrepitating type and the -1mm fraction, generated during the test was found to be not more

than six percent. It was noticed that 1 to 5 mm fraction was marginally lower when treated with Hungarian coal in comparison to the results obtained with Singareni coal. It has also been observed that the pellets are of uniform size and the average mean particle size of the pellets was around 10 mm which is considered acceptable for the rotary kiln operation.

iii) The decrepitating behaviour of the char generated from coal after the reduction test indicated that the coal is of medium decrepitating type and may require lower particle size of the coal when treated in a commercial rotary kiln.

iv) As the percentage of volatiles in the coal are found to be low, it may be necessary to inject high volatile coal preferrably bituminous type in the discharge end of the kiln for maintaining the temperature profile.

6.0 STAGE - V: MELTING OF SPONGE IRON

6.1.0 Sponge Iron Pellets prepared in the SIIL laboratory kiln were tested for melting in a laboratory electric furnace to study the melting behaviour. Three melting heats were taken with varying sponge iron proportions of 20%, 30% & 50% of size above 3 mm and the balance charge being heavy melting scrap. As the laboratory furnace did not have the facility for continuous charging of sponge iron, batch charging technique was adopted.

6.1.1 Sponge iron pellets were added intermittantly to a pool of molten bath obtained by melting of scrap. Calcined lime was added during sponge iron addition as well as during refining so as to obtain slag of desired basicity and to ensure phosphorus and sulphur control. At the end of refining period carbon and ferroalloys additions were carried out in the furnace to tap metal of desired chemical composition.

6.1.2 Two heats were aimed at producing structural steel of standard quality confirming to Indian Standard Specifications IS:226/75 (similar to BS:15, ASTM:A 75, DIN-17100, JIS.G. 3101). The third heat was aimed to produce steel of composition suitable for making carbon steel bars for production of machine

parts for general engineering purposes confirming to Indian Standard Specifications IS:2073/70 similar to BS:970, EN 8, DIN 17210, JIS.G. 4051.

6.2 MELTING PRACTICE:

6.2.0 The melting practice followed during 3 heats carried out is given below.

6.2.1 Charging:

Scrap formed the first charge in all the three heats. After complete melting of scrap sponge iron was added as second and third charge. Some quantity of lime was also added along with sponge iron additions so as to have a combined melting and refining operations. The details of charge is given at Annexure No.VI. As furnace was of smaller capacity, the heat times (Power on to tap) were higher and non representative when compared to commercial melting practice.

6.2.2 Slag: The slag volume and weight was normal as scrap used was highly metallic and the gangue content of sponge iron being around 6%. The slag weight increased marginally when 50% sponge iron pellets were used. Since gangue content of sponge iron was mainly acidic, slag had good fluidity and the basicity maintained around 1.5

by lime addition did not pose any major problems in phosphorus and sulphur removal.

6.2.3 Product Quality:

The chemical composition of the steel obtained in the three heats is placed at Annexure VII.

6.2.4 Phosphorous Content:

The phosphorous levels in tapped steel finished at 0.04 to 0.05 percent and were below the permissible levels of the specified composition of structural steel & carbon steel sections suitable for fabrication and general machining applications.

6.2.5 Sulphur Content:

The sulphur levels in tapped steel finished at 0.03 to 0.04 percent and were below the permissible levels.

6.2.6 Carbon:

Carbon level in the structural steel heat was 0.20 to 0.25% . While in the carbon steel heat it was 0.4%. To control the carbon content at the end of sponge iron melting it was found necessary to select scrap with appropriate carbon content and make carbon additions in the bath in the form of hard coke or graphite.

6.3 MELTING PERFORMANCE:

To study melting performance yield, heat time, power consumption, Electrode consumption, Refractory consumption need to be evaluated for each heat. But since the melting trials carried out were small, in a laboratory type melting furnace due to limited quantity of sponge iron pellets available, these parameters could not be assessed. However, it was established that sponge iron pellets prepared from Hungarian iron ore concentrate could be melted successfully to obtain steels of various grades.

7.0 CONCLUSIONS AND RECOMMENDATIONS:

7.1 Beneficiation:

7.1.1 From mineralogical, chemical tests and beneficiation studies of the sampleit is observed that it is feasible to produce concentrate from low grade Hungarian iron ore suitable for preparation of heat hardened pellets for direct reduction application.

7.1.2 The mineralogical composition of concentrate obtained is mainly hematite with minor amounts of magnetite and goethite and gangue minerals like quartz, clay and amphibole. The mineralogical as well as chemical composition is considered suitable for making heat hardened pellets for direct reduction application.

7.1.3 It is possible to produce concentrate with iron content around 66 per cent with an yield of 32.8 percent from the sample of iron ore supplied, using gravity concentration and magnetic separation.

7.1.4 Based on the yield figures obtained, it is concluded that approximately 3 tonnes of Iron Ore fines would have to be processed for beneficiation to obtain one tonne of concentrate.

7.2 PELLETIZATION:

7.2.1 Concentrate to be pelletized should have iron content above 66% and gangue content should be limited to 5 per cent maximum.

7.2.2 From physical and chemical tests carried out on concentrate and pellets the following conditions are considered optimum for preparation of heat hardened pellets.

i) Concentrate Blaine Number - 2000-2150 Cm^2/gm

ii) Binder (Bentonite) - 0.75%

iii) Moisture - 6%

iv) Induration Cycle:

a) Drying Temperature/time: 120-140°C for 8 minutes

ΔP = 300 mm Water gauge.

b) Preheating - (in two stages)

i) 700°C-750°C for 8 minutes

ΔP = 300 mm Water guage.

ii) 1000°C for 3 minutes

ΔP = 400 mm Water guage.

c) Firing

i) Temperature 1200-1250°C - for 12 minutes

ii) Pressure - ΔP = 500 mm water gauge.

7.2.3 Pellets prepared for direct reduction should be in the size range 9 to 16 mm (average size around 12 mm) which has been established in the tests.

7.2.4 The fines in the prepared pellets i.e., -6mm should be limited to 2 per cent maximum and this has been established in the tests.

7.3 SPONGE IRON PRODUCTION IN ROTARY KILN:

7.3.1 Reduction and Decrepitation Behaviour of Pellets:

7.3.1.1 From reduction tests carried out in laboratory rotary kiln it was observed that it is possible to reduce pellets to a desired metallisation levels i.e., 92 $\pm$ 2% , at 1000^{o}C with 3 hours of retention time.

7.3.1.2 Pellets have shown good reducibility as indicated by uniform metallisation in different size fractions. Based on the test results, it is considered that average particle size of pellet should be 10 to 12 mm.

7.3.1.3 The decrepitation behaviour of the pellets during reduction (-1mm = 6% and -3mm = 10%) is considered satisfactory. However, it is further possible to attempt at lower decrepitation levels by adjustment of pellet hardening conditions preferably in pilot plant scale or semi-commercial scale, induration systems instead of laboratory type pot grate furnace.

7.3.1.4 From laboratory rotary kiln reduction tests it is observed that the bed temperatures of the order of 950 to 1020°C would be required to be maintained in commercial sizes of the rotary kiln in order to produce sponge iron of acceptable levels of metallisation for steel making in Electric Arc Furnace.

7.3.2 COAL

7.3.2.1 It was observed that first coal sample supplied was contaminated with wood like fibrous structure, having low and inconsistent fixed carbon. Therefore, it was considered unsuitable for direct reduction.

7.3.2.2 From proximate analysis, ultimate analysis, calorific value and behaviour in reduction tests, it was observed that second coal sample was generally suitable for direct reduction. However, coal had relatively low volatile matter(around11%). Considering this difficiency, blending of coal with high volatile coal may be necessary to improve the reactivity of of the coal. This is considered particularly relevant for the coal required to be injected from the discharge end of the Rotary Kiln to maintain proper temperature profile.

7.3.2.3 Sulphur in coal was on higher side and sponge iron showed tendency to pick up sulphur during reduction. However, sulphur pick up could be controlled by addition of adequate quantities of suitable desulphurizer like limestone or dolomite.

7.3.2.4 The coal to be fed alongwith the pellets should be in the size range 1 to 10 mm. The coal required for injection from discharge end should be in the size range of 0 to 6 mm.

7.4 MELTING OF SPONGE IRON:

7.4.1 The finished product suitable for steel making was in the following two sizes:

i) 3 - 20 mm

ii) 0 - 3 mm

7.4.2 The product of 3 to 20 mm was considered as prime product and was suitable for direct use in the electric arc furnace steel making. Sponge Iron fines below - 3mm could be utilized for steel making either by briquetting or adopting special techniques like pneumatic injection.

7.4.3 To maintain minimum levels of phosphorus and to achieve shorter refining periods in steel making, it is desirable that phosphorus and sulphur

in reduced pellets be controlled at 0.08% maximum and 0.03% maximum respectively by regulating phosphorus in ore concentrate and sulphur in coal.

7.4.4 To recover iron from unreduced iron (FeO) in Sponge Iron and reduce Fe looses in slag, it was observed that high opening carbon in the melt before sponge iron addition as well as additional carbon in the form of coke or graphite was necessary.

ANNEXURE-I

PRELIMINARY TEST RESULTS ON FIRST COAL SAMPLES

1. PROXIMATE ANALYSIS OF COAL: (Without seggre-gation of wood like fibrous material)

Constituent	SAMPLE NUMBER				
	1	2	3	4	5
Volatile matter %	59.03	57.75	55.75	59.21	49.04
Ash - %	28.80	23.30	10.60	19.01	22.62
Fixed carbon %	12.17	19.00	33.65	21.78	28.34

2. PROXIMATE ANALYSIS: (With Seggregation of wood like fibrous material)

Constituent	Sample Number			
	1	2	3	4
Volatile matter %	55.10	52.50	57.20	52.35
Ash - %	19.40	17.70	15.60	17.00
Fixed Carbon %	25.50	29.80	27.20	30.65

3. Ash Softening Characteristics:

	1	2	3
Ash Softening temp. (^{o}C)	1160	1160	1180
Melting Temperature (^{o}C)	1280	1220	1260
Flow Temperature (^{o}C)	1300	1250	1280

REDUCTION TEST RESULTS ON LABORATORY ROTARY FURNACE

A) Iron Ore : Hospet - India
Fe(t) = 66.00 % size 6 to 15 mm

B) Coal : Hungary Coal samples
Fixed carbon 20% Size = 1 to 15 mm

C) REDUCTION CONDITIONS

i) Reduction temperature : 900^{o}C

ii) Retention time : 3 hrs, at 900^{o}C

iii) C-fix/Fe(t) ratio : 0.5

iv) Desulphurizer : Not used.

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D) SCREEN ANALYSIS OF PRODUCT:

Size mm	ORE		COAL	
	Before Test	After Test	Before Test	After Test
+ 20	NIL	NIL	NIL	NIL
(+15-20)	16.5	NIL	NIL	NIL
(+10-15)	40.0	9.93	30.30	15.90
(+8 - 10)	28.5	8.26	30.91	23.08
(+5 - 8)	15.0	17.35	20.61	20.51
(+3 - 5)	NIL	33.06	14.54	21.54
(+1 - 3)	NIL	20.74	3.64	6.67
- 1	NIL	20.66	NIL	12.30
Total	100.00	100.00	100.00	100.00

E. CHEMICAL ANALYSIS OF MAGNETIC PRODUCT:

Size mm	Fe. Total	Fe.Met	Metallisation	C	S
(+8-15)	95.50	85.72	89.76	0.40	0.27
(+1-8)	97.74	88.24	90.28	0.32	0.38
(-1)	91.04	84.89	93.24	1.90	0.92

ANNEXURE - II

BENEFICATION TESTS

WITH

IRON ORE SAMPLES FROM HUNGARY

SAIL

CONTENTS

PRELIMINARY REPORT ON THE TESTS WITH IRON ORE SAMPLES FROM HUNGARY

The ore concentration tests were undertaken in the Research and Development Laboratories of National Mineral Development Corporation, Hyderabad at the request of Sponge Iron India Limited. The experts of VASKUT (Hungarian Iron and Steel Research Enterprises) took part in the whole test run of ore concentration and on the basis of the final tests and results thereof it was agreed between VASKUT, NMDC and SIIL upon the type of flow-sheet for further benefication tests which were subsequently carried out at NMDC Laboratory.

The concentrate thus prepared ready for the pelletization process analysed 66.3% Fe and its weight was 265 Kgs.

SIIL propose to have the work relating to Pelletization with bentonite addition be carried out by the Indian Bureau of Mines, Nagpur. After this the direct reduction test would be undertaken at Kothagudem by SIIL.

The delivery of the final product back to Hungary will be undertaken by air from New Delhi. The costs of this transport will be paid by the Hungarian Government, according to the UNIDO contract.

SIIL

As far as the modalities of the transportation are concerned VASKUT would give detailed information to SIIL in this respect soon after SIIL gives information of the packing details (weight and mode of packing) of the metallised pellets to be transported.

Enclosures: Benefication tests with iron ore sample from Hungary.

Hyderabad, 27th April, 1983.

Sd/-	Sd/-	Sd/-
for S.I.I.L.	for VASKUT	for N.M.D.C.

SIIL

BENEFICATION TESTS WITH IRON ORE SAMPLES FROM HUNGARY

AIM:

To concentrate the low grade test sample, suitable for Sponge Iron production using Hungarian non-coking coal which in turn can be used for making high purity special steels.

SOURCE & DESCRIPTION OF THE ORE:

This ore is imported to Hungary from KRIWOY ROG Pit mines U.S.S.R. in a lump size of 0-30 mm. Iron content of the imported ore ranges from 51 to 54%.

Minerological studies carried out earlier have shown that the main constituents of the ore are as follows:

Mineral	Mineral composition	Weight percent
Hematite Quartzite	$Fe_2O_3 \times SiO_2$	57
Magnetite Quartzite	$Fe_3O_4 \times SiO_2$	5-8
Hematite Magnetite	$Fe_2O_3 \times Fe_3O_4$	4-5
Martite	Fe_2O_3	20-25
Quartz	SiO_2	5
Kaolinite	$Fe_2O_3 \times Al_2O_3 \times SiO_2$	6
Goethite	$Fe_2O_3 \times H_2O$	3-5 (See Appendix)

Preliminary concentration tests were carried out in Yugoslavia, U.S.S.R. & Sweden and a technology is developed for beneficiation of this ore, where a concentrate with an

concentrate with an iron content of 64% is obtained. This concentrate is sintered and used in Blast Furnace at present.

BACKGROUND:

It is a well known fact that to produce high purity special steels, the iron source should be free from tramp elements like Cu, Sn, Ni etc. and Sponge Iron is a possible solution for this problem. Hungary, as a part of its development programme, intend to produce high purity special steels for which it requires to concentrate further the presently available ore to an iron content of 67%. As per minerological studies this is possible only if martite (Fe_2O_3) and Goethite (Fe_2O_3 H_2O) are separted from the run of mine ore, the other parts are being not suitable for concentration. Petrographic studies have shown that these two components viz. Martite & Goethite are present only in the size fraction below 3.15 mm.

To develop appropriate technology, for concentration and Direct Reduction of this concentrate, Hungary has sought the assistance of UNIDO, as there are no pilot plant facilities available in that country. It's but natural, Sponge Iron India Limited (SIIL), a UNIDO/UNDP aided project and now a well established name in the

field of Direct Reduction technology was assigned this problem. In November 1982 Hungarian Government was informed by UNIDO that the tests can be carried out at SIIL and UNIDO was also willing to give financial assistance. After receiving the reply from UNIDO a sample of 10 tonnes has been taken from 0-30 mm size range. This ore was screened at -3.15 mm and a sample of 4 tonnes was taken. In December last year, in a discussion with Dr.Nijhawan of UNIDO it has been decided to supply 1400 Kgs of ore sample along with 700 Kgs of Hungarian Non-coking coal for carrying out reduction tests. The materials were received by SIIL at the plant site in the month of January 1983.

TEST PROGRAMME AT N.M.D.C. LABORATORY:

a) Beneficiation: As SIIL has no facilities for carrying out beneficiation tests the first part of the test programme i.e., beneficiation studies were carried out in the R&D Centre of M/s. National Mineral Development Corporation Ltd., Hyderabad which is capable of developing suitable technology for concentration with the highly competent technical personnel and the excellent testing facilities. (See Appendix-II).

After receiving the ore sample of about 1250 Kg from SIIL, as a first step, a representative sample was taken for petrological examination, screen analysis and chemical analysis. The results are presented in Table I & II and Apoendix-I. To study the behaviour of ore sample for gravity concentration, a trial run was taken with the contents of one drum weighing approximately 150 Kgs. This was a double stage gravimetry concentration using cyclone and Humphrey spirals. The Fe content of the concentrate after 2nd spiral was 66.28%. Results are presented in Table III. According to microscopic investigation the concentrate also contained free Quartz. It was also observed that the coarser fraction (+1 to -3.15 mm) was causing flow problems in the operation of spirals. So it was decided to screen out +1 mm fraction from the remaining sample. The wt of the -1 mm sample after screening out +1 mm was 735 Kgs. Gravity concentration was carried out on this material as the results of trial run were encouraging. The results of this two step gravity concentrations is presented in the flowsheet 1.

The next step was the Magnetic separation of the spiral concentrate (weight 351 Kgs) with which the -1 mm spiral concentration weighing around 35 Kgs from trial run (after screening off +1 mm fraction) was mixed. The

total feed for magnetic separation was around 386 Kgs. The first step in this was separation in low intensity one step magnetic separation (LIMS). Here the magnetic part i.e., magnetite present was separated. The second step was treating the low intensity non-magnetic tailings in high intensity one step magnetic separation (HIMS). Here the feebly magnetic part viz martite, goethite & magnetite (around 1%) that escaped LIMS, was separted. As the separation can not be expected to be 100% efficient some grains of quartz were present in the concentrate. This was continued by microscopic investigation which revealed the presence of martite as basic constituent, Goethite and some grains of quartz. Results were presented in flowsheet-2. Chemical analysis Screen analysis, Blain Number and Petrological examination of the concentrate are presented in Table IV & V and Appendix-II.

b) Grinding: In order to get the fineness required for pelletization the concentrate and middlings obtained from high intensity magnetic separation was ground in a ball mill. The aim of grinding was to produce a product of $d_{80\%}$ -50 to 60 microns.

The specification of equipment used are presented in Appendix-III.

CONCLUSION:

The beneficiation tests as discribed above have shown that it is feasible to produce the concentrate with a minimum of 66.3% Fe with an yield of 32.8% from the test samples supplied. It is also established that 80% of the produce is under 50 to 60 microns which is considered suitable for pelletisation. The above yield is higher than what was expected by the Vaskut Engineers as this was a single stage concentration programme.

Table I

SCREEN AND CHEMICAL ANALYSIS OF AS RECEIVED SAMPLE

Size Microns	Wt. %	% Fe Total	% SiO_2
+ 1168	25.2	51.28	24.85
-1168 + 295	24.6	57.14	15.11
- 295 + 104	15.0	62.01	8.13
- 104 + 74	6.9	62.21	9.65
- 74 + 44	6.8	55.58	18.32
- 44	21.5	54.21	16.47

Table II

CHEMICAL ANALYSIS OF AS RECEIVED SAMPLE

Constituent	Assay %
Fe	56.01
Fe_3O_4	2.5
SiO_2	16.65
Al_2O_3	1.43
CaO	0.50
MgO	0.25
LOI	0.82

Table III

RESULTS OF GRAVITY CONCENTRATION

Size Microns	Spiral Concentrate1 Wt. %	Tailings Wt. %	Spiral Concentrate2	Cyclone Underflow
+ 833	3.8	19.5	3.7	11.1
417 - 833	12.0	23.0	5.1	21.1
208 - 417	21.3	4.1	25.9	12.1
147 - 208	14.6	0.5	16.9	6.7
74 - 147	31.5	2.8	34.2	16.6
44 - 74	13.6	23.1	12.1	15.4
-44	3.2	27.0	2.0	17.0

Cyclone overflow 99% - 44 microns

Table IV

CHEMICAL ANALYSIS OF CONCENTRATE

Constituent	Assay %
Fe	66.15
Mag Fe	0.70
SiO_2	4.21
Al_2O_3	0.55
LOI	0.40
P	0.02
S	Traces
CaO	0.22
MgO	0.25
MnO	0.05
TiO_2	Traces
Na_2O	0.190
K_2O	0.06
Cu	Traces
Ni	Traces
V_2O_5	Traces
Zn	Traces

Table V

SCREEN ANALYSIS OF THE CONCENTRATE

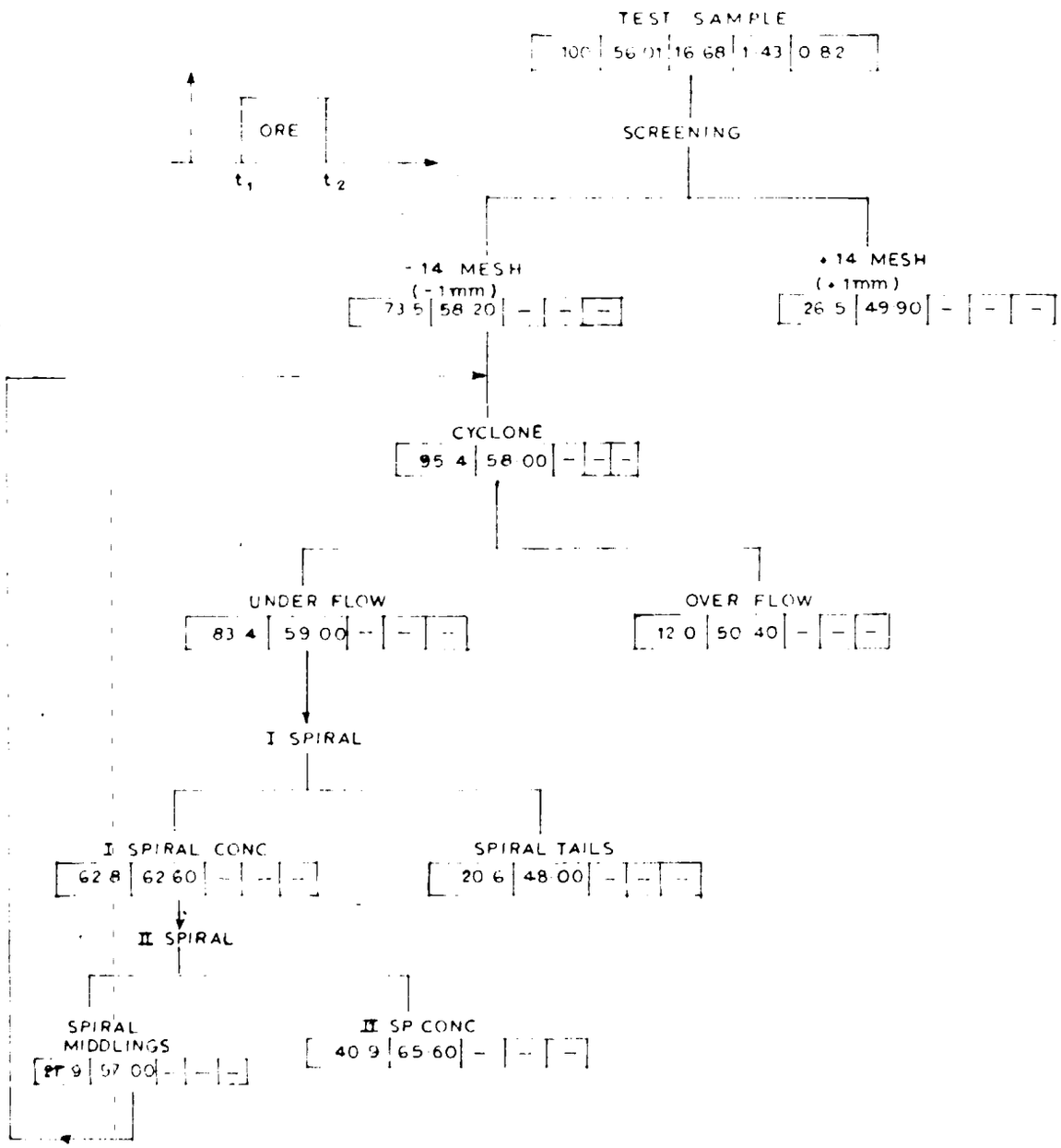
Size in microns	Wt. %
+ 104	2.1
-104 + 74	5.1
- 74 + 53	15.1
- 53 + 44	8.1
- 44	69.6
Total	100.0

Specific Surface Area : 1854 Cm^2/gm
(Blain Number) of the
Concentrate

NATIONAL MINERAL DEVELOPMENT CORPORATION LTD., HYD.

REV.	DESCRIPTION OF REVISION	MADE BY	CHECKED BY	APPROVED BY	DATE
	ORIGINAL COMPLETED DRAWING	[illegible]	MS Sreenivasa	MS Sreenivasa	
1					
2					

LEGEND : | Wt / | Fe | SiO_2 | Al_2O_3 | LOI |



SCALE	TITLE:	DRAWING NO.	REV.
	FLOW SHEET NO 1	4-13-163	

NATIONAL MINERAL DEVELOPMENT CORPORATION LTD., HYD.

REV.	DESCRIPTION OF REVISION	MADE BY	CHECKED BY	APPROVED BY	DATE
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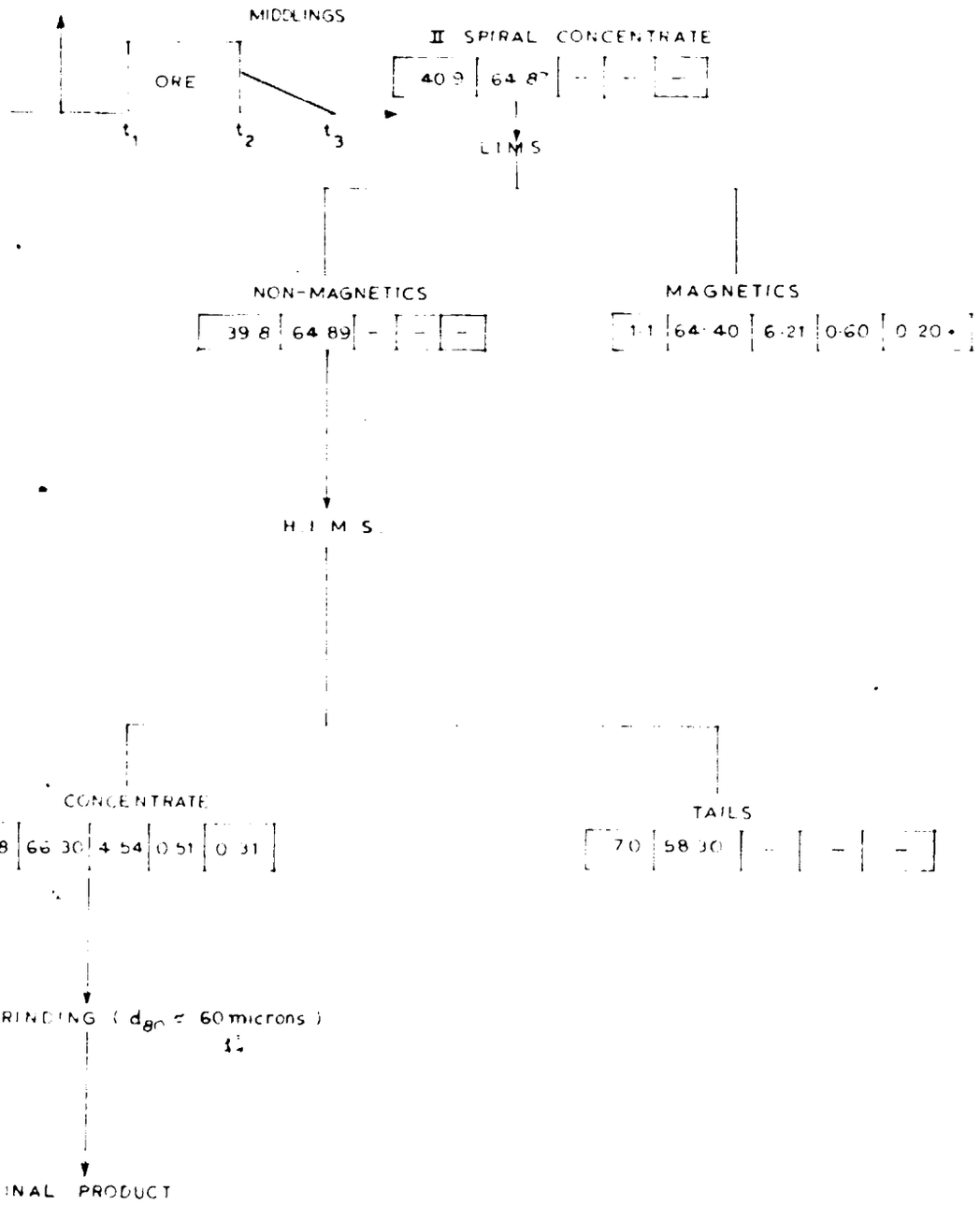
2					



SCALE	TITLE:	DRAWING NO.	REV.
	FLOW SHEET NO 2.	4-13-164	

Appendix - II

PETROLOGICAL REPORT ON THE CONCENTRATE

The sample was a fine powdery material. It was reddish brown in colour. It was found to be feebly magnetic.

For the purpose of finding out the mineralogical composition the fine powdery material was made into briquettes and polished.

The microscopic examination revealed the presence of hematite, martite, goethite and little magnetite. The gangue was siliceous in nature and was very minor. Due to fineness of the material the detailed characteristics could not be noticed. The texture was cryptocrystalline. It was difficult to even separately determine the size of the individual grains. However, the majority of the portion was occupied by the hematite and goethite. The gangue was very minor.

Appendix - III

EQUIPMENT SPECIFICATIONS

1. Cyclone

Make	:	Krebs
Size	:	4" dia
Apex	:	½"

2. Spiral Concentrator

Make	:	SALA International
Type	:	Two stage of 5 turns each

3. Low Intensity Wet Magnetic Separator

Make	:	Boxmag Rapid
Type	:	Drum type Permanent magnet
Size	:	15" dia, 12" width
Field Intensity	:	1500 Gauss

4. High Intensity Wet Magnetic Separator

Make	:	Erietz
Size	:	CF-5 Pilot Plant model
Operating ampearage & Field Intensity	:	2.5 amps - 8500 Gauss

5. Ball Mill

Make	:	Denver
Size	:	16" dia x 32" length

OPERATING CONDITIONS

1. Cyclone Underflow

Pulp Density	:	65% Solids by weight
Sp. Gravity	:	4.28

2. Ball Mill Discharge

Pulp Density	:	60% S
Sp. Gravity	:	4.76

ANNEXURE III

PREPARATION OF HIGH GRADE FIRED PELLETS

CONTENTS

ANNEXURES

SAIL

ANNEXURE - III

PREPERATION OF HIGH GRADE FIRED PELLETS

INTRODUCTION

1.0 About 260 Kg of Hungarian Iron Ore Concentrate (fines) was received from M/s. Sponge Iron India Limited (SIIL) with a request for (a) conducting pelletization studies to determine (i) bentonite quantity required for making green pellets of satisfactory strength i.e.drop number 6-7
(ii) Induration cycle for producing about 150-200 Kg of fired pellets of the following specifications.

Specifications:

(i) Size (9 mm - 16 mm)	:	$\geq$ 85%
(ii) Tumbler strength (+6.3mm)	:	$\sim$ 93%
(iii) Dust Index (-0.5 mm)	:	$\leq$ 3%
(iv) Compression strength	:	> 150 Kg/Pellet

The difficulties in producingabout 150-200 Kg of fired pellets of desired quality out of such a small quantity of sample (260 Kg only) were pointed out to SIIL. SIIL has emphasized that attempts should be made to produce at least 150 Kg of fired pellets of desired quality to enable them to carry out further test of reduction and melting.

The objective of this investigation was limited to produce fired pellets of stipulated specifications. Therefore, green pellets were made and fired, based on the knowledge of general behaviour of similar type of materials in pelletization plants elsewhere.

2.0 CHARACTERISTICS OF THE AS RECEIVED SAMPLE

2.1 Physical

(i) Specific gravity : 4.89

(ii) Blaine No. Cm^2/gm : 1500

(iii) Size (Mesh/Tyler) : Wt.%

	(Microns)	
+ 150	(+ 104)	: 2.0
- 150 + 200	(+104+ 74)	: 5.2
- 200 + 270	(- 74+ 53)	: 9.2
- 270 + 325	(- 53+ 44)	: 7.6
- 325	(- 44)	: 76.0

2.2 Chemical: A representative portion of the sample was chemically analysed. The results are presented in Table No. 1.

TABLE NO. 1.

Constituents	Assay %
Fe (T)	65.78
Fe O	0.38
SiO_2	4.64
Al_2O_3	0.80
CaO	0.14
MgO	0.11
S	Traces
P	.028
L.O.I (at 300°C)	0.11

2.3 Mineralogical: The as received sample consisted mainly of hematite with minor amounts of magnetite and goethite. Quartz, clay and amphibole were the gangue minerals present in minor amounts in the sample.

Presence of small remnants of unaltered magnetite within ground mass of hematite indicated that the hematite might be the alteration product of magnetite. Hematite at places was found to be replaced by goethite. Fine inclusions of hematite were also seen in some goethite grains. Goethite generally occured as fine inregular patches.

The associated gangue minerals were almost free except a few grains which were either interlocked with hematite or contained inclusions of hematite.

3.0 PELLETIZATION STUDIES

The pelletization studies were carried out to determine (i) the fineness of the feed and quantity of betonite needed to produce green pellets of satisfactory strength and (ii) the induration cycle for producing fired pellets of desired quality.

A general material flow sheet of pellet making process is given at Annexure - A.

3.1 Tests to determine feed size and bentonite quantity required for making green pellets of satisfactory strength:-

Batches of 2 Kg sample of different fineness were subjected to balling, employing varying quantities of bentonite and water. The steps involved in making and evaluating green balls were (i) feed preparation (ii) balling and (iii) quality evoluation.

3.1.1 Feed preparetion; Two batches of each 2 Kg. each were dry ground for 30 minutes, and 60 minutes in a 300 x 125 mm denver laboratory ball mill with a ball charge of 18.12 Kg (25 mm steel balls). Representative portions of the ground products as well as original sample were subjected to sieve analysis and surface area (blaine No: cm^2/gm) determinations. The results are presented in Table No. 2.

TABLE NO. 2 .

Size (Mesh/Tyler)		Wt. %		
		Grinding time in minutes		
Mesh	Microns	Orginal sample	30	60
+ 150	(+ 104)	2.0	-	-
- 150 + 200	(-104+74)	5.2	1.0	0.7
- 200 + 270	(-74 + 53)	9.2	4.3	2.5
- 270 + 325	(-53 + 44)	7.6	7.0	4.8
- 325	(- 44)	76.0	87.7	92.0
	Total	100.0	100.0	100.0
Surface area (cm^2/gm)		1500	2140	Not determined

3.1.2 Balling: Green balls were made from the original sample as well as from the ground products, using different dosages of bentonite in a 0.9 m disc pelletizer. In each case initially a very small quantity of material was put in the rotating disc and water sprayed on it by a sprayer to form seeds. After the seeds are formed, ground material and water in the form of spray were added alternatively until the seeds grew to the required size and developed adequate green strength. Then the disc was stopped and 40 pellets (9-15 mm size) from each batch were taken for evaluation of their quality in terms of drop number and crushing strength.

3.1.3 Quality Evaluation:

Drop Number: The drop number of green pellets was determined by dropping 20 balls from a height of 450 mm on to a steel plate until they showed cracks or crumbled. The number of drops withstood by the balls before breaking was noted and average of 20 noted values was taken as the drop number of a single pellet. This value is the measure of the ability of green balls to withstand drops encountered at conveyor belt transfer points in transit from balling to firing plant. The satisfactory values are 15 & 6 drops from heights of 300 mm & 450 mm respectively.

Crushing Strength: The average strength was determined by individually compressing 20 pellets on a 'Salter' top pan balance until they crumbled. The position of the indicator at which crumbling took place was noted and mean of the twenty readings was taken as the crushing strength of the green pellets. The crushing strength value of 1.8 to 2.3 Kg is considered satisfactory.

The feed size, bentonite quantity and quality evaluation results for different tests are presented in Table No.3.

TABLE NO. 3 .

Test No.	Conditions			Quality		
	Size (Mesh/ Tyler) -325 %	Blaine No Cm^2/gm	% Moisture required	% Bentonite	Crushing strength Kg/pellet	Drop Number (x from a height of 450mm
1				0.75	1.0	Nil
2	76.0	1500	7	1.00	1.0	Nil
3				1.50	1.2	1.0
4				0.75	< 2	6.4
5	87.7	2140	6	0.50	> 2	3.6
6	92.0	-	5	0.75	2.0	4.0

3.1.4 Discussions of the results of green pellets preparation

I) Results presented in Table No.3 indicate that as received smaple being coarse failed to produce green pellets of satisfactory strength even after employing 1.5% of bentonite as binder (test No.1,2 & 3)

II) The as received sample when ground to 87.7%-325 mesh size (Blaine No.2140 Cm^2/gm)needed 0.75% bentonite and about 6% moisture to produce green pellet of satisfactory strength (test No.4)

III) Pellets quality deteoriated when a very fine feed (92%-325 mesh) was used for pellet making, possibly due to inadequate water addition. It was decided to grind the as received sample to 87.7% - 325 mesh size, (Blaine No.2140 Cm^2/gm) and employ 0.75% bentonite for making green pellets for further test work.

3.2 Tests to ascertain Induration Cycle needed to produce fired pellets of desired quality:

Various induration tests were conducted on batches of 18-22 Kg green pellets, employing different induration cycles to select a Cycle suitable to produce fired pellets of desired quality. The details of Equipment used and procedure followed for induration of green pellets are as follows:

3.2.1 Equipment:

A pot grate of 500 mm (height) X 210 mm (dia) designed to simulate the straight grate pelletising system was used for induration of the green pellets. Though this equipment is meant to simulate the Dravo-Lurgi process with a green pellet bed height of 300 - 400 mm, in the present study only 150 - 200 mm bed heights were used mainly to conserve the limited quantity of sample available and thus to conduct as many tests as possible

for collecting the required data. The bed height used in this case are more or less similar to those employed in the Allis - Chalmers Grate - kiln system.

The schematic diagram of the pot grate simulation unit indegeneously fabricated and installed in IBM'S Pilot Plant is given at annexure - B. The main features of this unit are as follows:

(1) A horizontally mounted oil-fired burner (diesel oil used as fuel and air to support combustion) for producting hot gas.

(2) Regulated supply of ambient air into the burner-hood to control the temperature of heating gas during drying and preheating.

(3) Automatic control of differential pressure across the pellet bed by a pneumatic system.

(4) A Chimney over burnerhood for exit of excess hot gases and avoiding the possibility of explosion within the furnace.

(5) Temperature probe in burnerhood (T_3), connected to single point graphical recorder.

(6) Temperatures probes at two points, one close to the top of the bed and the other at the bottom of the bed immediately above the hearth layer (T_1 & T_2 in our case) connected to multipoint recorder to record temperature at different depths.

(7) Supply of constant volume of air to burner throughout the process to obviate frequent manupulations of air/fuel ratio.

(8) A U-bend with circular cross section to ensure smooth gas flow.

(9) Pneumatic lift arrangement for U-bends for making and breaking of gas seals.

(10) Quick pot rotation by pneumatic actuations to change gas flow directions.

3.2.2 Procedure: The dummy pots were placed under burnerhood and suction hood respectively. About 18-22 Kg of green pellets (bed-height = 150 -200mm) of satisfactory strength were placed in the pot over a hearth layer of 300 - 350 mm depth of fired pellets already placed over the grate bottom of the pot. Two platinum and platinum-rhodium thermocouples were introduced into the pellet pot; the first one (T_1) above hearth layer before putting green pellets and the second (T_2) over the top layer of green pellets. The burner was lighted and ambient air blower was switched on with its butterfly valve fully open. After stabiligation of flame (25-30 minutes) the pot under burnerhood was rotated by 120^0 on actuating pneumatic jack to bring the pellet pot under burnerhood for down-draught drying. The U-bend

was raised to effect gas-seal. Suction fan and temperature recorders were switched on and pressure controller was set at desired value. The valve in the ambient air supply was manipulated to control the drying temperature to avoid spalling of pellets. The drying was continuted for the required time. After completion of drying, the hot gas temperature was raised by gradual reduction in the input of ambient air. Preheating was conducted at desired temperatures for required time. After preheating the dilution air was cut off, the pressure controller set at desired higher level, if required and burner oil supply manipulated to attain the firing temperature. The firing was continued till T_1 and T_2 showed almost identical temperature. This temperature was maintained for required time to ensure complete firing of pellets. After completion of firing the burner was switched off, the U-bend lowered, pellet pot rotated and brought under suction hood for up draught cooling. The cooled pellets were unloaded by means of an electric hoist, and the pellets were evaluated for compression strength adopting the following procedure.

Compression strength: 30 pellets of 10 - 12 mm size were chosen from representative portion of pellets and then compressed separately between two parallel steel plates on a hydraulic press until they break. The indicator position at the breaking point was noted and average of 30 values was taken as the compression strength of pellet (Kg/pellet).

3.2.3 Results of Induration studies: The test conditions for various induration tests, visual observations made during test work and compression strength of fired pellets obtained from different tests are given in Table No. 4.

TABLE NO. 4 .

Test No.	Test Condi-tions	Stages of Induration				Comp-ression strength Kg/pellet	Observa-tion (Visual)
		Drying	Pre-heat-ing 1	Pre-heat-ing 2	Fir-ing		
1	△P	425-450	425-450	-	-	-	Pellets spalled
	T	220±20	700-800	-	-	-	Bed Chocked
	t	8	4				

Test No.	Test Conditions	Stages of Induration				Compression strength Kg/pellet	Observation (Visual)
		Drying	Pre heating	Pre heating	Firing		
2	△P	425-450	425-450	-	425-450	135	Pellet shelled Surface Cracks on pellets.
	T	130± 10	800	-	1230±10		
	t	11	4	-	8		
3	△P	425-450	425-450	-	425-450		Shelling of pellets Surfaces Cracks on pellets.
	T	130± 10	800	-	1230± 10	275	
	t	12	5	-	12		
4	△P	450-475	450-475	-	450-475	320	Less shelling some surface Cracks on Pellets.
	T	130± 10	800-850	-	1220± 10		
	t	12	10	-	15		
5	△P	425-450	425-450	425-450	425-450	160	Pellets Shelled surface Cracks on pellets.
	T	130± 10	800-850	1000	1220±10		
	t	8	4	3	10		
6	△P	450-475	450-475	450-475	450-475	325	Some surface Cracks on pellets.
	T	130± 10	800	1000	1220± 20		
	t	8	7	3	15		

Test No.	Test Condi-tions	Stages of Induration: Drying	Pre heating	Pre heat-ing	Firing	Comp-ression stren-gth Kg/pel-let	Obser-ation (Visual)
7	△P	250	250	250	375	240	Some shelling Occured
	T	130±10	800	1000	1220±20		
	t	7	7	3	5		
8	△P	300	300	400	500		No sur-face cracks
	T	130±10	700-750	1000	1220±20		
	t	8	8	3	12		
9	△P	450-475	450-475	450-475	450-475		Surface Cracks on pellets.
	T	130± 10	700-750	1000	1220±20		
	t	10	7	3	15		

△P : Pressure differential (mm of water) across the pellet bed.

T : Temperature in centrigrade

t : Time in minutes.

3.2.4 Discussions of induration results

1) Drying of green pellets at about 200°C (Test No.1) caused pellet spalling which presumably was due to rapid release of moisture from the balls. Therefore a lower drying temperature (130 ± 10°C) was employed to prevent the spalling of pellets.

2) When preheating time was short, pellets shelled appreciably (Test Nos. 2,3 & 5); therefore, attempts were made to prevent pellet shelling and spalling by maintainglow pressure drops across pellet bed and by raising the temperature gradually (Test No.8)

3) Two stage preheating, first at 700°C - 800°C for a few minutes and then at 1000°C for about 3 minutes adopted in some tests to prevent shelling of the outer layers of the pellets. It has been an established fact that maximum fired strength is developed on hematitie pellets during preheating at temperature of 1000-1100°C as indicated by results of test Nos. 6,7,8 & 9.

4) Prolonged firing was needed to ensure complete firing of the pellet upto the core and thereby to attain sufficient strength (Test Nos. 4,6 & 8).

5) When firing temperature rose above 1300°C surface cracks were seen on fired pellets (Test No.9).

6) The induration cycle which produced pellets of sufficient strength comprised of (i) Drying at about 120-140°C for eight minutes (ii) Two stage preheating, first at 700 - 750°C for eight minutes & then at 1000°C for three minutes. (iii) Finally firing at a temperature of 1200 - 1250°C for about twelve minutes (Test No.8). Maintaining low pressure drops across pellet bed during drying and preheating stages was found to be beneficial.

4.0 PRODUCTION OF FIRED PELLETS OF DESIRED QUALITY

Green pellets of satisfactory strength were made employing the conditions of test No.4, Table No.3 and fired pellets of desired quality produced employing the induration cycle of test No.8, Table No.4.

4.1 Quality Evaluation of fired pellets:

The fired pellets were tested for their Tumbler and Abrasion indices.

4.1.1 Tumbler and Abrasion indices:

15 Kg of + 8 mm size pellets were fed into a drum of 0.5 m length and 1.0 m diameter, the inside of which contained 2 lifters of 5 cm height. The drum along with the pellets was rotated at 25 ± 1 r p m for 200 revolutions.

Subsequently the tumbled product was screened to separate + 6.35 mm and - 0.5 mm fractions. The percentages of + 6.35 mm material and - 0.5 mm material gave the tumbler index and abrasion index of fired pellets respectively.

4.1.2 Characteristics of Fired Pellets

The characteristics of fired pellets produced are as follows:

1. Bulk Density	:	2.38 tonnes/cubic meter
2. Compression Strength	:	330 Kgs/pellet (Average)
3. Tumbler Index (+ 6.35 mm)	:	93.3%
4. Abrasion Index (-0.5 mm)	:	2.6%
5. Size composition:		
+ 15 mm	:	0.3 %
- 15 mm + 9.52 mm	:	98.5 %
- 9.52 mm + 6.35 mm	:	1.2 %

6. Chemical Analysis:

Constituent		%
Fe (T)	:	65.51
FeO	:	0.78
SiO_2	:	5.04
Al_2O_3	:	1.37
CaO	:	0.28
MgO	:	0.22
S	:	0.007
P	:	0.037

4.2 The pellets produced met the SIIL'S specifications in all respects and about 105 Kg of fired pellets of above characteristics was handed over to Sponge Iron India Limited.

5.0 CONCLUSIONS AND RECOMMENDATIONS:

1. The sample dry-ground to 87.7% - 325 mesh size (surface area of 2140 cm^2/gm) required about 0.75% bentonite and 6% water to produce green pellets of satsifactory strength (drop number : 6 to 7 and green compression strength of more than 2 Kgs).

2. The green pellets were heat sensitive and required a lower drying temperature (120-140°C) for removal of moisture from them.

3. The induration cycle whichproduced fired pellets meeting party's specifications, comprised of

(i) drying at a temperature of 130± 10°C for 8 mintues.

(ii) Two stage preheating, first at 700-750°C for 8 minutes and then at 1000°C for 3 minutes.

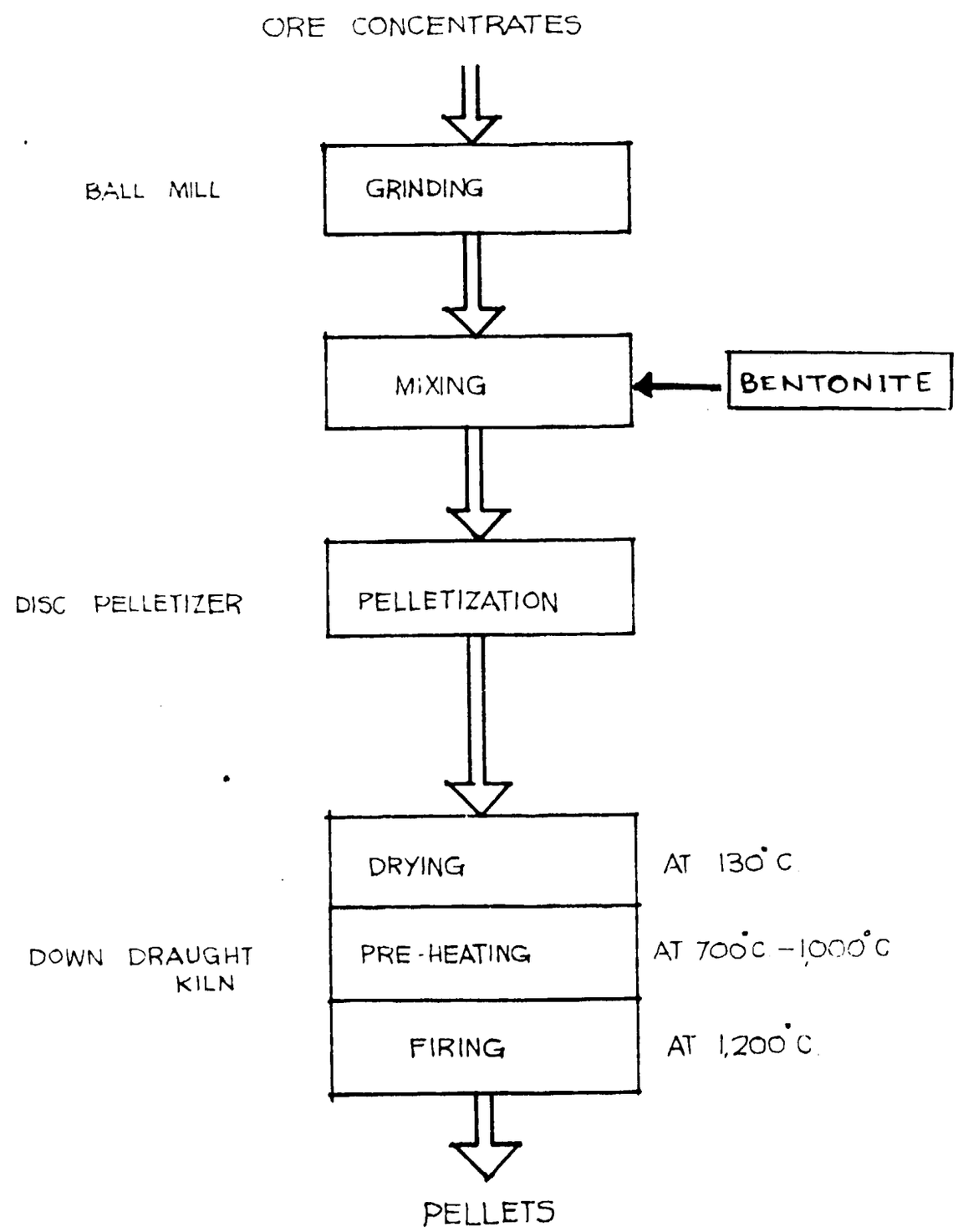
(iii) Firing at a temperature of 1200-1250°C for 12 minutes.

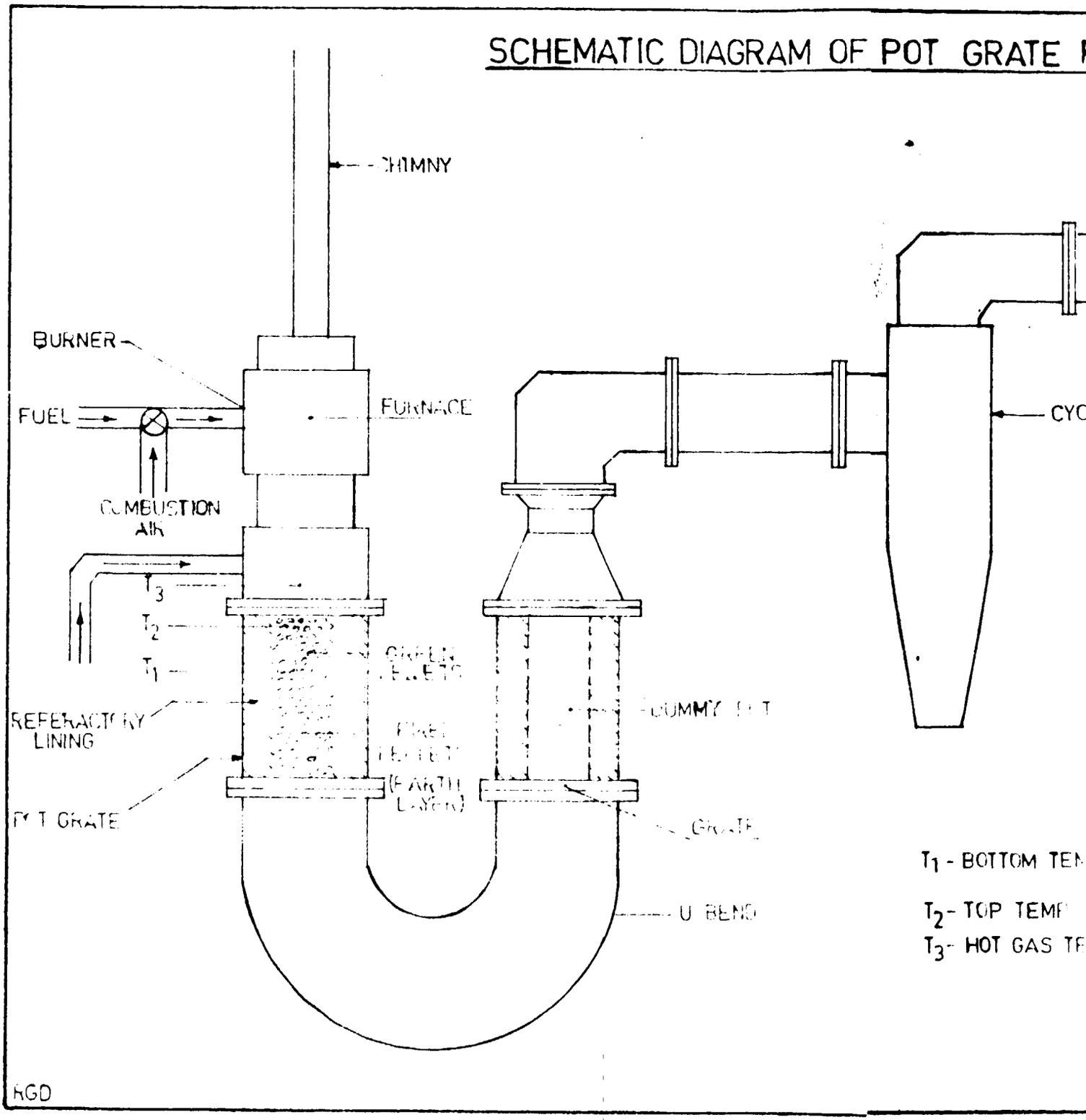
4. Short preheating time caused shelling while higher firing temperature (more than 1300°C) produced surface cracks on the pellets.

5. About 150 Kgs of fired pellets of desired quality was supplied to the party to enable them to conduct reduction tests in their laboratory.

6. In order to investigate the various pelletising parameters and optimise them, further work is called for on a larger sample of the concentrate.

FLOW SHEET FOR PELLETIZATION ANNEXURE - 'A'

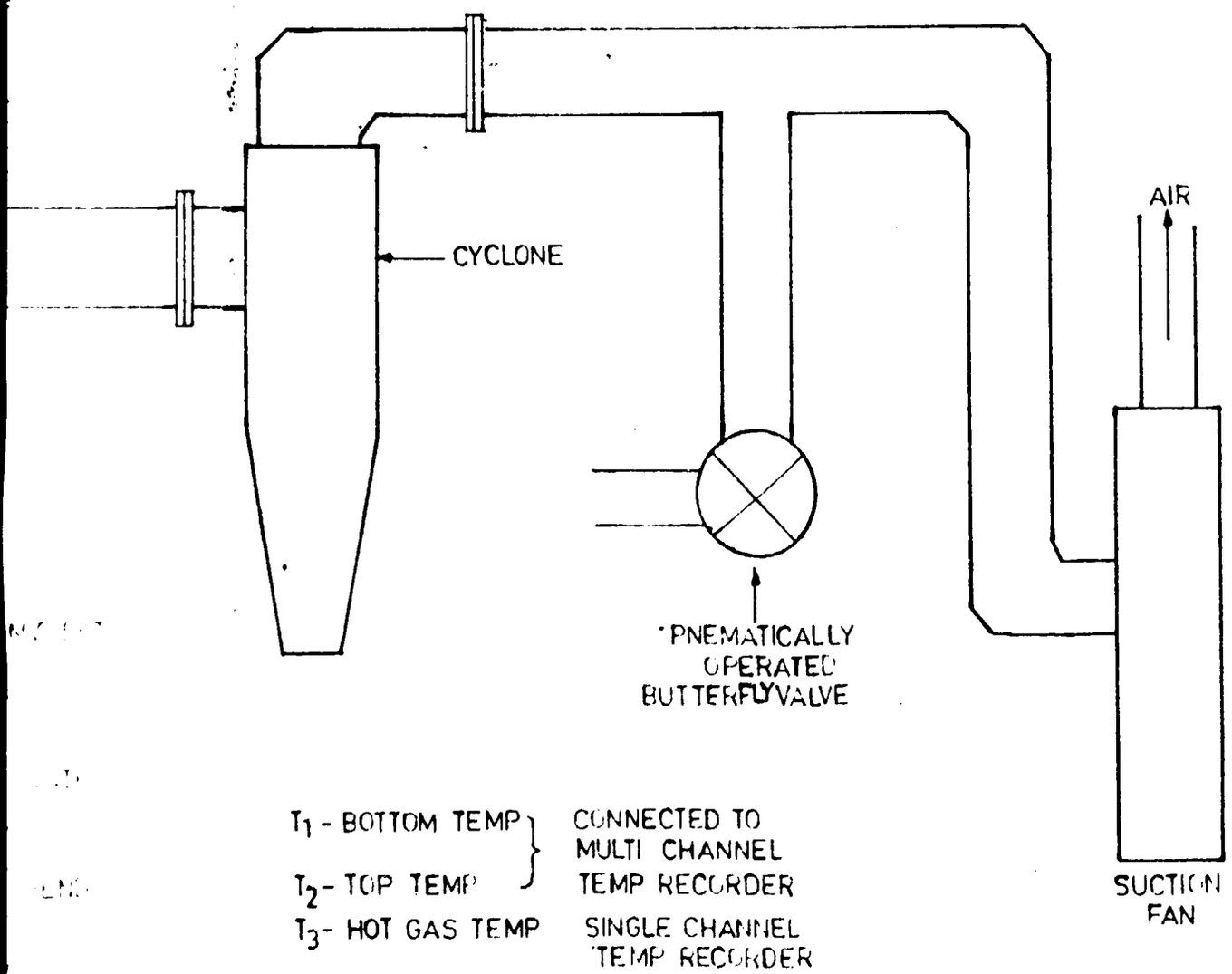



SCHEMATIC DIAGRAM OF POT GRATE
CHIMNY
BURNER
FUEL
FURNACE
CYC
COMBUSTION AIR
T_3
T_2
T_1
REFERACTORY LINING
DUMMY
POT GRATE
GRATE
U BEND
T_1 - BOTTOM TEM
T_2 - TOP TEMP
T_3 - HOT GAS TE
HGD

SECTION 1

ANNEXURE - B

AGRAM OF POT GRATE FURNACE



T_1 - BOTTOM TEMP } CONNECTED TO MULTI CHANNEL TEMP RECORDER

T_2 - TOP TEMP }

T_3 - HOT GAS TEMP SINGLE CHANNEL TEMP RECORDER

ANNEXURE - IV

SPECIFICATIONS OF RAW MATERIALS USED FOR REDUCTION TESTS

i) Iron Ore:

Constituents	Iron ore fines as received from Hungary	Concentrate after beneficiation at NMDC	Pellets made from Hungarian concentrate
Fe (T)	56.01	66.30	65.78
$SiO_2 + Al_2O_3$	18.08	5.05	5.44
CaO + MgO	0.75	N A	N A
L.O.I	0.82	0.31	0.11

ii) Hungary Coal:

Proximate Analysis

		Average Results
Volatile matter	=	11.20
Ash	=	15.10
Fixed Carbon	=	73.70
Sulphur	=	3.86

Ultimate Analysis:

Moisture	= 9.09
Ash	= 13.47
Carbon	= 69.71
H2	= 1.2
N2	= 1.03
Sulphur	= 2.43
O2	= 3.07

SAIL

Ash softening temperature studies

Intial deformation point	=	1230°C
Hemi spherical point	=	1300°C
Flow point	=	1330°C

iii) Singareni Coal

Proximate Analysis

Volatile matter	=	29.48
Ash	=	23.50
Fixed Carbon	=	47.02
Sulphur	=	0.8

BENCH SCALE RESULTS ON PELLETS MADE FROM HUNGARIAN ORE CONCENTRATE

1. Physical Tests

i) Screen Analysis:

Screen size mm	Weight Percent			
	Test 1	Test 2	Test 3	Average
(-20 + 15)	-	-	-	-
(-15 + 10)	90.52	92.20	93.28	92.0
(-10 + 8)	9.48	7.80	6.72	8.0
(-8 + 5)	-	-	-	-
-5	-	-	-	-
TOTAL	100.0	100.0	100.0	100.0

ii) Tumbler Test (As per ASTM or IGI Standard)

	Test -1	Test -2	Average
	%	%	%
Tumbler Index (+6.3 mm)	91.58	89.00	90.29
Abrasion Index (-0.5 mm)	4.42	5.83	5.13

ANNEXURE-V

REDUCIBILITY AND DECREPITATION RESULTS

1.0 CHEMICAL ANALYSIS OF THE PRODUCT

1.1 With Hungary Coal

Size mm	Test No.	Fe (T)	Fe (M)	Metn	C	S
-5	1	91.59	86.01	93.91		
	2	92.71	85.45	92.17		
	3	91.92	85.70	93.23		
	Ave	92.07	85.72	93.10	Average Carbon in the Sponge Iron : 0.25	Without Limestone : 0.27 (Av) With Limestone : 0.033(Av)
+5 to -10	1	94.93	88.80	93.10		
	2	93.83	87.13	92.86		
	3	93.97	87.88	93.52		
	Av	94.24	87.94	93.31		
+10 to -15	1	92.71	86.54	93.37		
	2	92.15	83.78	90.91		
	3	92.42	84.12	91.92		
	Av	92.44	84.82	91.76		

SIL

1.2 With Singareni Coal

Size mm	Test No.	Fe (T)	Fe (M)	Matn	C	S
-5	1	90.48	85.45	94.44	Average Carbon content in sponge iron : 0.15	Without Limestone : 0.04 (AV)
	2	89.36	83.21	93.12		
	3	90.05	83.91	93.18		
	AV	89.96	84.19	93.58		
+5 to -10	1	92.15	86.57	93.94		With Limestone : 0.027 (AV)
	2	88.80	79.59	89.63		
	3	89.99	84.81	94.24		
	AV	90.31	83.66	92.63		
+10 to -15	1	91.05	84.33	92.62		
	2	89.36	83.21	93.11		
	3	90.17	83.45	92.55		
	AV	90.19	83.66	92.76		

2.0 Decrepitation Behaviour During Reduction

Screen Size mm	Pellet feed for test	Screen Analysis after Reduction Test							
		Hungary Coal				Singareni Coal			
		1	2	3	Ave	1	2	3	4
(-15+10)	90.00	52.00	43.17	47.18	47.45	41.10	35.53	36.41	37.68
(-10+ 8)	10.00	25.33	21.22	23.47	23.34	23.97	32.93	28.47	28.45
(- 8+ 5)	-	9.33	10.79	10.11	10.08	8.90	7.80	7.12	7.94
(- 5+ 3)	-	6.00	10.00	9.17	8.39	14.38	13.65	14.41	14.15
(- 3+ 1)	-	3.33	5.72	3.37	4.47	4.79	3.90	7.11	5.26
(- 1)	-	4.01	9.10	6.70	6.27	6.86	6.19	6.48	6.52

Process Degradation Index

With Hungarian Coal	24.77
With Singareni Coal	30.12

ANNEXURE - VI

CHARGE FOR MELTING TRIALS

Heat Number	Sponge Iron		Scrap		Yield %
	Proportion %	Quantity Kg	Proportion %	Quantity Kg	
1	20	10	80	40	90.6
2	30	15	70	35	89.9
3	50	25	50	25	88.5

ANNEXURE - VII

CHEMICAL COMPOSITION OF TAPPED STEEL

Heat Number	Carbon	Sulphur	Phosphorus
1	0.22	0.032	0.046
1 A	0.26	0.034	0.046
2	0.41	0.038	0.049
3	0.24	0.038	0.048

SIL