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**DEVELOPMENT OF TECHNOLOGY FOR PRODUCTION OF  
SYNTHETIC RUTILE THROUGH DIRECT REDUCTION -  
MAGNETIC SEPARATION AND ELECTROSMELTING TECHNOLOGY**

UC/IND/87/146/11-52

INDIA

**Technical Report: Magnetic Separation of Ores/Minerals**

Prepared for the Government of India

by the United Nations Industrial Development Organization,  
acting as executing agency for  
United Nations Development Programs

Based on the work of Moon Kim  
Consultant

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United Nations Industrial Development Organization  
Vienna

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## I. ABSTRACT

Title and Number of the Project: Consultant in magnetic separation of ores/minerals, UC/IND/87/146/11-52.

Objective and Duration of the Activity: Technical assistance in the investigation of a process for the production of synthetic rutile from ilmenite by adopting direct reduction-magnetic separation and smelting techniques. The project was originally to be carried out in collaboration with a metallurgical consultant in reduction techniques for the period of one and a half months, but the duration of the project was reduced to three weeks including travel time, preparation of final report, and without collaboration of the pyrometallurgist.

Main Conclusions:

1. There were no proper high intensity magnetic separator, adequate sampling equipment, process mineralogical facilities, nor other auxiliary equipment and apparatus, etc. at the site (laboratory and plant, Paloncha).
2. There were no process mineralogist to undertake process mineralogical examinations of the feed and the test products.
3. In spite of the lack of the above items, the consultant conducted some of the process investigations on the products of direct reduction of ilmenite ores, by the application of sizing and differential magnetic separation (using the crossbelt magnetic separator at the P.G. Centre, Osmania University, Kothagudem, which was, however, not properly equipped). Most of the results of assay and X-ray diffractometer analysis have not yet been reported to the writer.

4. There is no conclusion on the process investigation because of lack of information and data on the test results.

**Recommendation:**

Based on the observation and information/data obtained, the following items are recommended.

1. In order to separate iron values effectively from titanium values, high metallization of iron and prevention of reoxidation of iron and titanium values should be achieved during the direct reduction of ilmenite concentrates and the cooling stages.
2. For the determination of liberation sizes of iron and titanium values, process mineralogical examinations and/or sizing and assay tests with heavy liquid separation should be carried out.
3. After all the machines, equipment, and facilities are properly secured, and the works described above, 1 and 2 conducted, three stage systematic and sequential process investigation can be carried out on the products of direct reduction of ilmenite concentrates by the application of differential magnetic separation, followed by chemical assays and mineralogical studies and/or X-ray diffractometer analysis, etc..
4. Based on the metallurgical criteria obtained from the tests, it can be determined whether this process is feasible both technically and economically.

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### III. INTRODUCTION

This report was written by the consultant who conducted this work to assist the counterpart, Sponge Iron India Limited, in Hyderabad (Headquarter) and Paloncha, Andhra Pradesh, technically, in the investigation of a process for treating the product of direct-reduction of ilmenite by magnetic separation.

The objective of this project entailed conducting tests for the separation of metallic iron values from titanium values. Therefore, items number 1 and 2 of the original job description was excluded (see Appendix 1).

In order to avoid a wasting of the iron content in ilmenite and the significant environmental hazards from conventional processing, the process technology of separation of reduced metallic iron from titanium value should be developed for further processing of either leaching or electrosmelting. This process may be achieved by the application of differential magnetic separation on the direct-reduction products.

If the reduced metallic iron is completely free from other minerals and materials, the highly magnetic susceptible metallic iron particles can be collected in the magnetic portion at low magnetic intensity application. But in practice, due to finely disseminated metallic iron values in other materials, and some in unreduced state, it is rather difficult to decide the right size of the grain liberation for economic separation. Furthermore, the unreduced iron and/or reoxidized iron and titanium values in the products can not be separated from other materials at low magnetic intensity application only. This requires application of high intensity magnetic separation for the removal of the other iron values from other materials (mainly titanium values, if negligible or very small amounts of other impurities presented in the products).

Due to lack of the facilities and manpower (suitable high intensity magnetic separator, instruments, process mineralogist, etc.) around the areas of Paloncha and Kothagudem, the consultant was not able to fully achieve the original goal.

Initially, process mineralogical examination on the products from the direct reduction was to be conducted for the identification of the composed minerals and materials, their liberation sizes, association states, and volumes (or surface areas) of each component materials, etc.. However, no capable mineralogist nor instrument was found in the areas of Paloncha and Kothagudem, after several days of visiting and discussions of the works with the Osmania University in Kothagudem.

In order to find out the liberation sizes of the constituent minerals in the products of direct reduction and for the separation of iron values and other impurities from  $TiO_2$  values, both sizing and assay and differential magnetic separation methods were to be applied.

Although no test on the reduced ilmenite samples was conducted by proper test facilities and without mineralogical studies, the test result could expect some indication and/or clue as to the suitable treatment of the direct reduction product. The result of most of the chemical assay and X-ray diffractometer analysis on the test products are, however, still pending.

#### IV. ACTIVITIES, FINDINGS AND CONCLUSION

The consultant had a strong impression that the counterpart, Sponge Iron India Limited had already a number of years of good experience in commercial operation of direct reduction of iron ores, and had also recently conducted a bench scale of direct reduction of ilmenite concentrates in a laboratory scale rotary kiln.

The staff of the plant laboratory mentioned that the metallization of iron was 88.7% in the product of direct reduction of ilmenite concentrates (refer to Table 1.1. and 1.1.A. Appendix).

One of the staff metallurgists said that the separation of reduced iron from carbon and titanium values were not achieved. This was probably caused by the non-liberation of metallic iron particles in the product of direct reduction and/or by the reoxidation of the products during the reduction and cooling.

Therefore, the main objective of the work was, firstly, to find out the liberation sizes of reduced iron, of titanium materials, of impurities, other unreduced iron and/or reoxidized iron and titanium values (if any), and also the ratio of the composed materials, etc., secondly, to separate the iron values and possibly also impurities effectively from titanium values.

Initially, to carry out this testwork, process mineralogical examination should have been carried out in order to find out the items No. 1, above, unfortunately there was no capable mineralogist found in the areas of Paloncha and Kothagudem.

For the effective separation of iron values and other impurities from titanium values, high intensity magnetic separation in either dry or wet process was to be applied, depending upon the grain sizes treated. Only dry crossbelt magnetic separator with damaged main belt and no indication of magnetic strength by electric current applied was available at the P. G. Centre, Osmania University, Kothagudem.



Despite the unfavorable condition for testing, both sizing and assay and the high intensity magnetic separation (by the application of a few different magnetic strengths) were conducted on the two sample products of direct reduction of ilmenite concentrates. The tested products selectively sampled were subjected to chemical and X-ray diffractometer analyses.

The chemical analysis on the test products was required at the plant research laboratory in Paloncha. The geochemical Department of Osmania in Hyderabad and Inorganic Chemistry Division laboratory, Indian Institute of Chemical Technology, Hyderabad were requested to do X-ray diffractometer analysis on ten samples each from the magnetic separation test. Some results were received by the writer (refer to tables 1.1.A., 1.3.B. and 4, Appendix).

Most of the analyses on the test products are still pending.

In addition to the training of the local technical staff in conducting the tests, a lecture of the methodology and systematic management of the process investigation was presented. The attendants of the lecture were 7 staff members who were mainly involved in research and development work and the key personnel of the plant site.

### Findings:

Test results obtained showed that:

1. Sizing test (Refer to table 2. Sizing test, Appendix):

A. The feed size of the ilmenite concentrates to the test kiln was minus 500 microns, but about 20% by weight of the product from the direct reduction test of ilmenite was the grain sizes of plus 500 microns, which might be mainly carbon materials.

B. About two thirds of the products were in the size ranges of -500+150 microns.

2. Magnetic separation test:

A. The first magnetic product (the lowest magnetic intensity applied) of -150+89 micron sized fractions was less weight than that of -300+212 and of -212+150 micron sized fractions (see Table 3.2.D., Appendix).

B. About 95% of iron values was collected in the magnetic portions by the crossbelt magnetic separation at 1 ampere and 25 voltages applied (see the Table 5.3.2.E. Accumulated % Fe Distribution in Mag-3 products, Appendix).

C. Because of the damaged main belt of the separator, the weight loss during the magnetic separation was 1.13% - 8.22%, 3.22% - 7.87%, and 6.61% - 11.58% of the feed, for the sized fractions of -300+212 micron, -212+150 microns, and -150+89 microns, respectively. Refer to Table A, B, and C of 3.2., Loss %, Appendix .

3. X-ray diffractometer analysis:

A. In the non-magnetic portion of -150+89 micron sized fractions applied at 2.8 amperes and 75 volts, there were mainly pseudo-brookite and pseudo-rutile, and some amounts of  $TiO_2$  (high pressure modification ?) or beta- $TiO_2$ , carbon, coesite ( $SiO_2$ ), and alpha-iron. The reasons for the high magnetic susceptible materials, such as pseudo-brookite, pseudo-rutile, and alpha iron in the final non-magnetic portions, were unclear. The presence of these materials may be due to: an inefficient and ineffective separation by improper feeding mechanism, or an admixture of titanium and iron values with low or non-magnetic materials (ie. silicates, carbon, etc.), or a higher magnetic intensity required for the separation of titanium values from other impurities.

B. There was no carbon shown in the reduced ilmenite product (DRI-II, composite sample) by XRD analysis. However, with bare eyes, it could be easily recognized that most of the relatively coarse sizes of grains were likely carbon materials with some inclusions of other materials.

Conclusion:

Because of lack of most of the data and information from the results of chemical and X-ray diffractometer analyses, the consultant was unable to analyze the testwork done and the metallurgical investigation for the separation of iron from titanium values. At the moment, no concrete conclusion has been reached yet, however, some of the following points have been concluded:

1. To separate metallic iron values effectively from the titanium values by magnetic separation, minimization of unreduced iron and prevention of reoxidation of iron and titanium values must be achieved during the reduction and cooling stages.
2. Even the size of -150+89 microns (around -100 mesh) was seemingly not fine enough to be liberated for the iron and titanium particles. Refer to the identifications of alpha-iron, pseudo-brookite, and pseudo-rutile in all of the products, from Magnetics-1 through non-magnetic portions of -150+89 micron sized fractions, Table 4, Appendix).

3. Without mineralogical examination before and after the testwork, test process and the results were not certain for the right direction of the investigation.

4. Improper feeding of the samples to the magnetic separator, adamaged belt and no indication of the magnetic intensity caused inefficient and inaccurate separation.

5. Without knowledge of the magnetic flux density applied, the monitoring and management of the testwork rather uncertain for the differential magnetic separation.

6. In general, the testwork and some of the results reported were not satisfactory due to the lack of the proper equipment, facilities, and mineralogical examinations. The tests were conducted only to give some indication and/or clue for future tests.

#### IV. RECOMMENDATION

Based on the observations, experimental work, and information obtained, the consultant recommends Sponge Iron India Limited to execute the following items 1 through 9:

1. Forward results of the chemical and X-ray diffractometer analyses to the consultant as soon as possible.

Chemical assays of iron on ten samples and of  $TiO_2$  on two were received, whereas only three X-ray diffractometer analyses were reported out of the twenty samples requested for.

2. The following equipment, machines and facilities should be arranged for a test run in the near future.

-Sample splitter (riffle type, large to microsize, 1/8" width)

-Vibrating feeder for high intensity magnetic separator

-Gauss meter; with digital window and probe (automatic calibration)

-High intensity magnetic separator (either dry or wet type, depending on the feed size)

-Other auxiliary equipment and apparatus.

3. Hire a capable process mineralogist who is expertly knowledgeable, and able to conduct process mineralogical examination for future work.

4. Upon the completion of the results from the last test analyzed, conduct a series of the test runs at least three to five times (at a very preliminary stage) by differential magnetic separation on the product from direct reduction of ilmenite concentrates.

5. Carry out another series of the test runs based on the result of the above tests (item 4), in order to remove iron values and other impurities from titanium values in the products.

6. If unfavorable problems are caused by the reduction process (ie. unreduced iron values and/or reoxidation of iron and titanium values), investigate the conditions and parameters of the direct reduction of ilmenite concentrates, and then correct the operation of the reduction test for maximum and economic recovery of iron and titanium values by differential magnetic separation.

7. Conduct more tests of differential magnetic separation on the product of direct reduction of ilmenite concentrates for determination of effective and optimal process conditions.

8. Review all the data obtained from the above tests, and determine whether the separation process is feasible technically and economically to avoid a waste of metallic iron values and enrich titanium values, and to properly exclude possible hazardous problems for further processing.

9. In order to carry out these test programs, the Sponge Iron India Limited hire outside consultant, if necessary.

10. The consultant also suggests that:

A. U.N.I.D.O. urge the supplier of 75 kva electric submerged arc furnace to send all the necessary materials, information and other pertinent data on commissioning and operation to the Sponge Iron India Limited as soon as possible.

B. U.N.I.D.O. reconsider the supply a high intensity magnetic separator:

Type: Dry high intensity magnetic separator (crossbelt or induced roll) Range of magnetic strength: 0 to 20 Kilogauss

The counterpart informed the consultant that the high intensity magnetic separator was originally to be supplied as a part of the project.

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1. **JOB DESCRIPTION**  
UC/IND/87/146/11-52

**Post title** Consultant/Expert in Magnetic Separation of Ores/minerals

**Duration** ~~1-5 months~~ 3 weeks

**Date required** As early as possible

**Duty station** Kothagudem/Hyderabad with travel within the country

**Purpose of project** Technical assistance in the investigation of a process for production of synthetic rutile from ilmenite by adopting direct reduction - magnetic separation and smelting techniques.

**Duties** The Consultant/Expert will be required to work in collaboration with a Metallurgical Consultant/Expert in reduction techniques (11-51) and undertake the following:

- (1) Examine various methods of and selection of an optimum method for the preparation of ilmenite and coal to render them suitable for direct reduction tests in a rotary kiln.
- (2) Conduct various tests in reduction of ilmenite with coal in a rotary kiln for determining optimum parameters for reduction.
- (3) Examine suitable methods for the liberation of the product of reduction as in (2) above in order to separate individual mineral entities by differential magnetic separation.
- (4) Conduct various tests in differential magnetic separation on the product of reduction and determine the optimum parameters for separation.
- (5) Train the local technical staff in conducting tests as in (1) to (4) above.



## 2. People Met

### 2.1. Counterpart staff:

-Mr. Chiranjiv Singh, Chairman and Managing Director, Hyderabad

-Mr. K. P. Patnaik, Chief General Manager, Hyderabad

-Mr. K.S.N. Murthy, Chief Works Manager, Paloncha

-Mr. J.M. Reddy, Deputy Manager, Hyderabad

-Mr. K. Suryanaryana, Personnel Manager, Paloncha

-Mr. G. V. Subramanyam, In charge of R/D, Paloncha

-Mr. V.B.S. Sastry, Chemist, R/D, Paloncha

-Mr. Chirra L. Nath, Metallurgist, Paloncha

-Mr. Korlagani Hari Kishan, Assistant Engineer, Hyderabad

-Mr. K. Sreenivasa Reddy, Assistant Engineer, Paloncha

### 2.2. Other people:

#### A. Osmania University

At P.G. Centre, Kothagudem campus,

-Mr. A.A. Moiz, In Charge of the Centre

-Mr. R. Pavanaguru, Geology Dept.

-Mr. D. Chandrasekhar, In Charge of the Laboratory

At Hyderabad campus,

-Mr. K. Surya Prakash Rao, Head of Applied Geochemistry

#### B. Indian Institute of Chemical Technology, Hyderabad,

-Mr. P. Kanta Rao, Deputy Director & Head, Inorganic Chemistry Division

### 3. Visits

#### 3.1. Hyderabad

-On the first day in Hyderabad, at headquarter office of the Sponge Iron India Limited (S.I.I.L.) located at Khanij Bhavan, 6th floor, Castle Hill, Masab Tank, met Messrs. Singh, Patnaik, and Reddy, the company chairman, Chief General Manager, and Deputy Manager, respectively, and discussed the objective of the work and itinerary.

-After returning to Hyderabad from Paloncha and Kothagudem, visited Dr. S.P. Rao, Head of Applied Geochemistry and his staff, at Osmania Univeristy campus and Dr. P.K. Rao, Deputy Director, and his staff, at the Indian Institute of Chemical Technology, to discuss the possibility of their services (X-ray diffractometer and electron microscanning analyses) and utilization of the equipment and facilities (high intensity magnetic separator, etc.).

-On the final day in Hyderabad, discussed with the staff of the company as to the work done in Paloncha, Kothagudem and Hyderabad, and made the recommendations.

#### 3.2. Paloncha and Kothagudem

-The plant site is in Paloncha. 350 km away from Hyderabad.

After reviewing and observing the facilities at the plant and laboratory, found that there were no proper facilities of high intensity magnetic separation, mineralogical examination, nor a process mineralogist at the plant laboratory. Therefore, start to search other places for a capable mineralogist and high intensity magnetic separator for conducting the testwork.

-The plant staff led a visit to the P.G. Centre & School of Mines, Osmania university's Kothagudem campus. Visited Dr. Moiz and his staff at the Centre, and discussed any possible services of the campus staff as to the process mineralogical examinations of the test products, and also the use of the high intensity magnetic separator at

the mineral dressing laboratory. After several days, only found a possible utilization of

crossbelt magnetic separator which was, however, neither in good condition nor with indication of the magnetic strength to run the test.

-The magnetic separator was the sole high intensity magnetic separator available in the site area for the differential magnetic separation. Therefore, during the final two days in the site, differential magnetic separation tests were carried out on the sized products of the reduced ilmenite concentrate (direct reduction of the ilmenite concentrate in the laboratory scale rotary kiln).

-During the stay in Paloncha, in addition to the training of the technical staff on the test, a lecture on the methodology and systematic management of the testwork was given for the plant and laboratory staff. Particularly, sampling, process mineralogy, and the proper way of testwork were emphasized in the lecture.

#### 4. Main Facilities used for the Test

(at S.I.I.L.'s Paloncha plant and Osmania University's Kothagudem campus)

A. Laboratory rotary kiln, equipped at plant laboratory, was German made and supplied by U.N.I.D.O.. The ore sample charge was 1 kg.

B. High Intensity Magnetic separator, crossbelt type, at Osmania University's Kothagudem campus, was supplied by local manufacturer, Mineral Processing Equipment Private Limited, Bombay. The type and Series No.: MS 12.1, MEO-M112. The width of main belt was 10 cm. its speed was constant, around 6.3 mpm. The surface of the belt was damaged on the center part. The width of crossbelt was 7 cm. One of two crossbelts (second) was not in working condition. The gap between main belt and crossbelt was 10 cm.

5. Tables

1. Chemical Analysis

1.1. Feed and the Product of Direct Reduction of Ilmenite

	<u>Ilmenite Concentrate</u>	<u>Reduced Ilmenite**</u>
% T. Fe	28.48	34.63
% Met. Fe		30.72*
% Fe ++	14.52	3.35
% FeO	18.67	4.31
% Fe +++	13.96	0.56
% Fe <sub>2</sub> O <sub>3</sub>	19.96	0.80
% TiO <sub>2</sub>	55.98	58.49
% SiO <sub>2</sub>	1.80	2.34
% Al <sub>2</sub> O <sub>3</sub>	1.00	1.20
% CaO	0.25	0.35
% MgO	0.45	0.55
% P	0.012	0.027
% S	0.006	0.026
% C		?

\* Metallization: 98.71%

\*\* The material doesnot seemed to be identical to the ones tested for magnetic separation

1.2. Reductant (Leco Coal)

A. Dry Basis (%)

Moisture: 8.0  
 V. M. : 20.0  
 Ash : 7.0  
 Fixed C: 73.0

B. Calorie Value:

Gross: 7024.45 cal/gm  
 Net : 6682.33 cal/gm

C. Ash Analysis (%):

SiO : 42.56  
 Al<sub>2</sub>O<sub>3</sub> : 38.81  
 Fe<sub>2</sub>O<sub>3</sub> : 11.98  
 CaO : 10.75  
 MgO : 1.05  
 S : 1.10

1.1.A. Chemical Analyses on Ilmenite Concentrate  
and Reduced Ilmenite

Ilmenite

Reduced Ilmenite

Fe (T)	28.48
Fe ++	14.52
FeO	18.67
Fe <sup>3+</sup>	13.96
Fe <sub>2</sub> O <sub>3</sub>	19.96
TiO <sub>2</sub>	55.98
SiO <sub>2</sub>	1.8
Al <sub>2</sub> O <sub>3</sub>	1.0
P =	0.012
S	0.006
CaO =	0.25
MgO =	0.45

34.9	34.63
2.52	34.63
3.24	4.0
0.87	0.0
1.24	0.0
57.19	5.0
2.34	2.0
1.2	1.0
0.027	0.0
0.026	0.0
0.35	0.0
0.55	0.0
<hr/>	
Fe	30.72

Fe (T) = 34.63  
 Fe (M) = 30.72  
 mil = 88.7

### 1.3. Products of Magnetic Separation

#### A. Reduced product-II

	<u>% T. Fe</u>	<u>% Met. Fe</u>	<u>% TiO<sub>2</sub></u>	<u>% C</u>
<u>-150+89</u>				
Mag-1	32.39	29.60		
Mag-2	30.44	27.38		
Mag-3	30.44	26.80		
Non-Mag.	9.77	5.585		
<u>-212+150</u>				
Mag-1	32.39	30.72		
Mag-2	31.83	29.04		
Non-Mag.	3.35	1.12		
<u>-300+212</u>				
Mag-1	32.95	30.72	59.90	
Mag-2	31.83	29.32	27.70	
Non-Mag.	4.47	1.12		

\* Analysis of TiO<sub>2</sub> and carbon are still pending

#### 2. Sizing Test

Sizes,	Feed to the kiln		Reduced Product I		Reduced Product II	
	Weight Grams	%	Weight Grams	%	Weight Grams	%
+1000	-	-	116	19.02	171.79	14.09
-1000+850	-	-	6	0.98	21.65	1.78
-850+710	-	-	10	1.64	32.98	2.70
-710+500	1	0.15	14	2.30	33.85	2.78
-500+300					81.98	6.64
-300+212	385 <sup>a</sup>	57.04 <sup>a</sup>	346 <sup>a</sup>	56.72 <sup>a</sup>	275.75	22.61
-212+150	168	24.89	65	10.66	439.97	36.07
-150+106	117	17.33	43	7.05		
-106+75	4	0.59	4	0.65	143.93 <sup>c</sup>	11.80 <sup>b</sup>
-75	-	-	6	0.98	18.70	1.53
Total	675	100.00	610	100.00	1219.60	100.00

\* a: In the size ranges of -500+212 microns

b: In the size ranges of -150+ 89 microns

<u>+ 89 Microns</u>		<u>- 210 + 150 Microns</u>		<u>- 300 + 210 Microns</u>	
Ref:		Ref:		Ref:	
0.3	Fe(T) = 32.39 Fe (Met) = 29.60 Met = 91.39	0.3	Fe(T) = 32.39 Fe (Met) = 30.72 Met = 94.84	Mag. - I	Fe(T) = 32.95 Fe (M) = 30.72 Met = 93.22
0.5	Fe(T) = 30.44 Fe (Met) = 27.38 Met = 89.90	0.5	Fe(T) = 31.83 Fe (Met) = 29.04 Met = 91.24	Mag. - II	Fe(T) = 31.83 Fe (Met) = 29.32 Met = 92.12
1.0	Fe(T) = 30.44 Fe (Met) = 26.80 Met = 88.06	Non-Mag.	Fe(T) = 3.35 Fe (Met) = 1.12 Met + 33.34	Non-Mag.	Fe(T) = 4.47 Fe (Met) = 1.12 Met = 25.05
Non-Mag.	Fe(T) = 9.77 Fe (Met) = 5.585 Met = 57.16				

1. TiO<sub>2</sub> and Carbon are being analysed.
2. Results of the some fractions could not be analysed as the samples given are too small in quantity which can not be ground and analysed.

### 3. Magnetic Separation Test

#### 3.1. With Reduced Product I

Electricity applied	+1000 Product gm. %	-400+300 gm. %	-300+212 gm. %
0.3 A & 6 V Mag.		4.5 54.22	
0.5 A & 10 V " N-Mag.	?	0.4 4.82	
1.0 A & 25 V Mag.	?	3.4 40.96	15 58.18
" " " N-Mag.	10.4+		7 31.82
Total		8.3 100.00	22 100.00

#### 3.2. With Reduced Product II

##### A. -300+212 micron sized fraction

Product \ Amp	0.3	0.5	1.0	1.5	2.0	3.0
Volt	6	8	22	35	48	75
Magnetic, gm	49.53	15.48	3.26	1.21	0.53	0.26
Non-Mag. gm	32.23	14.10	9.70	7.93	7.31	6.76
Total gm	81.76	29.58	12.96	9.14	7.84	7.02
Loss, gm		0.65	1.14	0.57	0.09	0.29
%		8.22	8.09	5.88	1.13	3.97

##### B. -212+150 micron sized fraction

Product \ Amp	0.3	0.5	1.0	1.5	2.0	3.0
Volt	6	10	25	37	50	75
Magnetics, gm	83.76	24.32	7.13	1.71	0.43	0.45
Non-Mag. gm	46.06	18.17	9.61	7.38	6.50	5.80
Total gm	129.82	42.49	16.74	9.07	6.93	6.25
Loss, gm		3.57	1.41	0.54	0.43	0.25
%		7.75	7.87	5.62	5.34	3.85



C. -150+89 micron sized fractions

Product \ Amp.	0.3	0.5	1.0	1.5	2.0	3.0
Volt	6	10	25	37	50	75
Magnetics, gm	16.15	7.33	5.58	0.35	0.31	0.18
Non-Mag. gm	20.73	11.00	4.38	3.63	3.08	2.64
Total gm	36.88	18.33	9.96	3.98	3.39	2.82
Loss, gm		2.40	1.04	0.40	0.24	0.26
%		11.58	9.45	9.13	6.61	8.44

D. Summarized (A through C)

Electricity applied	Product	-300+212		-212+150		-150+89	
		gm.	%	gm.	%	gm.	%
0.3 A & 6 V	Mag-1	49.53	64.30	83.76	67.77	16.15	49.63
0.5 A & 10 V	" 2	15.48	20.10	24.32	19.68	7.33	22.53
1.0 A & 25 V	" 3	3.26	4.23	7.13	5.77	5.58	17.15
1.5 A & 35 V	" 4	1.21	1.57	1.71	1.38	0.35	1.08
2.0 A & 50 V	" 5	0.53	0.69	0.43	0.35	0.31	0.95
3.0 A & 75 V	" 6	0.26	0.34	0.45	0.36	0.18	0.55
" " "	N-Mag.	6.76	8.77	5.80	4.69	2.64	8.11
Total		77.03	100.00	123.60	100.00	32.54	100.00

E. Distribution of iron values in the products

	Mag-1	Mag-2	Mag-3	Mag-4	Mag-5	Mag-6	N-Mag
<u>-150+89</u>							
% wt.	49.63	22.53	17.15	1.08	0.95	0.55	8.11
% I.Fe	32.39	30.44	30.44	N.A.	N.A.	N.A.	9.77
% Fe Dist'n	54.09	25.00	17.56	1.09*	0.96*	0.55*	2.67
Acc. " "	54.09	77.17	94.73	95.82	96.78	97.33	100.00
<u>-212+150</u>							
% wt.	67.77	19.68	5.77	1.38	0.35	0.36	4.69
% I.Fe	32.39	31.83	N.A.	N.A.	N.A.	N.A.	3.35
% Fe Dist'n	71.43	20.38	5.63	1.35*	0.34*	0.35*	0.52
Acc. " "	71.43	91.81	97.44	98.79	99.14	99.48	100.00

-3008212

% wt.	64.30	20.10	4.23	1.57	0.69	0.34	8.77
% T.Fe	32.95	31.83	N.A.	N.A.	N.A.	N.A.	4.47
% Fe Dist'n	70.56	21.31	4.23*	1.57*	0.69*	0.34*	1.30
Acc. " "	70.56	91.87	96.10	97.67	98.36	98.70	100.00

\* Calculated figures based on the assumption of 30% Fe (arbitrary figures).

4. X-ray Diffractometer Analysis

mlh

6/14/92

<u>S.No.</u>	<u>Name of the sample</u>	<u>Name of the constituents with the JCPDS X-ray Powder data file Nos.</u>
1.	DRI-II -150+89M (non Mag.)	1. Pseudo-Brookite:9-182 (Fe <sub>2</sub> TiO <sub>5</sub> ) Major 2. Pseudo-Rutile :19-635 (Fe <sub>2</sub> Ti <sub>3</sub> O <sub>9</sub> ) 3. Trace of Microcline:22-675 4. Coesite (SiO <sub>2</sub> ) :14-654 5. TiO <sub>2</sub> (High pressure modification) or B-TiO <sub>2</sub> 21-1236 or 23-1446 6. Carbon:20-1079 7. α-Fe 6-698.
2.	DRI-II H/ al (composite)	1. α-Fe : 6-696 Major 2. Pseudo-Rutile:19-635 Major (Fe <sub>2</sub> Ti <sub>3</sub> O <sub>9</sub> ) 3. Trace Na Al Si <sub>3</sub> O <sub>8</sub> :20572 4. Pseudo-Brookite:9-182 Major (Fe <sub>2</sub> TiO <sub>5</sub> )
3.	DRI-II 150 + 89 M Mag-1	1. α - Fe : 6-696 2. Pseudo Brookite : -9-182 Fe <sub>2</sub> TiO <sub>5</sub> 3. Pseudo Rutile:19-635 (Fe <sub>2</sub> Ti <sub>3</sub> O <sub>9</sub> ) 4. Trace of Albite, 30 572 (Na Al Si <sub>3</sub> O <sub>8</sub> )

Rec'd 7/1/92

- |     |                                    |  |
|-----|------------------------------------|--|
| 4.  | DRI-II<br>-150+ 89 M<br>Mag -2     | 1. $\alpha$ - Fe : 6-696<br>2. Pseudo-Brookite:9-182<br>3. Pseudo-Rutile:19-635<br>4. Trace of Albite:20-572<br>(Na Al Si308)<br>Coesite 14654             |
| 5.  | DRI 2<br>-210+150 HYD              | 1. $\alpha$ - Fe:6-696<br>2. Pseudo-Brookite:9-182<br>3. Pseudo-Rutile:19-635<br>4. Trace of Albite:20-572   |
| 6.  | DRI - II<br>-150 + 89 M<br>Mag - 3 | 1. $\alpha$ - Fe : 6-696<br>2. Pseudo-Brookite:9-182<br>3. Pseudo- Rutile :19-635<br>4. Trace of Albite : 20-572<br>(Na Al Si308)                          |
| 7.  | DRI-II<br>-150+89 M<br>Mag-4       | 1. $\alpha$ - Fe:6-696<br>2. Pseudo-Brookite . 9-182<br>3. Pseudo-Rutile:19-639<br>4. Trace of Coesite (SiO2)<br>: 14-654<br>5. Albite(Na Al Si300),20 572 |
| 8.  | DRI-II<br>-150+89M<br>Mag-5        | 1. $\alpha$ -Fe:6-696<br>2. Pseudo-Brookite:9-182<br>3. Pseudo Rutile:19-639<br>4. Trace of Albite : 20-572<br>(Na Al Si308)                               |
| 9.  | DRI-II<br>-150 + 89 M<br>Mag -6    | 1. $\alpha$ - Fe:6-696<br>2. Pseudo-Brookite:9-182<br>3. Pseudo-Rutile:19-639<br>4. Trace of Albite :20-572<br>(Na Al Si308)                               |
| 10. | DRI-II<br>-425+ 300 HYD            | 1. $\alpha$ - Fe : 6-696<br>2. TiO2 - 23-1446<br>3. Pseudo- Brookite<br>4. Pseudo - Rutile<br>5. Na Al Si04 : 11-221                                       |

Philips x - ray diffractometer Model PW 1140 Tc 4°

KV = 30 (Voltage)

m A = 16

Range -  $10^3$  c/s

0 range - 6° - 86° (20)

Iron  $\lambda$  wave length 1.93507

Filter - Graphite monochromator

Scanning speed 2 cm/1 min.

The above message may  
please be faxed.



6. Supplier of Gaussmeter

A. Jobmaster Magnetics

9010-T Liberty Road, Randellstown, MD 21333 USA  
Tel.: 410-655-1400, FAX: 410-521-5461, or  
2399 Cawthra Road, #37, Missisauga, Ontario, Canada  
L5A 2W9, Tel.: 416-897-1300, FAX: 897-1468

B. Davis Instruments

4701 Mt. Hopes Drive, Baltimore, MD 21215 USA  
Tel.: 410-358-3900, FAX: 358-0252