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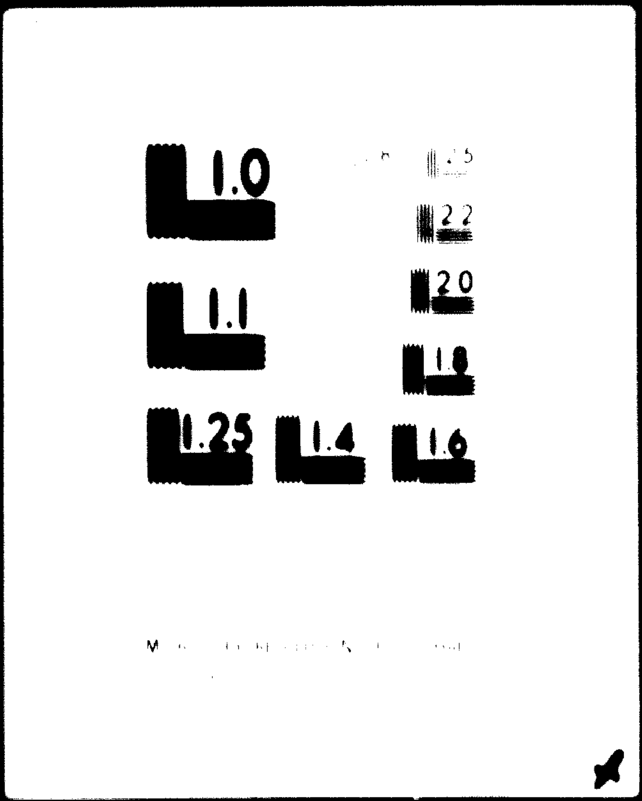

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BENCH AND BIG SCALE TESTS ON THE REDUCIBILITY CHARACTERISTICS OF BAHARIYAH (U.A.R.) IRON ORE.

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNIDO CONTRACT NO. [illegible]

3926

PREPARED BY

[redacted]

Pittsburgh, Pennsylvania
U.S.A.

S-O CONTRACT NO. [illegible]
APRIL 28, 1972

FINAL REPORT

BENCH AND BAG SCALE TESTS ON THE REDUCIBILITY CHARACTERISTICS OF BAHARIYAH (U.A.R.) IRON ORE

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNIDO CONTRACT NO. 70/80

PREPARED BY

Swindell-Dressler Company
A Division of Pullman Incorporated

Pittsburgh, Pennsylvania
U.S.A.

S-D CONTRACT NO. 50511
APRIL 26, 1972

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INTRODUCTION

In December 1970, the United Nations Industrial Development Organization (UNIDO) awarded Swindell-Dressler Company, A Division of Pullman Incorporated, the contract (UNIDO Contract No. 70/80) for the bench and bag scale tests of Bahariyan (UAR) Iron Ore.

The purpose of this study is to qualitatively establish whether or not the reducibility characteristics of the test samples of the iron ore and pellets are equal to, better, or lower than the Encino (Mexican) iron ore which has been processed commercially in the HyL sponge iron plants at Monterrey, Mexico.

The bench scale tests were carried out by the Development Division of Swindell-Dressler Company and the report covering this work is in Section 3.

The bag scale tests were conducted by the Research and Development Department of Hojalata y Lamina, S. A. at Monterrey, N. L., Mexico. This work is reported in Section 4.

The required beneficiation tests and pellet production of the Bahariya iron ore was performed for Swindell-Dressler Company by the Mineral Resources Research Center, University of Minnesota, Minneapolis, Minnesota. Their report is in Section 5.

SUMMARY OF RESULTS

1. Sample No. 50511-A - Representative run-of-mine sample of Bahariya iron ore

Iron Content: 56.57%

The screen analysis indicates that 77-78 % by weight is minus 9.5 millimeters (3/8 inch).

The ore, as tested, is extremely friable. This would explain the existence of a high concentration of fines found in the sample. The HyL process requires the lump ore feed to be 95-98% + 10 millimeters in order to keep within the required pressure drop and suitable flow distribution within the reactor. As this Baharian ore sample indicates that only 22-23 % of the ore is + 3/8", it is considered too fine for use in the HyL process.

Ore Beneficiation is recommended for this ore sample, in order to increase its Fe concentration and to utilise the fines. This would result in cost savings at the melt shop, during the melting process.

If the ore is beneficiated and then pelletised, it is anticipated that the resulting pellet will be suitable for the HyL direct reduction process.

2. Sample No. 50511-B - Representative run-of-mine sample of Bahariya iron ore

Iron Content in Raw Ore: 47.39%

The raw ore was beneficiated and pelletised to produce a 60% Fe pellet. This was achieved by means of pelletising after magnetic roasting and magnetic concentration. The size of the Bahariya pellet was on an average, smaller than the standard Alzada Pellet, but this size differential caused no problem for the HyL Direct Reduction Process.

The test results indicate that the beneficiated Bahariya pellet has good metallisation and good physical properties. Batch metallisation tests indicate that the Bahariya pellet compared favorably with the Alzada pellet.

The Bahariya iron oxide pellet, sample 50511-B, appears suitable for the production of sponge iron by the HyL direct reduction process.

3. Sample No. 50511-C - Sample of high grade Bahariya iron ore selected at mine site.

Iron Content: 58.07%

The screen analysis indicates that 77-78% by weight is minus 9.5 millimeters (3/8 inch).

The ore, as tested, is extremely friable. This would explain the existence of a high concentration of fines found in the sample. The HyL process requires the lump ore feed to be 95-98% + 10 millimeters in order to keep within the required pressure drop and suitable flow distribution within the reactor. As this Bahariya ore sample indicated that only 22-23% of the ore is +3/8", it is considered too fine for use in the HyL process.

Ore beneficiation is recommended for this ore sample in order to increase its Fe concentration and to utilise the fines. This would result in cost savings at the melt shop, during the melting process.

If the ore is beneficiated and then pelletised, it is anticipated that the resulting pellet will be suitable for the HyL direct reduction process.

Swindell-Dressler Company

LABORATORY EVALUATION

of

BAHARIYA IRON OXIDE (50511-A & C)

UNIDO CONTRACT 70/80

SWINDELL-DRESSLER CONTRACT 60511

Development Division
April 21, 1972

PREPARED BY
D. G. Olsen/P. H. [illegible]

REVIEWED BY
M. A. [illegible]

APPROVED BY
R. H. [illegible]

1. INTRODUCTION

Two samples of Bahariya iron ore have been submitted for HyL reducibility studies. One sample was a high grade ore (50511-C) and the other was a run-of-mine ore (50511-A).

Preliminary evaluation tests were conducted that included screen and chemical analyses of the samples.

II. SCREEN ANALYSIS - RAW ORES

The ores were separated into +3/8" (lump) and -3/8" (fines) fractions. The entire lump fractions and one-fourth of the fines fractions were screened through a series of sieves.

A - Lump Ore and Fines Fractions

SAMPLE	+3/8", Lump Kilos	+3/8", Lump %	-3/8", Fines Kilos	-3/8", Fines %
High Grade	11.305	23.0	37.280	77.0
Run-of-Mine	11.236	22.5	37.90	77.5

B - Lump Ore, +3/8"

SIEVE	Kilos Retained		% Retained	
	High Grade	Run-of-Mine	High Grade	Run-of-Mine
2"	0	2.270	0	20.20
1-1/2"	0	0	0	0
1"	1.240	2.043	10.95	18.18
3/4"	3.740	1.702	33.07	15.15
1/2"	4.480	2.951	39.64	26.26
3/8"	1.845	2.270	16.34	20.21
	11.305	11.236	100.00	100.00

II. SCREEN ANALYSIS - RAW ORES (continued)

C - Fines, -3/8"

SIEVE	Kilos Retained High Grade	Kilos Retained Run-of-Mine	% Retained High Grade	% Retained Run-of-Mine
1/4"	0.641	0.667	7.13	7.41
4 mesh	0.257	0.192	2.86	2.14
8	0.992	1.144	11.03	12.71
14	0.596	0.954	6.62	10.60
28	0.909	1.530	10.10	17.00
48	1.285	2.300	14.28	25.56
100	2.186	1.368	24.30	15.20
200	1.105	0.615	12.28	6.83
Pan	1.026	0.229	11.40	2.55
	8.997	8.9990	100.00	100.00

III. CHEMICAL ANALYSIS - RAW ORES

Oven dried portions of the raw ores were analyzed for total iron, silica and chemical water.

	High Grade	Run-of-Mine
Total Fe, %	58.07	56.57
SiO_2, %	1.23	3.06
Chemical H_2O, %	6.47	7.84

IV. CONCLUSION AND DISCUSSIONS

The results obtained from the screen and chemical analyses indicates that the iron ore samples (50511-A & C) are not suitable for direct reduction.

The HyL process requires the lump ore feed to be 95-98% + 10 millimeters (approximately 3/8"). This minimum, + 3/8" size requirement for the HyL process, is necessary to keep within the required pressure drop and suitable flow distribution within the reactor. The Bahariya ore(s) (Sample 50511-A & C) indicates that only 22-23% is + 3/8". Although this is not a decisive factor in the final judgment on an ore suitability for direct reduction (since it could always be corrected through mining operation), it indicates that a sizeable portion of the ore will be lost during the screening operation. Usually, if an ore tends to disintegrate and produce-3/8" fines, a pelletization process is recommended. On the other hand, the chemical analysis indicates the iron content of the Bahariya ore(s) is between 55-58%, with a relatively high amount of silica. Usually, such ore is not recommended for direct reduction as it would lower the efficiency of the plant (direct reduction as well as melting processes).

So, it is recommended to consider a benefication/pelletization process for such ore(s). Such a step would increase the efficiency of not only the mining operation but also the direct reduction plant and the melt shop. For relatively good ores, it was found that the use of pellets in the HyL process, rather than ore lumps, would increase the direct reduction plant output by about 20-25%, while reducing the fuel

IV. CONCLUSION AND DISCUSSIONS (continued)

consumption by at least 10%. For the low iron Bahariya ore(s), the anticipated gains obtained through a beneficiation/pelletization process would be greater.

For the above mentioned reasons, no further reduction tests were conducted on such ore(s).

Swindell-Dressler Company

LABORATORY EVALUATION

of

BAHARIYA IRON OXIDE PELLETS (50511-B)

Report No. 60611

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION
UNIDO Contract No. 70/80

PREPARED BY
D. G. [illegible]

REVIEWED BY
M. A. [illegible]

APPROVED BY
R. H. [illegible]

Development Division
March 8, 1972

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I. INTRODUCTION

This report contains the results of bench scale HyL reducibility tests conducted on a sample of Bahariya iron oxide pellets.* The pellets were prepared from a beneficiated sample of run-of-mine ore which was submitted by the United Nations Industrial Development Organisation (UNIDO).

The tests include a screen analysis, crushing strength and shipping bulk density determination, as well as chemical analysis of the raw pellets. They also include single particle and batch reduction runs.

The data obtained from these tests were compared with the results of the same series of tests conducted on our standard HyL Alzada pellets.

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* Sample No. 50511-B

II. RAW IRON OXIDE PELLET TESTS

A. Screen Analysis

The screen analysis was run on the entire Bahariya pellet sample received:

Sieve	Kilos Retained		% Retained	
	Alzada	Bahariya	Alzada	Bahariya
12.7mm (1/2")	13.87	0.00	80.18	0.00
9.51mm (3/8")	3.43	1.25	19.82	6.44
6.35mm (1/4")	0.00	18.15	0.00	93.56
	17.30	19.40	100.00	100.00

B. Crushing Strength Determination

Ten Alzada pellets of approximately 1.24 cm diameter and ten Bahariya pellets of approximately 1.00 cm diameter (largest size available) were crushed using a laboratory press. The crushing strength data were as follows:

	Crushing Strength	
	Range, Kilos	Average, Kilos
Alzada	50.0 - 136.4	81.4
Bahariya	113.6 - 136.4	122.7

C. Chemical Analysis

Total iron, as well as ferrous and ferric oxides of iron were determined by wet chemistry procedures. The results were as follows:

	Alzada	Bahariya
Total Fe, %	66.21	59.72
Hematite, %	94.66	85.04
Magnetite, %	nil	1.03
Available Oxygen (calculated), %	28.40	25.83
Gangue	5.34	13.93

II. RAW IRON OXIDE PELLET TESTS

C. Chemical Analysis (continued)

In addition, the Bahariya raw pellets were analysed for TiO_2, P and S:

TiO_2 = 0.38 %

P = 0.314%

S = 0.0085 %

D. Shipping Bulk Density

The shipping bulk density of the pellets were determined for the pellets as received, i.e., without further size classification:

Shipping Bulk Density

Alzada	2.01 g/cc
Bahariya	2.46 g/cc

III. REDUCTION EXPERIMENTS

A. Single Particle Experiments

These reduction experiments were conducted at isothermal conditions in a Stanton Thermogravimetric apparatus (Model HT), under the following conditions:

Reducing Gas Composition	61.5% H_2 15.7% CO 7.1% CO_2 15.7% N_2
Reducing Gas Flow Rate	0.28 liters/cm^2/min
Average Pellet Diameter	0.98 cm
Pellet Weight Range	1.95 - 1.98 gm
Reduction Temperatures	800 - 900 - 1000°C

Each pellet was heated to the desired temperature level in a stream of N_2, then reduce isothermally. More than one test were done at each temperature level to determine the reproducibility of the results. The data obtained for each temperature level were evaluated by plotting the percent fraction reduction (R) vs. time (t) and comparing this curve with the "standard" reduction curve for the Alsada pellets. These (R) vs. (t) curves are shown in Figures 1 through 3.

On the other hand, Figure 4 shows the temperature dependence of the chemical reaction rate constant (k), which was computed from the slopes of the tangent to the (r) vs. (t) curve (at each of the

III. REDUCTION EXPERIMENTS

A. Single Particle Experiments (continued)

three temperature levels) at time t ≤ 2.5 minutes (where resistance to gas diffusion is negligible). The slope of the straight line of the logarithm of (k) vs the reciprocal of the absolute temperature (i.e., Arrhenius Plot) is a measure of the activation energy of the chemical reaction between the oxide(s) of the ore and the reducing gas.

B. Batch Reduction Experiment

A one-kilo batch of -12.7mm (1/2") + 9.51mm (3/8") pellets was reduced in a capsule placed in an electrically heated furnace. The reducing gas flow rate was 20 liter/minute and the gas composition was identical to the one used in the single particle reduction tests. The reduction was done isothermally at a bed temperature of about 900°C. The pellet bed was heated and cooled in a stream of nitrogen.

Samples (9 pellets each) were removed from the top, middle and bottom portions of the reduced batch. Each sample was dropped ten times from a distance of 106 cm (a simulated impact test). The portion of the sample degraded to less than 9.51mm (3/8") was then determined.

% Degradation (Impact Test)

	Top	Middle	Bottom
Alauda	8.62	0	0
Bahariya	14.44	35.81	31.44

IV. DISCUSSION OF RESULTS (continued)

The simulated impact and tumble tests verified the effect of cracking and swelling phenomena of the Bahariya pellets during reduction. The high percent of the -9.51 mm(-3/8") fraction after the degradation tests, resulted mainly from breaking away the chips resulting from the deep cracks formed during reduction.

V. CONCLUSION

The results obtained from single particle and packed bed reducibility tests indicate that the beneficiated Bahariya pellets, used in this evaluation, were of a slightly lower grade than the Alzada. Their reducibility improved at high temperature due to the cracking and swelling phenomena that accompanied the reduction process, facilitating the gas movement to and from the unreacted core.

This Bahariya iron oxide pellet is suitable for direct reduction by the HyL Process. By further beneficiating the Bahariya iron ore to yield a higher iron content concentration than the 59% Fe sample used in this study, a cost saving would be realized at the melt shop, during the melting process. Also the use of high reduction temperatures, preferably the maximum allowable, is recommended, in order to reduce reduction time and decrease gas consumption.

III. EXPERIMENTAL PROCEDURE

B. Batch Reduction Experiments (continued)

The remainder of the reduced batch was tumbled, in a ceramic jar equipped with internal lifters, for 15 minutes. Again, the weight of the broken sponge particles, i.e., smaller than 9.51mm (3/8") size, was determined:

	% Degradation (Tumble Test)
Alzada	13.40
Baheriya	22.62

The samples used in the impact and tumble tests were analysed for percent metallization. The results of these analyses are listed below and are shown in Figure 5 where the variation of metallization with packed bed depth are plotted for both the Alzada and Baheriya pellets.

Batch Metallization

	Total Fe, %		Metallic Fe, %		Metallization, %	
	Alzada	Baheriya	Alzada	Baheriya	Alzada	Baheriya
Top	73.06	65.51	4.56	8.51	6.24	12.99
Middle	70.05	71.76	26.01	40.14	37.15	55.94
Bottom	88.60	77.31	77.60	67.15	87.58	86.86
Composite	77.91	71.07	32.11	35.72	41.13	50.26

IV. DISCUSSION OF RESULTS

The screen analysis showed that the pellets were, on the average, of smaller size than the Standard Alsada. Almost 95% of the pellets were in the range of -9.51 mm (3/8") + 6.35 mm (1/4"). The crushing strength showed thatthe beneficiated Bahariya pellets had a higher mean crushing strength than the Alsada. Nevertheless, the chemical analysis showed that the beneficiated Bahariya pellets still have about 14 % gangue, with an iron content of only 59.7 % Due to the average small size of the pellets, the shipping bulk density was higher than the Standard, i.e., up to 2.46 gm/cc. This also could result from a denser Bahariya pellet as compared to the Alsada. The single particle reduction tests showed that the beneficiated Bahariya pellets did not lend themselves to the reduction process, at lower temperatures, however at higher temperatures (1000°C) the reduction compared favorably with the Alsada pellets. It was noticed that the pellets showed some expansion, accompanied by deep surface cracks, during the reduction process. Also noticed, was the presence of a "lag period" between the reducing gas on time and the start of the recorded weight loss. The magnitude of this time-lag decreased as the temperature increased from 800° to 1000°C. The energy of activation of the chemical reaction between the oxides and the reducing gas indicates that the Bahariya pellets exhibited a greater response to temperature variations than the Alsada pellets.

Although, on the micro-single particle reduction level, one pellet of Alsada reduced faster than one pellet of Bahariya, due to weight and purity difference, in the macro-packed bed case, the situation was different. For the same amount of weight, reduced in a packed bed,

IV. DISCUSSION OF RESULTS (Continued)

the average metallization of the Bahariya was higher due to the larger exposed surface area as well as the smaller amount of iron per unit of weight.

Furthermore, at each temperature level, if one takes the fraction reduction attained by the single particle(s) at different time intervals and relates them to the fraction reduction of the Alzada pellets (as the Standard), and calls that value the comparison factor (F), the following values will be obtained:

	Alzada		Bahariya	
1000°C	F	% Reduction	F	% Reduction
10 Min.	1.0	77.0	0.78	60.0
20 Min.	1.0	96.0	0.99	94.9
30 Min.	1.0	99.0	1.00	99.3
900°C				
10 Min.	1.0	47.0	0.61	28.5
25 Min.	1.0	76.0	0.80	61.0
45 Min.	1.0	94.0	0.88	83.0
800°C				
10 Min.	1.0	41.0	0.55	22.6
30 Min.	1.0	77.0	0.71	54.5
50 Min.	1.0	93.0	0.80	74.4

NOTE: $F = \text{Reduction Fraction} = \frac{\text{\% Reduction, Test Pellet}}{\text{\% Reduction, Alzada Pellet}}$

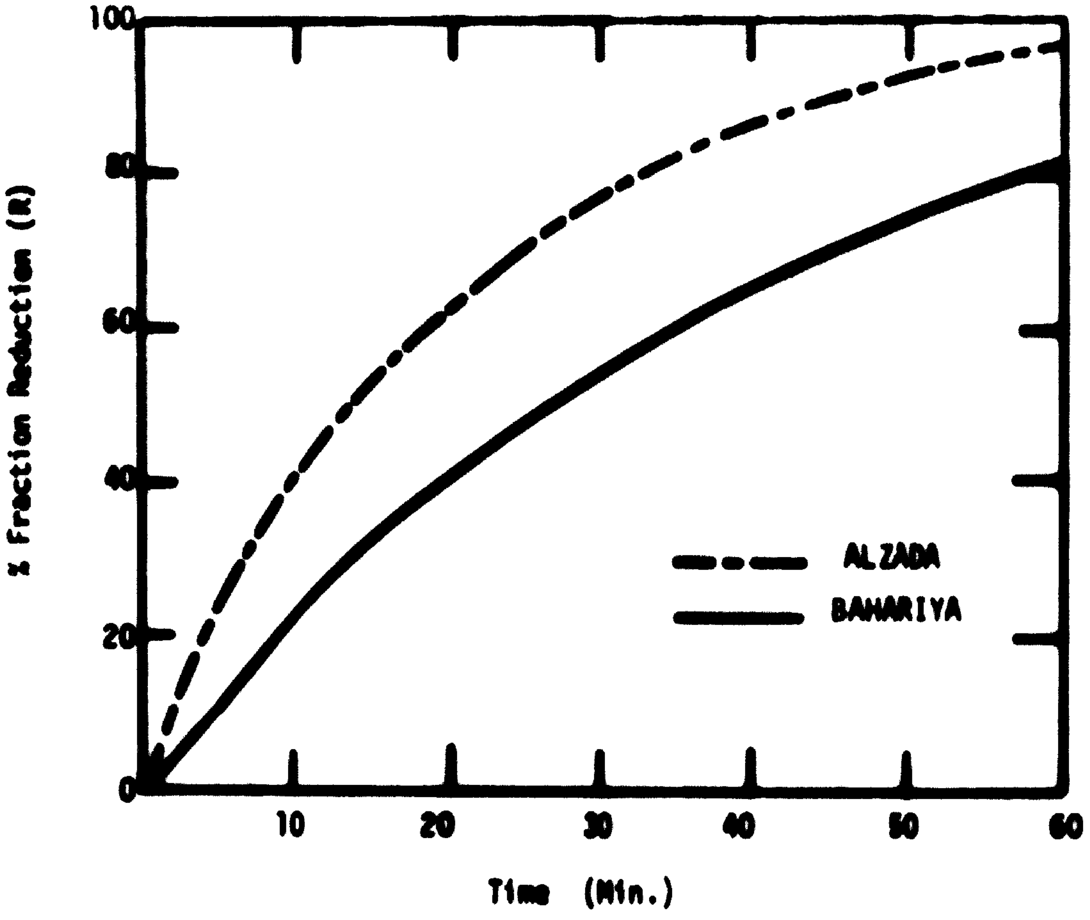
50511

BAHARIYA PELLETS

SINGLE PARTICLE REDUCTION RATE

at 900°C

AS COMPARED TO ALZADA PELLETS



R-Gas Flow Rate	0.28	l/cm^2-min.
R-Gas Composition	61.5%	H_2
	15.7%	CO
	7.1%	CO_2
	15.7%	N_2

Fig: 1

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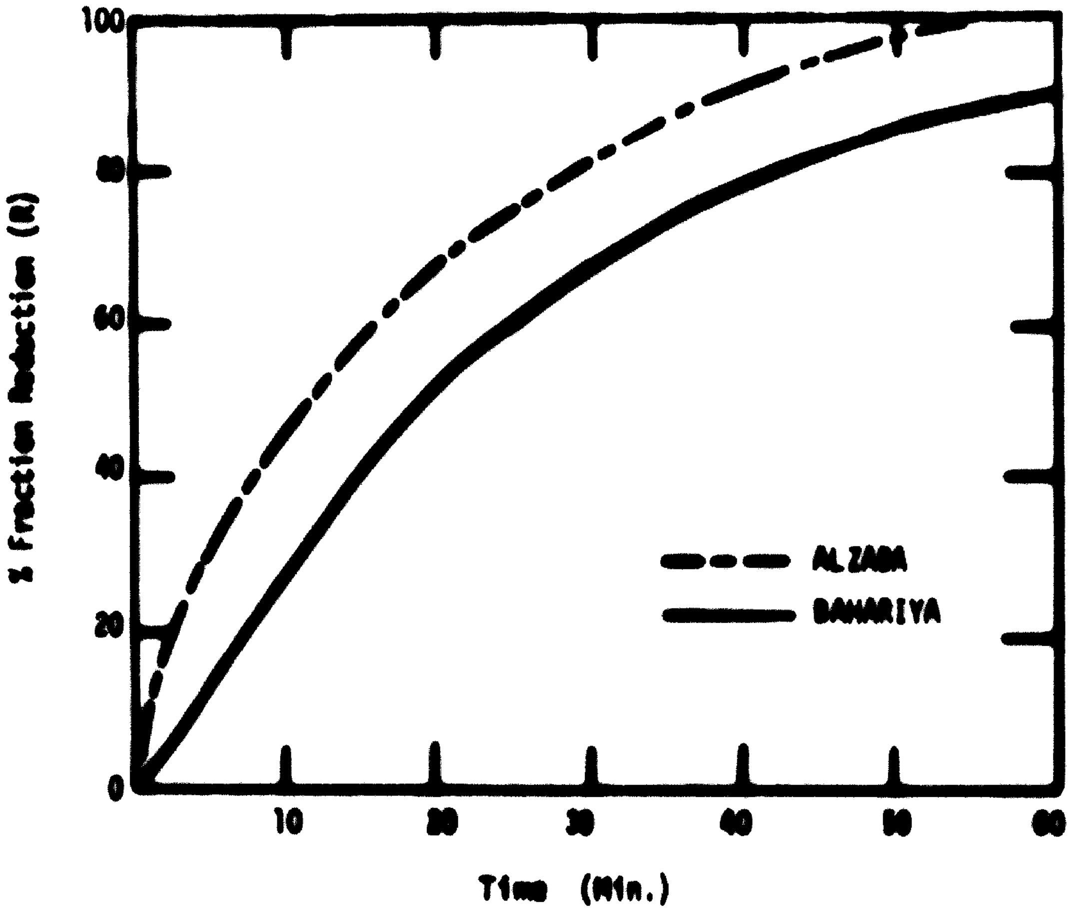
BAHARIYA PELLET

SINGLE PARTICLE REDUCTION RATE

at 900°C

AS COMPARED TO ALZADA PELLETS



R-Gas Flow Rate	0.28	l/cm^2-min.
R-Gas Composition	61.5%	H_2
	15.7%	CO
	7.1%	CO_2
	15.7%	N_2

Fig: 2

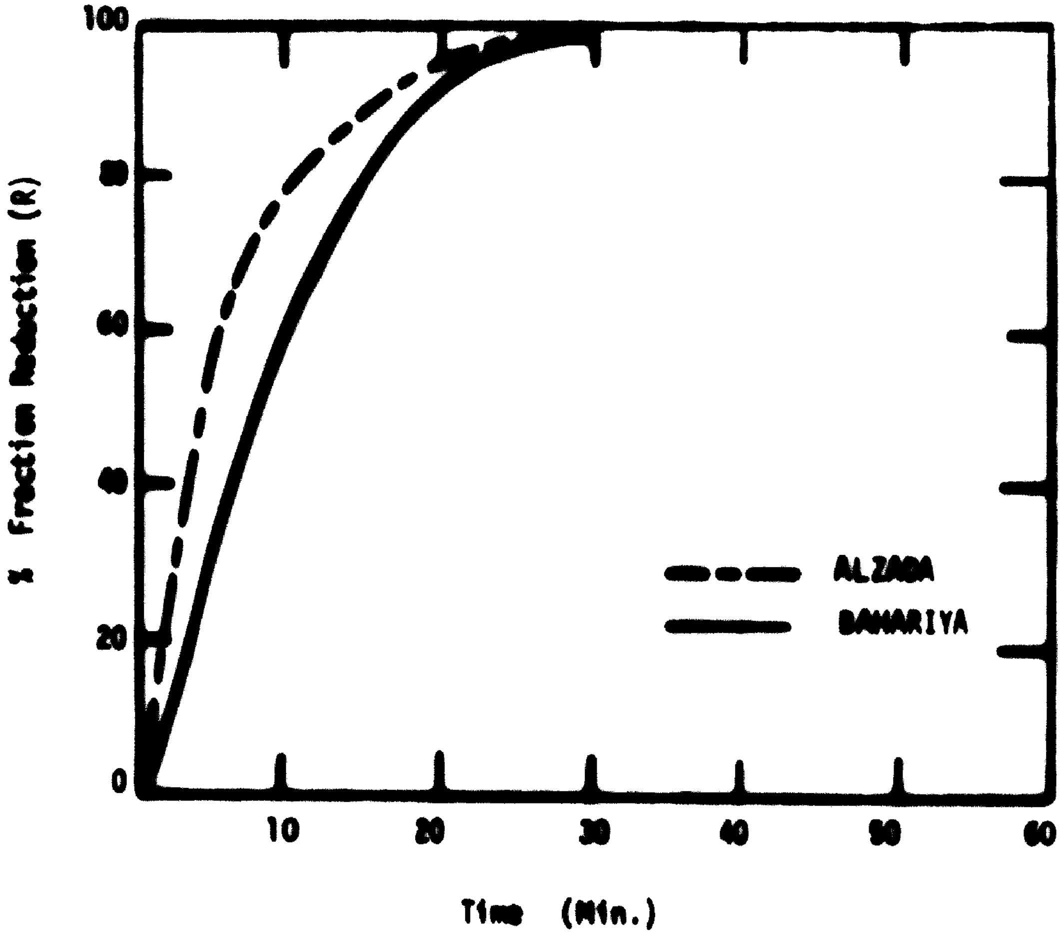
50511

BAHARIYA PELLET

SINGLE PARTICLE REDUCTION RATE

at 1000°C

AS COMPARED TO ALZADA PELLETS



R-Gas Flow Rate 0.28 l/cm^2-min.

R-Gas Composition 61.5% H_2

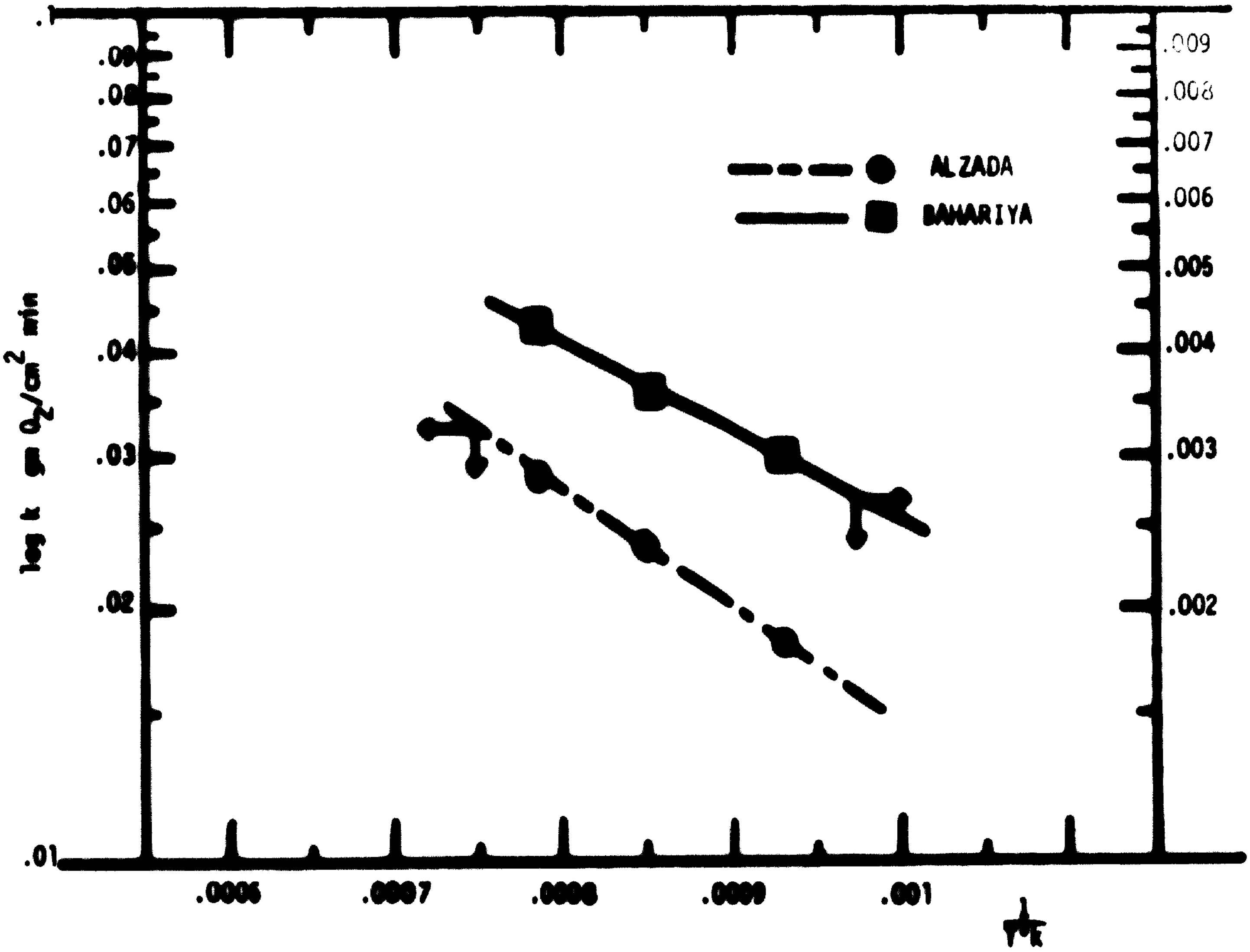
15.7% CO

7.1% CO_2

15.7% N_2

Fig: 3

BAHARIYA PELLET
TEMPERATURE DEPENDENCE COEFFICIENT
OF SINGLE PARTICLE KINETIC CONSTANT
AS COMPARED TO ALZADA PELLETS



ALZADA PELLETS ΔH = 6.7 k-cal/g mole

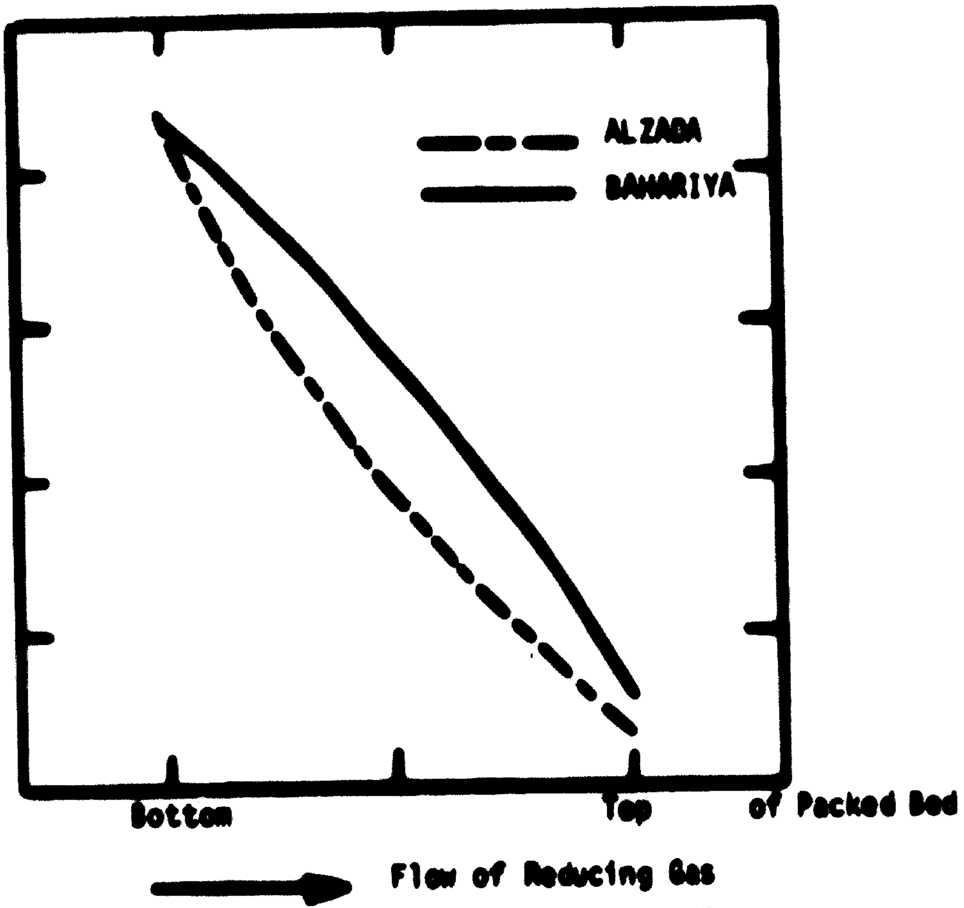
BAHARIYA PELLETS ΔH = 4.5 k-cal/g mole

Fig: 4

50611

BAHARIYA PELLET

VARIATION OF METALLIZATION
WITH PACKED BED DEPTH
AS COMPARED TO ALZADA PELLETS



Reduction Capsule	12.5 cm diameter
Weight of Ore	1 kg
Size of Pellets	-1.27 cm + 0.95 cm
R-Gas Flow Rate	20 liters/min
R-Gas Composition	as single-particle exper.
Reduction Temperature	850°C-T.C.[~800°C in bed]
Reduction Time	45 min.

Fig: 5

REPORT ON BAG SCALE TESTS

S/D JOB No. 50511

Conducted by

HOJALATA Y LAMINA, S. A.
Research and Development
Monterrey, N. L. México

Prepared by:

Ing. P. W. MacKay
Ing. E. R. Martínez V.

Presented to:

Ing. Jesús M. Peña
Manager
Research & Development
Hojalata y Lámina, S. A.

Transmitted to:

Mr. G. F. Johnson
SWINDELL DRESSLER CO.
Pittsburgh, Pa.

February 4, 1972.

REPORT ON BAG SCALE TESTS

R/D JOB No. 50511

The bag scale tests for Egyptian iron ore* on contract 50511 have been carried out at Monterrey Pilot Plant.

Three wire mesh bags, containing 5 Kgs. each one of Egyptian iron ore, were grouped with samples of Alzada Pellets. Groups of 2 bags (Egyptian and Alzada ores) were placed at three different levels in the reactor. The reactor was operated under normal conditions, the charge was cooled until the TR-12 aquired 60°C for at least 2 hours.

For each sample were determinated: the chemical analysis of iron ore and sponge iron (at 3 levels), the porosity of sponge iron (at 3 levels) and the resistance to compression for the sponge iron (at 3 levels).

Tables I and II disclose a summary of the results for each sample. Figures 1 and 2 shows the photograph of each sample, the photograph contains iron ore and sponge iron of the three different levels, together with the photograph there are some cualitative appreciation of the sponge iron in each bag, and comments on the reducibility of the Egyptian iron ore compared with the Alzada Pellets. In Table III are shown the operating conditions for the bag test run in the Pilot Plant.

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* Sample 50511-B

TABLE I

RESULTS FOR SAMPLE No. 30511 - B

CHEMICAL ANALYSIS OF IRON ORE

% Fe Total	60.2
% FeO (Det.)	0.5
% Fe_2O_3 (Calc.)	85.5
% Hematite	84.4
% Magnetite	1.6
% Sulfur	0.007
% Phosphorus	0.394
% Red. Oxygen	25.81
% Gangue	13.99

CHEMICAL ANALYSIS OF SPONGE IRON

	TOP	MIDDLE	BOTTOM
% Fe Total	78.7	77.9	66.8
% Fe Metal	71.0	69.3	15.5
% Metallization	90.2	89.0	23.2
% Carbon	1.84	2.46	1.00
% Sulfur	0.010	0.008	0.005
% Phosphorus	0.463	0.466	0.415
% Gangue	16.80	16.70	17.10

POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

	TOP	MIDDLE	BOTTOM
% Porosity	46.48	46.27	21.05
Resistance to compression (Kg./pellet). Average of 10 pellets.	81	91	71

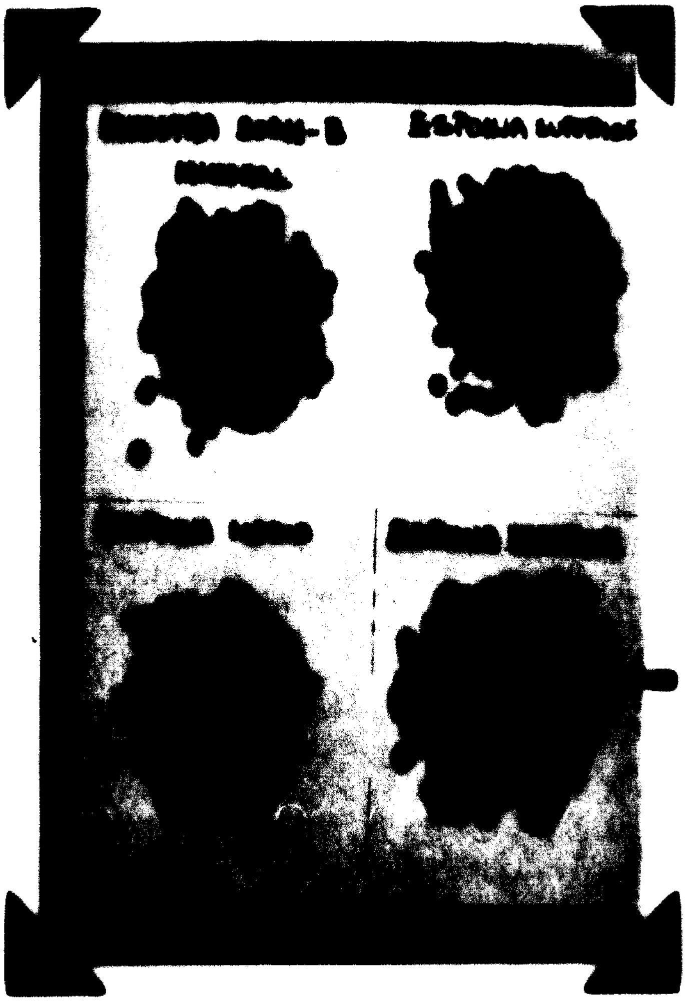

FIGURE 1

SAMPLE No. 50511 - B

INSPECTION OF SPONGE IRON SAMPLES

TOP: No fusion. No size reduction. Some cracks.
MIDDLE: No fusion. No size reduction. Some cracks.
BOTTOM: No fusion. No size reduction. Some cracks.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50511-B = 67.47 %
Average Metallization of Alzada Pellets (bags) = 77.57 %

Good metallization and very good physical characteristics, it seems to be suitable for the production of sponge iron by the HyL process.

TABLE II

RESULTS FOR ALBADA PELLETS

CHEMICAL ANALYSIS OF IRON ORE

% Fe Total	66.8
% FeO (Det.)	1.5
% Fe_2O_3 (Calc.)	93.8
% Hematite	90.5
% Magnetite	4.8
% Sulfur	0.008
% Phosphorus	0.065
% Red. Oxygen	28.52
% Gangue	4.90

CHEMICAL ANALYSIS OF SPONGE IRON

	TOP	MIDDLE	BOTTOM
% Fe Total	90.3	89.8	78.5
% Fe Metal	86.5	84.1	33.9
% Metallization	95.8	93.7	43.2
% Carbon	1.88	1.92	1.74
% Sulfur	0.012	0.007	0.005
% Phosphorus	0.090	0.092	0.086
% Gangue	6.6	6.5	6.9

POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

	TOP	MIDDLE	BOTTOM
% Porosity	59.21	60.53	30.88
Resistance to compression (Kg./pellet). Average of 10 pellets.	83	78	44

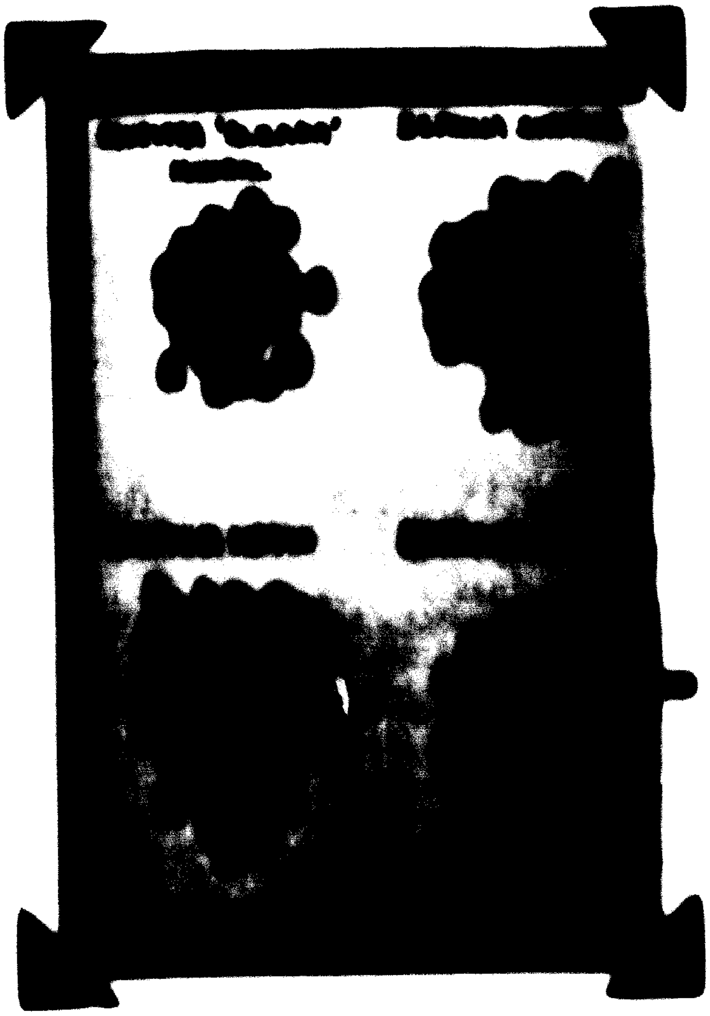

FIGURE 2

ALZADA PELLETS

INSPECTION OF THE SPONGE IRON SAMPLES:

TOP: No fusion. No size reduction.
MIDDLE: No fusion. Sligth size reduction.
BOTTOM: No fusion. Sligth size reduction.

TABLE III

OPERATING CONDITIONS

REFORMER GAS ANALYSIS

H_2	71.93 %
CO	13.00 %
CO_2	7.87 %
CH_4	7.20 %

R - GAS PREHEAT TEMPERATURE = 730°C

AIR PREHEAT TEMPERATURE = 730°C

COMBUSTION CHAMBER TEMPERATURE = 1,030°C

METALLIZATION OF REACTOR CHARGE = 89.90 %

GAS CONSUMPTION, REFORMED GAS = 1,152.26 NM^3/Ton. Fe

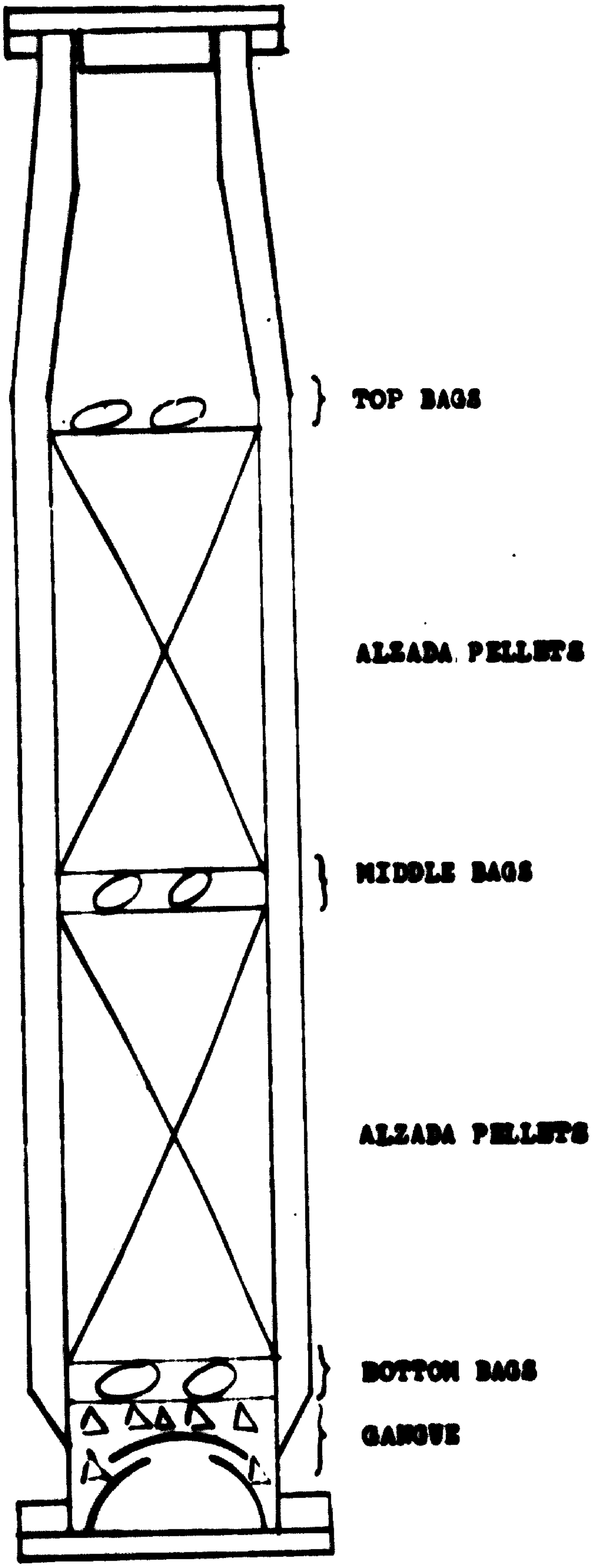

FIG. 3 CHARGE DIAGRAM.

BENCH SCALE AND PILOT PLANT TESTING
OF
BAHARIYA IRON ORE (50511-B)

for

Swindell-Dressler Company

Prepared by
R.L. Wiegel
R. L. Wiegel
Research Associate

Approved by
J.E. Lawver
J. E. Lawver
Director

Mineral Resources Research Center
University of Minnesota
Minneapolis, Minnesota

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INTRODUCTION

In early July 1971 a small sample of Bahariya, U.A.R., iron ore (S-D sample number 50511-B) was received from Mr. Gordon Johnson of Swindell-Dressler Company with a request[1] for a proposal to beneficiate and produce 100 kg pellets for S-D direct reduction testing. These pellets were to meet the following criteria:

minimum Fe 64%   silica 3-4%
maximum S 0.15% physical size 3/8" - 5/8"

In response a few preliminary tests were made and a brief report[2] was issued by N. F. Schulz regarding the beneficiation of the Bahariya ore by magnetic roasting and magnetic concentration techniques. A magnetic concentrate of 63% Fe and 5% SiO_2 was made at 94% iron recovery, which when pelletized would not meet the 64% Fe minimum specified by S-D. These results together with a proposal for additional testing which would include flotation of magnetic concentrate were submitted[3] to Mr. R. F. Dunn also of Swindell-Dressler Company. The decision was then made by S-D to proceed with the production of 100 kg of pellets via magnetic roasting and magnetic concentration only, ignoring the 64% Fe requirement in the final oxide pellet.

The bulk sample of seven drums of ore was received by the Mineral Resources Research Center in mid-September. Bench scale testing and pilot scale production of the 100 kg plus of magnetic concentrate was completed by late October, but problems were encountered in producing acceptable pellets, which delayed completion of the project until mid-November, at which time 80 kg of fired pellets were sent to Laredo, Texas and 20 kg to Etna, Pennsylvania.

SUMMARY OF RESULTS

A portion of the crude ore was crushed, roasted to magnetite, and magnetically concentrated to produce a 62% Fe, 0.16% S, 6.5% SiO_2 product at 88% weight recovery and 96% iron recovery. The iron and silica contents of the concentrate were about 1% poorer than anticipated.

Initial balling and firing tests gave pellets with severe surface cracks which resulted in poor abrasion test results. Adjustments in ball size from 7/16 x 5/8 to 3/8 x 1/2 and balling rate, and the addition of 0.8% bentonite, however, permitted the production of pellets with reasonable quality. The final product assayed: 59.7% Fe, 1.6% Mn, 7.2% SiO_2, 1.7% Al_2O_3, 0.33% P, and 0.011% S.

Calculations from pilot plant data indicated a work index of 13 for roasted material ground to 80% passing 39 microns. This would yield estimated energy requirements of 21 KWH/LT crude for crushing and grinding commercially.

Fuel requirements for reduction and pelletizing the concentrate are estimated at 0.8 and 1.0 MM Btu per LT of crude and pellet respectively.

DISCUSSION OF RESULTS

Preliminary Testing of Small Sample

A sample of the ore was roasted to the magnetite state in the Bench Canister Roaster at 650°C for one hour in an atmosphere containing 10% H_2, 20% CO_2, and 70% N_2 (dry basis), humidified to about 15% water vapor. The roasted ore was pulverized dry to minus 150 mesh and a series of magnetic separations was made in a Davis Tube Concentrator on 10-gram samples to determine the magnetic separation characteristics of the roasted ore.

The separation results and chemical analyses of the crude ore, roasted product, and magnetic concentrates are given in Table 1. The most acceptable results corresponded to a concentrate grade of 62.8% Fe at 95% iron recovery. The sulfur content of the concentrate at this condition was about 0.17% and the silica 5.4%. Further treatment by magnetic separation produced a concentrate of 64.2% Fe, 0.14% S, and 4.1% SiO_2, but at only 67% iron recovery.

To attain the specification of 64% Fe minimum in fully oxidized iron ore pellets, the grade of the concentrate would have to be 66% Fe if no binder is used and 66.7% Fe if 1% inorganic binder must be used for agglomeration.

It was therefore concluded that the specifications for sulfur and silica could be met, at low recovery, but it was extremely doubtful that the required iron content could be reached by magnetic roasting and separation.

Swindell-Dressler representatives then made the decision that flotation of magnetic concentrate was not justified and accepted the lower pellet iron content and higher silica.

Pilot Scale Testing

The seven drums (4000 lb) of ore were crushed, using a roll crusher, through 3 mesh (1/4 inch), and mixed, before a 600 lb sample of material was split out for further testing.

In order to roast the quantities of material required here it was necessary to crush and grind the material to a size suitable for balling. These balls were roasted and not hard fired and were readily broken following roasting. A schematic flowsheet for the pilot testing is shown in Figure 1. This 600 lb sample was therefore dry ground in a batch ball mill, to give approximately 60% passing 325 mesh, which was necessary to produce fines for balling before magnetic roasting. The ground ore was then moistened and balled in a 3 1/2 ft. disk. Ball size ranged from 3/8 to 5/8 inch.

The balls were charged in a 20 inch diameter by 18 inch deep basket (approx. 300 lb) and the basket placed in a reduction furnace. The charge was heated to 680°C by passing hot combustion products from a natural gas burner through the charge. Reduction was accomplished by adjusting the burner gas-air mixture to produce a combustion product containing a combined H_2, CO content of four to six percent. Reduction was considered complete when the exit gases coming off the charge contained the same percent combustibles as the inlet gas. The ore charge was then cooled to below 100°C with precooled combustion gases. These roasting conditions are suitable for the conversion of other iron oxides to magnetite.

The roasted material was then passed through a roll crusher to break up the remaining balls. Size distributions and assays for these products are shown in Table 2.

Bench Scale Tests on Roasted Product

A small portion of the roasted material was subjected to bench scale grinding and Davis tube magnetic separation tests to determine the "target" for the pilot concentration tests. These results, as shown in Table 3, indicate that a maximum grade of about 63% Fe could be attained by magnetic separation alone. Grinding beyond 90% passing 325 mesh results in slight grade improvement, 63.4 vs 62.7% Fe, with the loss of significant recovery, 92.9% vs 95.8%. These results are in general agreement with the conclusions reached as a result of the preliminary testing of the small sample.

Concentration

A circuit consisting of a ball mill, Sweco screen, two single drum magnetic separators and a high-frequency demagnetizing coil together with necessary pumps and piping was assembled for the concentration of the roasted ore. An equipment list and flowsheet are shown in Table 4 and Figure 2.

Roasted ore was fed at the rate of about 71 pounds per hour to this circuit, with a total of about 400 pounds of ore being consumed. Following one hour of preliminary operation for the circuit to come into equilibrium, two sets of composite samples were collected, each representing two hours of operation. These composites were assayed for iron and Davis tube magnetic iron and size distributions were determined. The primary data are shown in Table 5. Since it was felt that the sampling of Sweco screen oversize would unduly disturb the process, the calculations were made without these data. Metallurgical calculations for the concentration process were made using the MATBAL computer program, which provides a consistent set of calculated stream weights and adjusted analyses based on a statistical treatment of the two sets of data. In this case the Fe assay, and Davis tube magnetic iron assay were used in the calculations. The resulting metallurgical balance is shown in Table 6 and indicates a concentrate grade of 62.1% Fe, a weight recovery of 87.9% and an iron recovery of 96.4%. The chemical analysis of the combined concentrate was: 62.11% Fe, 0.159% S, and 6.50% SiO_2, somewhat lower than the anticipated product.

The final concentrate was collected in settling boxes, water was decanted, and the consolidated solids were removed and dried on a hot plate at 220°F to a moisture of about 15%. Filtration of materials similar to this has proved to be a problem in the past, and it was decided in view of the quantity of material processed that settling and low temperature drying would be appropriate.

Pelletizing Magnetic Concentrate

Dried concentrate was moistened to 8 percent moisture and balled in a 3 1/2 foot balling disk. Water as spray was added as needed. Finished balls 7/16 inch to 5/8 inch in diameter were produced.

Small pot firing tests indicated unsatisfactory pellets would be produced from these balls. High shrinkage and severe surface cracking of the pellets resulted in a poor tumbler index.

Approximately 220 pounds of concentrate containing 8 percent moisture was then mixed with 0.8% bentonite. This material was balled in the 3 1/2 foot disk using a slower feet rate than in the previous test. The ball size was also reduced to 3/8 inch to 1/2 inch diameter.

The balls were fired in a 12 inch diameter by 9 inch deep pot grate furnace at a firing temperature of 2250°F. The details of green ball and pellet qualities which are given in Table 7 indicate the pellets were of reasonable quality.

Grinding Results

Since the roasted crude was already 60% passing 325 mesh, it was decided that a Bond ball mill grindability test would be suspicious (feed normally minus 6 mesh), and therefore the work index for the material was calculated from the pilot plant data. The dimensions and operating conditions of the 1 ft. dia. x 2 ft. ball mill gave sufficient information to calculate useful power input to the mill. The feed rate, and size distributions of feed and product from the grinding circuit permitted calculation of the work index. These calculations are shown in Table 8 and indicate a work index of 13.1 corrected to the standard 8 ft. diameter ball mill.

Numerically the work index represents the energy (KWH/NT) required to reduce the material from theoretically infinite feed size to 80 percent passing 100 microns. It can then be used to estimate energy requirements for grinding from any feed size to any product size. It is, of course, limited practically to the size range in which grindability or pilot-plant tests were made.

Since roasting to magnetite preceded the grinding in these tests, it is not a definitive measure of the work index of the crude ore, and in fact it is recognized that roasting will quite often cause a reduction in work index. Since the crushing and coarse grinding energy requirements are usually lower than for fine grinding, and work indexes for hematite and limonite ores are usually in the 10-13 range, the calculated size reduction energy requirements for crushing the coarse grinding crude can be estimated on this basis without introducing too much error.

Requirements for Process Flowsheet

There are several alternatives available in carrying out the crush-roast-concentrate portion of the process, including:

1) crush to 3/4 in., roast in rotary or vertical kiln or traveling grate, quench, grind, and concentrate

2) crush or grind in a dry autogenous mill to 14 mesh, roast in fluid bed, quench, grind and concentrate.

There is questionable difference in the reducing gas requirements for the various roasting steps.

Since the first process would maximize the amount of grinding following roasting, when the work index is lowest, it is used in this report to estimate energy requirements. The flowsheet used in making these estimates is shown in Figure 3 using 150 LTPH pellets as a basis (~1 MM-LTPY). There is also the possibility that dry magnetic cobbing could be used on the minus 3/4" reduced product to further reduce grinding energy requirements. Dry magnetic cobbing is shown in the flowsheet, but grinding energy is estimated on the basis of no weight rejection there.

The estimated crushing energy requirement for attaining 80% passing 1/2 inch, which is assumed suitable for roasting, is 1.7 KWH/LT. The estimated energy requirement for rod and ball milling is 19.2 KWH/LT of crude ore, based on achieving the 80% passing 30 micron grind experienced in the pilot plant. Calculations leading to these results are shown in Table 9.

Reducing gas could be obtained by the partial combustion of oil or natural gas, the process requirements are in the range of 0.8 to 1.0 MM Btu equivalent per LT of crude ore.

Fuel requirements for the pelletizing process should be based on the assumption that the exothermic magnetite to hematite reaction (0.4 MM Btu per LT pellet) is not available at the appropriate temperature to be useful in heat economy. An estimate of 0.9 to 1.0 MM Btu per LT is therefore appropriate.

REFERENCES

1. Letter 7/8/71 G. P. Johnson to J. E. Lawver regarding Iron Ore Beneficiation and Pelletizer Test 510 Job No. 50611.
2. Report 7/21/71 Laboratory Test Magnetic Roasting and Separation Bahariya Iron Ore 50611-A (MRRC Prj C-201, Ore 1780) by N. F. Schulz.
3. Letter 7/23/71 J. E. Lawver to R. F. Dunn regarding as above.

FIGURE 1. Overall Pilot Testing Flowsheet Crude Ore Through Pelletizing

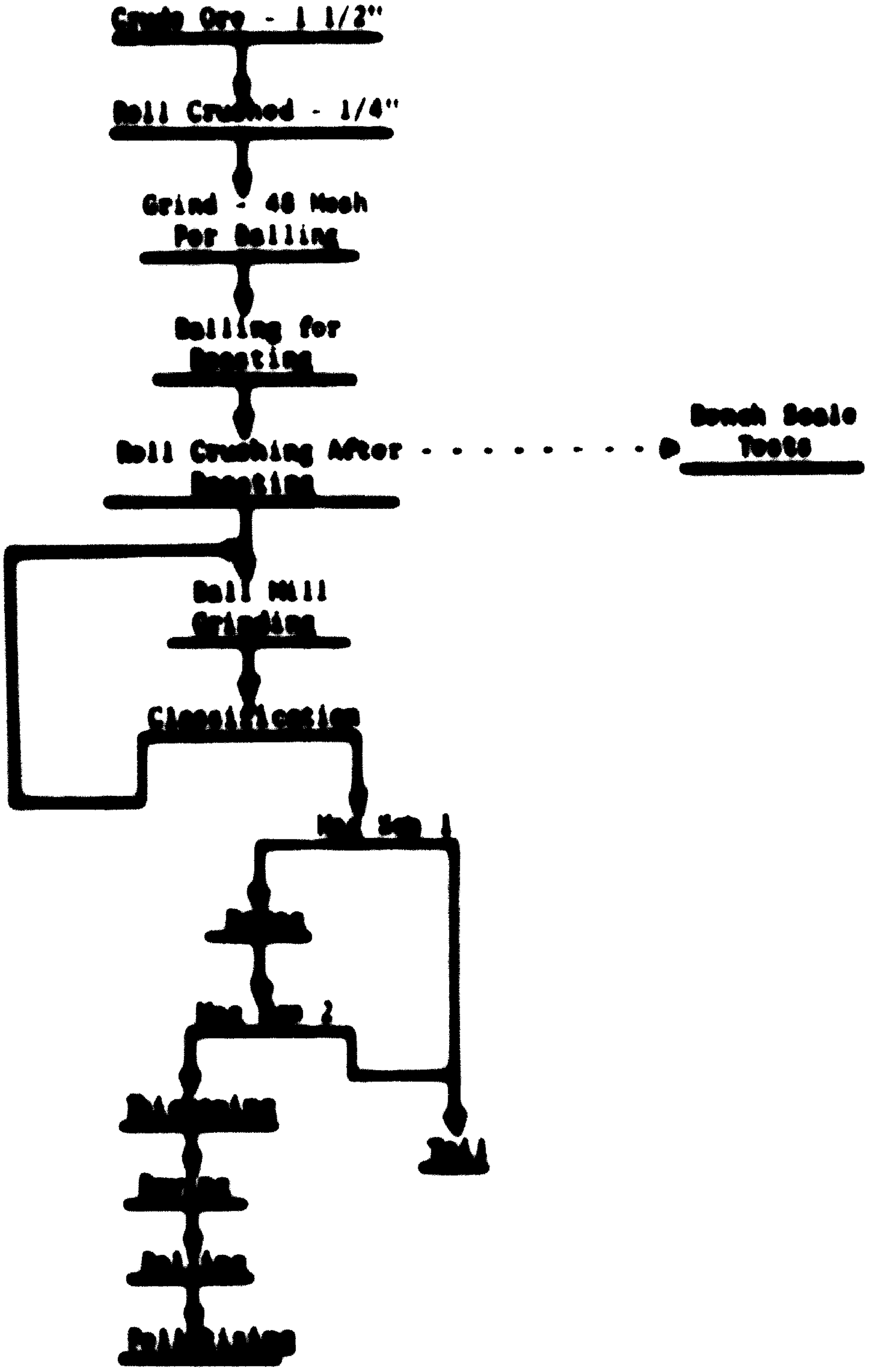

TABLE 1. Chemical Assay and Magnetic Separation Data for Testing of Small Sample

Material	%Fe	$\%Fe^{++}$	%LOI	%S	$\%SiO_2$	%Weight Recovery	%Iron Recovery
Crude Ore	47.50	1.70	10.36	1.00	-	-	-
Roasted Ore	54.33	19.32	-	0.72	-	-	-
Conc No. 1	61.10	-	-	0.194	7.13	87.6	98.6
Calc'd Tail	6.33	-	-	-	-	-	-
Conc No. 2	62.79	-	-	0.173	5.36	82.1	94.9
Calc'd Tail	15.58	-	-	-	-	-	-
Conc No. 3	64.25	-	-	0.130	4.07	57.0	67.4
Calc'd Tail	41.17	-	-	-	-	-	-

TABLE 2. Size Distributions of Selected Products

Size	Cumulative % Passing Crude Ore	Crushed Crude Ore	Ground Crude Prior to Balling and Roasting	Ground Crude Following Balling, Roasting, and Recrushing
1.05 in	95.7			
0.742	90.3			
0.525	84.3			
0.375	76.0			
3 mesh	69.0			
4	62.5	94.6		
6	57.4	87.6		
8	52.6	79.8		
10	48.0	73.9		
14	43.8	67.1		
20	39.9	60.7		
28	36.0	54.5		
35	32.4	49.0	99.2	99.7
48	28.4	43.7	97.1	96.3
65	25.8	37.8	91.4	91.8
100	22.9	33.3	84.3	84.3
150	20.6	29.6	77.2	77.1
200	18.1	26.2	69.8	66.6
270	16.5	24.2	64.7	61.6
325	15.8	23.3	62.4	57.7
Assays				
+8 Mesh Fe	53.28			
8/48 Mesh Fe	48.97			
-48 Mesh Fe	46.02			
Fe	50.18			56.44
Fe^{+2}				18.51

TABLE 3. Batch Laboratory Grinding and Concentration of Roasted Crude

Grind Time* (min)	0	5	10	20
Davis Tube Results				
Conc wt	90.00	87.19	86.81	84.16
Fe	61.14	62.60	62.73	63.42
Fe Recovery	96.98	96.36	95.84	92.91
Tail Fe	17.11	16.09	17.89	25.67
Size Distribution Davis Tube Feed cum % passing				
35	99.7			
48	96.3			
65	91.8			
100	84.3	99.8		
150	77.1	98.5	99.3	
200	66.6	95.1	97.3	99.6
270	61.6	90.3	93.8	98.5
325	57.7	87.0	91.1	97.3

* Ground in 4" x 8" dia. laboratory mill at 50% solids

TABLE 4. Pilot Plant Equipment List

Feeder

∿ 1 1/2 ft x 1 1/2 ft x 2 ft cone shaped hopper with variable speed belt feeder.

Ball Mill

1 ft dia. x 2 ft Denver, 68 rpm, 265 lb ball charge

1 5/8 in. x 1 3/8 in.	40 lb
1 3/8 in. x 1 1/8 in.	50
1 1/8 in. x 7/8 in.	80
7/8 in. x 5/8 in.	90
-5/8 in.	5

Pumps

3 - 1 in. Denver vertical sand pumps

Screen

Sweco Vibro Energy Separator, 15 in. dia.

Magnetic Separators

2 Dings single drum, countercurrent separators, 30 in. dia. x 9 1/2 in. drums, 20 rpm, 4 pole electromagnets 2.2 amp @ 115 volt field

Demagnetizing Coil

40 amp, 4000 cps

Dewatering Tanks

2 - ∿ 2 ft x 2 ft x 4 ft overflow tanks for collecting and dewatering concentrate

FIGURE 2. PILOT PLANT CONCENTRATION FLOWSHEET

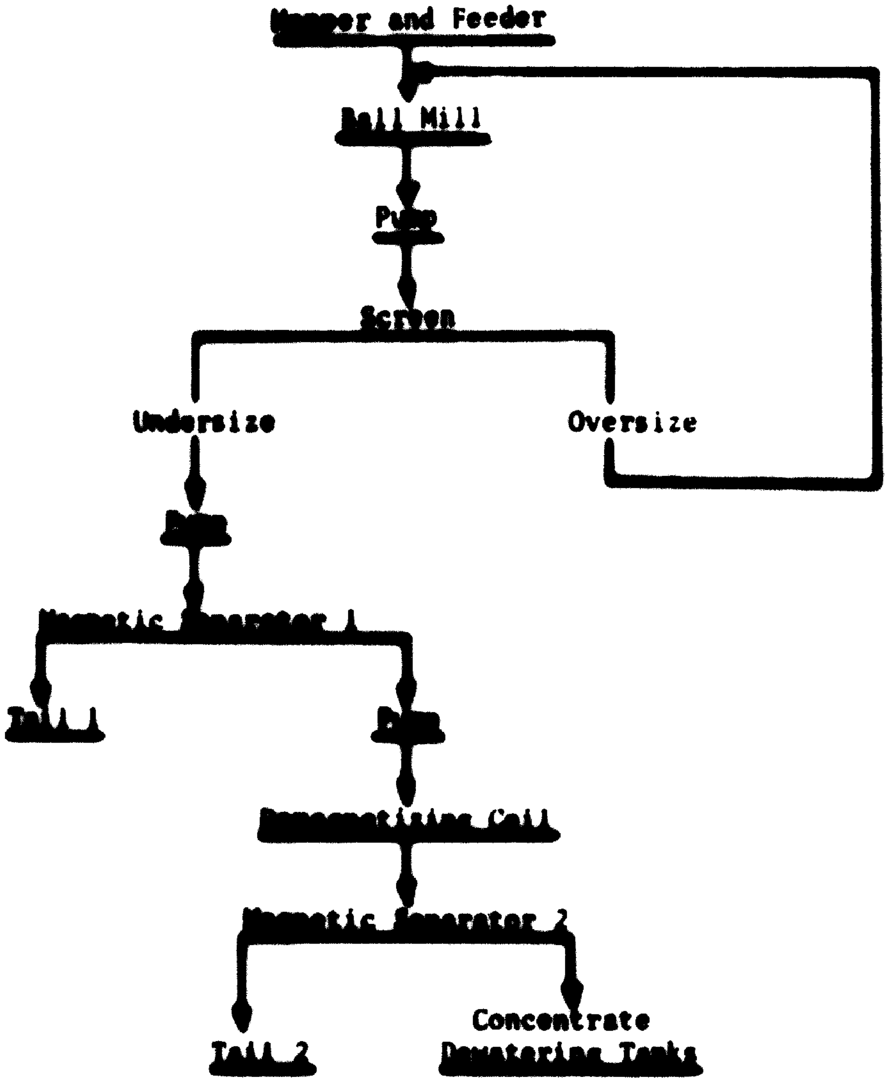

TABLE 5. Assays and Size Distributions for Pilot Concentrations Samples

		% DT					% On				
A Series	%Fe	mag Fe	35	48	65	100	150	200	270	325	-325
Feed	56.25	53.60	0.22	3.56	4.44	8.44	7.47	9.78	4.93	4.00	57.16
Sweco U Size	56.79	55.08			0.14	0.82	2.04	5.10	3.95	4.08	83.88
1 Mag Tail	12.28	1.83					not available				
1 Mag Conc	61.30	59.96			0.36	1.00	2.28	5.02	3.70	4.11	83.53
2 Mag Tail	35.12	23.64					not available				
2 Mag Conc	62.21	60.29			0.24	0.96	1.97	4.42	3.46	4.09	84.86
B Series											
Feed	56.30	53.60	0.36	3.33	4.53	6.52	6.88	11.16	5.07	3.91	58.22
Sweco U Size	56.83	54.88			0.35	0.83	2.08	4.86	3.82	4.17	83.80
1 Mag Tail	12.20	2.43					not available				
1 Mag Conc	61.34	59.60			0.42	1.32	2.42	5.01	3.60	4.21	82.93
2 Mag Tail	35.20	23.64					not available				
2 Mag Conc	62.03	60.19			0.40	1.24	2.40	4.84	3.80	4.32	83.00
C(at end of run) Ball Mill Disch.	56.59	54.61			0.65	1.60	3.27	6.55	4.47	4.65	78.80

Combined Conc A & B		
	Fe	62.11
	S	0.159
	SiO_2	6.50

TABLE 6. Material Balance for Pilot Plant Concentration

	Actual Avg		Adjusted		Calc Solid Flow lb/hr	Solid Flow % Feed	Recovery	
	Fe	DTmagFe	Fe	DTmagFe			Fe	DTmagFe
Feed	56.28	53.60	56.57	54.10	70.80	100.00	100.00	100.00
Sweco U Size	56.81	54.98	56.57	54.10	70.80	100.00	100.00	100.00
1 Mag Tail	12.24	2.13	12.24	2.17	6.88	9.72	2.10	0.39
1 Mag Conc	61.32	59.78	61.34	59.69	63.92	90.28	97.90	99.61
2 Mag Tail	35.16	23.64	35.16	23.65	1.69	2.39	1.49	1.05
2 Mag Conc	62.12	60.24	62.05	60.67	62.23	87.89	96.41	98.56

TABLE 7. Pelletizing Data Characteristics

	Concentrate	Green Ball	Fired Pellet
Specific Gravity	4.58	-	-
Surface Area (Blaine)*	7420 cm^2/g	-	-
Bentonite	-	0.8%	-
Moisture	-	17%	-
18 inch drop, ave.	-	7	-
range	-	5-12	-
Wet strength, ave lb	-	6.0	-
range lb	-	4.5-8.0	-
Dry strength, ave lb	-	7.5	-
range lb	-	4.5-9.5	-
Size, in.	-	3/8 - 1/2	5/1 - 7/16
Compresion, ave lb	-	-	520
range lb	-	-	200-950
Tumble Index (600 g) + 1/4 inch	-	-	97.1%
- 1/4 inch + 28M	-	-	2.0%
- 28M	-	-	0.9%
Shrinkage	-	-	~35%
Chem Assay			
Fe			59.68
Fe^{++}			0.16
Mn			1.63
SiO_2			7.18
Al_2O_3			1.73
P			0.33
S			0.011

* Blaine measured at 0.6 porosity, the minimum porosity readily attainable. Surface usually measured at 0.5 and therefore not directly comparable.

TABLE 8. Calculation of Work Index from Pilot Plant Data

Pilot Ball Mill

Dimensions 1 ft dia. x 2 ft

Weight of Balls 260 lb @ 290 lb/cu ft

Speed 68 rpm

Feed Rate 70.8 lb/hr → 0.0354 NT/hr

Vp fraction of mill volume occupied by balls 0.570

Cs critical speed 0.888

$Kwb = 3.1\ D^{0.3}\ (3.2 - 3\ Vp)\ Cs\ (1 - 0.1/2^{9-10\ Cs})$

Mill Power = 3.73 x 260/2000 = 0.484 KW

Correction to 8 ft dia. mill $f = (D/8)^{0.2} = 0.660$

Energy consumed = W = 0.484 x 0.660/0.0354 = 9.02 KWH/NT ore in 8 ft mill

P_{80} = 39 microns $10/\sqrt{P_{80}} = 1.601$

F_{80} = 120 " $10/\sqrt{F_{80}} = \underline{0.913}$

0.688

$W_i = 9.02/0.688 = 13.1$ KWH/NT

FIGURE 3. Overall Commercial Flowsheet Crude Ore Thru Pelletizing

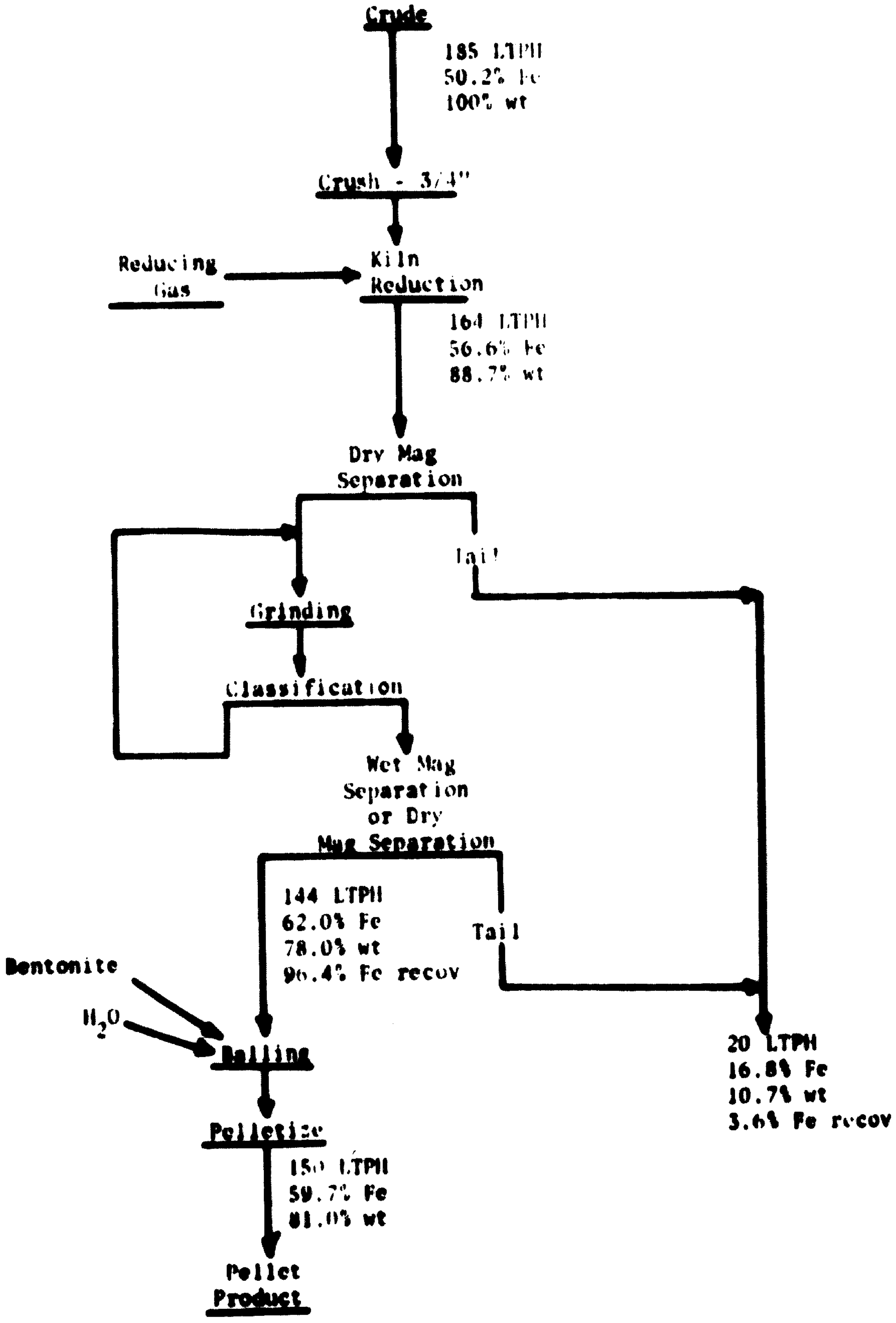

TABLE 9. Grinding Energy Requirement Calculations

Crushing to 80% passing 1/2"

$W_i = 13$ $P_{80} = 12{,}700$ microns $F_{80} = \infty$

$$W = \frac{10W_i}{\sqrt{P_{80}}} = 1.5 \text{ KWH/NT} = 1.7 \text{ KWH/LT crude}$$

Rod Mill and Ball Mill Grinding to 80% passing 32 microns

$W_i = 13$ $P_{80} = 39$ microns $F_{80} = 12{,}700$ microns

$$W = W_i\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right) = 19.3 \text{ KWH/NT} = 21.6 \text{ KWH/LT roasted crude}$$

or 19.2 KWH/LT crude

(Note: These energy requirements are based on 8 ft. dia. mills and would be reduced by factor $(D/8)^{0.2}$ for larger diameter mills.)

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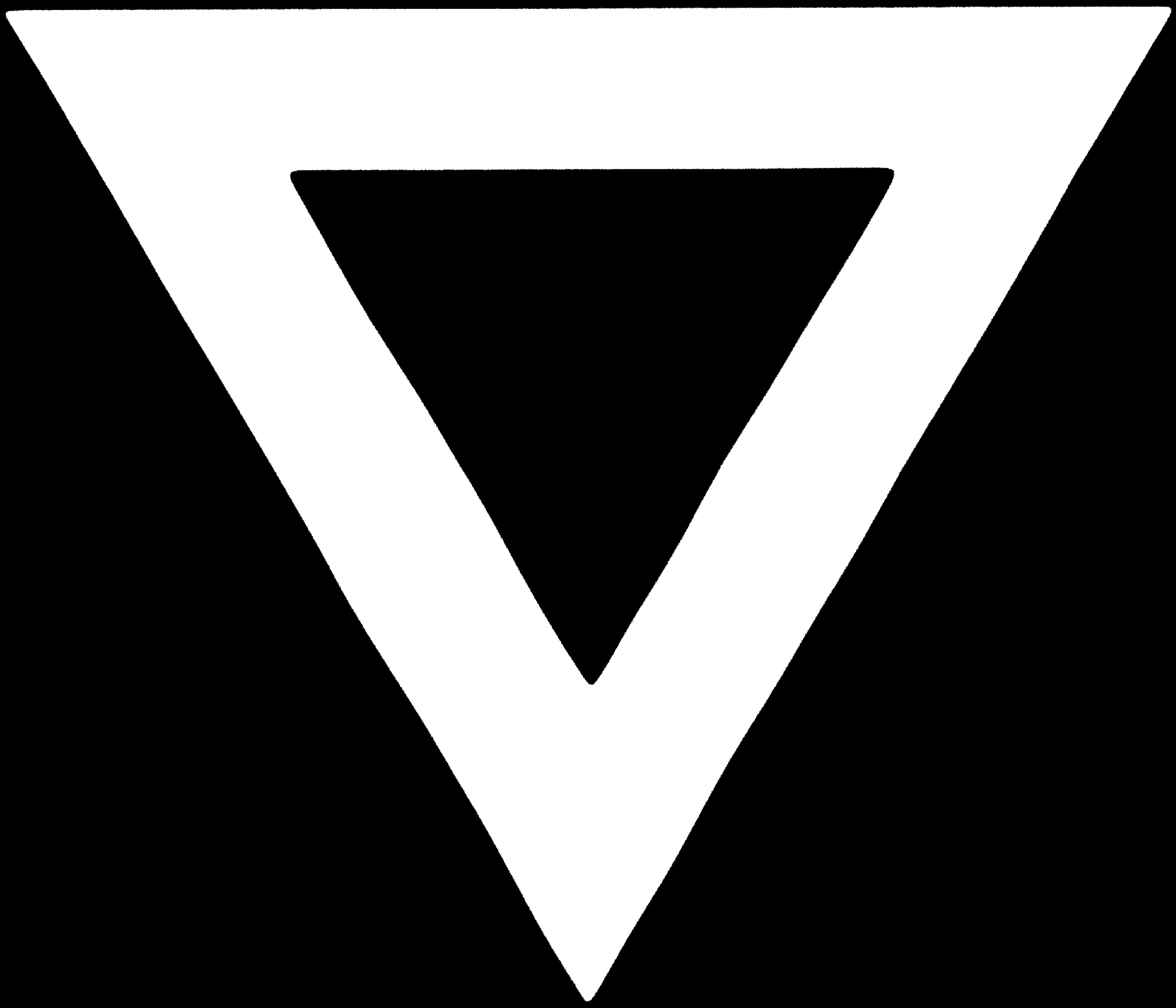

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