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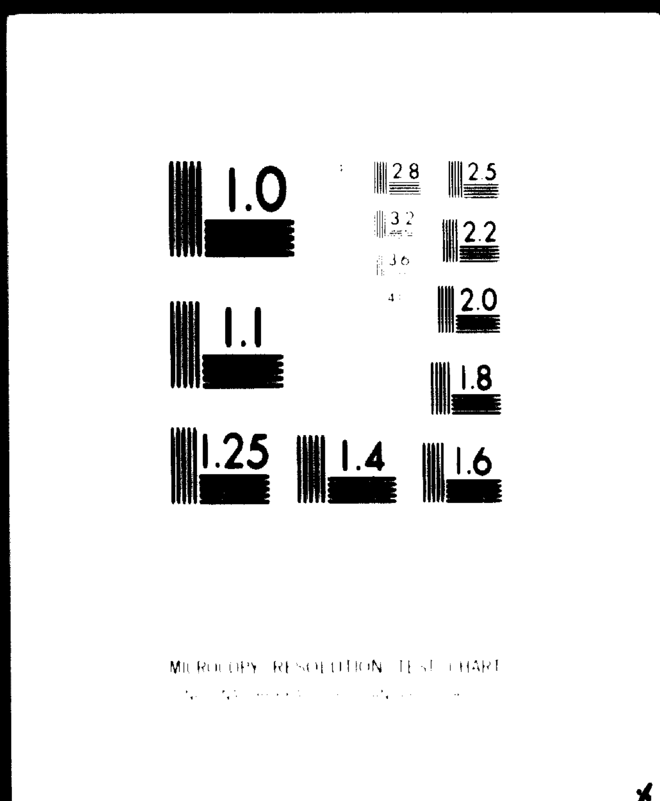


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# FINAL REPORT

## BENCH AND BAG SCALE TESTS ON THE REDUCIBILITY CHARACTERISTICS OF IRANIAN AND INDIAN ORES

UNITED NATIONS INDUSTRIAL DEVELOPMENT ORGANIZATION

UNIDO CONTRACT NO. 70/50

000564

PREPARED BY

Swindell-Dressler Company
A Division of Pullman Incorporated
Pittsburgh, Pennsylvania
U.S.A.

S-D CONTRACT NO. 50467
NOVEMBER 1, 1971

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## TABLE OF CONTENTS

## INTRODUCTION

In September 1970, The United Nations Industrial Development Organization (UNIDO) awarded Swindell-Dressler Company, Division of Pullman Incorporated the contract (UNIDO Contract No. 70/50) for the bench and bag scale tests of Iranian and Indian iron ores and iron oxide pellets.

The purpose of this test program was to qualitatively establish whether or not the reducibility characteristics of the test samples of the iron ores and oxide pellets are equal to better, or poorer than the Encino (Mexican) iron ore which has been processed commercially in the HyL sponge iron plants at Monterrey, Mexico. Also a qualitative comparison was made with the Alzada oxide pellets which are processed in the HyL sponge iron plants. The results also indicate which ores or pellets appear unsuitable for reduction by the HyL process and should not be further tested.

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 Shams Abad Iranian Iron Ore (Sample No. 50487-A-3) was performed for Swindell-Dressler Company by the Mineral Resources Research Center, University of Minnesota, Minneapolis, Minnesota. Their report is in Section 5.

Samples tested were:

Iranian Ores

1. Niassar Kashan Iron Ore - Sample No. 50487-A-1

   This sample was from Niassar Iron Mine located 40 KM west of Kashan, Iran.

2. Semnan Iron Ore Deposit No. 1 - Sample No. 50487-A-2-1

   This sample was from the Semnan Iron Mine located 10 KM north of Semnan, Iran.

3. Semnan Iron Ore Deposit No. 2 - Sample No. 50487-A-2-2

   This sample was from the Hamyard Iron Ore Mine located 100 KM east of Semnan.

4. Shams Abad Iron Ore - Sample No. 50487-A-3

   This sample was from the Shams Abad Iron Mine located 65 KM northwest of Arak, Iran. This sample underwent beneficiation tests. Pellets produced from the obtained concentrate, wera used in the bench and bag scale reducibility tests.

Indian Oras

1. Hospet Iron Ore - Sample No. 50487-B-1

   This sample was from Hospat Iron Ore deposit in India.

2. Donomalai Iron Ore - Sample No. 50487 - B-2

   This sample was from tha Donomalai Iron Ore Deposits locatad in the Hospet ragion of India.

3. Iron Oxide Pellets - Sample No. 50487-B-3

   This sample of pallats was from the Chowgule pelletising plant located at Pale (Goa) India.

## SUMMARY OF RESULTS

1. Iranian Ores

The samples of the Kashan and Semnan ores tested poorer than Encino ore and further testing is not recommended.

The sample of iron oxide pellets as produced from the beneficiated Shams Abad ore tested equal to the Encino (Mexican) ore. It is recommended that additional studies be conducted to determine the estimated operating and capital costs for the beneficiation and pelletizing process. Pellets, as produced, appear suitable for HyL process.

2. Indian Ores

The samples of the Hospet and Donamalai iron ores tested poorer than Encino (Mexican) ore and further testing is not recommended.

The sample of the iron oxide pellets from Chowgule Pelletizing Plant tested better than the Encino (Mexican) ore and is the most suitable of all the samples tested for the HyL process.

### Individual Sample Results

1. Niassar Iron Ore: from Iran

   Iron content: 65 to 68% by weight

   Low metallization compared to Encino (Mexican) ore.

   Considerable size reduction and some fines formation.

   Sulfur content of 0.17 to 0.258% requires pretreatment before reduction.

   Conclusion: not suitable for reduction by HyL process.

2. <u>Semnan Iron Ore Deposit No. 1,</u> from Iran

   Iron content: wide variation in analyses of various samples-

   62.8 to 68%.

   Low metallization compared to Encino (Mexican) ore.

   Ore has tendancy to fuse (agglomerate) under reduction conditions.

   Some size reduction and fines production.

   Sulfur content of 0.015 to 2.5% indicates requirement for pretreatment before reduction.

   Conclusion: not suitable for reduction by HyL process.

3. <u>Semnan Iron Ore Deposit No. 2</u>, from Iran

   Iron content: 61.6 to 62.0%

   Good metallization compared to Encino (Mexican) ore but sample had considerable size reduction and some fines production.

   Conclusion: although good metallization, size reduction and fines are a disadvantage; not ideally suitable for reduction by HyL process.

4. <u>Shams Abad Ore</u>, from Iran

   Iron content of ore as received: 46%

   This ore underwent beneficiation tests with the aim to produce a 64% Fe concentrate. The beneficiation tests indicated that anionic silica flotation of crude ore ground to a fine size was not effective, but fine grinding, roasting to convert iron oxides to magnetite, and magnetic concentration did produce concentrate grades in the range of 60 to 62% Fe at iron recoveries of 95% or higher.

Pelleta produced from concentrate had an iron content of 59 to 62%.

Reduction tests showed good metallization when compared to Encino (Mexican) ore with no size reduction or fines formation.

Conclusion: Pellets appear suitable for HyL process.

5. Hospet Iron Ore, from India

Iron content: 67 to 68%

Good metallization compared to Encino (Mexican) ore but considerable size reduction and fines production.

In single particle test samples aplit and reduction curves could not be developed..

Conclusion: not ideally suitable for HyL process.

6. Donamalai Iron Ore, from India

This was a composi sample from several types of run of mine ore - iron content 68%.

Good metallization when compared to Encino (Mexican) ore but showed tendancy to agglomerate under reduction conditions with considerable aize reduction and fines production.

Conclusion: not ideally auitable for HyL reduction.

7. Iron oxide pellsta from Chowgule Pelletizing Plant, India

Iron content: 66.8 to 68 1%

Better metallization when compared to Encino (Mexican) ore and approximately requal to Alzada (Mexican) oxide pellets.

Excellent physical properties under reduction conditions.

Conclusion: pellets appear suitable for HyL process and gave the best results of all samples tested.

*Swindell-Dressler Company*

# LABORATORY EVALUATION

of

# UNIDO IRON OXIDE LUMP AND PELLET ORE SAMPLES

*UNIDO CONTRACT 70/50*


Report by: ______________
[illegible]

Approved by: ______________
[illegible]



SD Contract 30487
Development Division
November 3, 1971

## I - INTRODUCTION

This report contains the results of standard bench scale reducibility evaluation tests conducted on the seven iron oxide lump/pellet ore samples submitted by the United Nations Industrial Development Organisation (UNIDO):

(1) Sample No. 50487-A-1: Niassar Kashan Iranian lump ore.

(2) Sample No. 50487-A-2-1: North of Semnan Iranian lump ore.

(3) Sample No. 50487-A-2-2: Mamyard Semnan Iranian lump ore.

(4) Sample No. 50487-A-3: Shams Abad Iranian pellets.

(5) Sample No. 50487-B-1: Noapet Indian lump ore.

(6) Sample No. 50487-B-2: Donimalai Indian lump ore.

(7) Sample No. 50487-B-3: GOA Indian pellets.

The standard reducibility evaluation tests include screen and chemical analysis of the raw samples as well as single particle and batch reduction runs.

The data obtained from the reduction tests were evaluated and compared against the reduction characteristics of our Standards for the HyL process; namely, the Encino lump ore or the Alzada pellets.

## II - SCREEN ANALYSES

Each lump/pellet screen analyses test was run on only 20% of the thoroughly blended sample. The rest were sent to Monterrey, Mexico, for further HyL plant testing.

Although no problem was encountered in screening the pellet samples, the lump ores did contain appreciable amounts of material larger than 50.8 mm. Lumps of this size were crushed so that the entire sample passed through a 2 inch sieve (50.8 mm), but retained on a 1/2 inch sieve (12.7 mm). This is the acceptable size range for lump ore feed to conventional HyL reactor. This was done to all of the ore samples. Nominal oxide pellet size for HyL charge is +3/8", -5/8".

| Sample | Sample Wgt. Kilos | % By Weight Retained | | | | | | |
|---|---|---|---|---|---|---|---|---|
| | | 50.8mm | 38.1mm | 25.4mm | 19.05mm | 12.7mm | 9.53mm | Pan |
| 50487-A-1 Niassar Kashan | 28.9 | - | 34.60 | 41.52 | 14.56 | 9.40 | - | - |
| 50487-A-2-1 North of Semnan | 19.30 | - | 36.96 | 44.81 | 14.46 | 3.77 | - | - |
| 50487-A-2-2 Hamyard Semnan | 18.4 | - | 45.20 | 44.59 | 6.55 | 3.70 | - | - |
| 50487-A-3 Shams Abad | 20.996 | - | - | - | - | 27.02 | 69.71 | 3.24 |
| 50487-B-1 Hospet | 19.07 | - | 33.35 | 51.70 | 12.69 | 2.30 | - | - |
| 50487-B-2 Donimalai | 26.0 | - | 27.92 | 34.50 | 30.58 | 7.00 | - | - |
| 50487-B-3 GOA | 17.78 | - | - | - | - | 67.14 | 19.19 | 13.73 |

## III - CHEMICAL ANALYSES

| | Encino Lump | Alzada Pellet | 50487-A-1 Niassar Kashan | 50487-A-2-1 North of Semnan | 50487-A-2-2 Hamyard Semnan | 50487-A-3 Shams Abad | 50487-B-1 Hospet | 50487-B-2 Donimalai | 50487-B-3 GOA |
|---|---|---|---|---|---|---|---|---|---|
| % Fe | 66.49 | 66.21 | 67.88 | 68.06 | 61.97 | 62.00 | 68.16 | 68.00 | 66.88 |
| % FeO | 11.46 | nil | 12.60 | 27.76 | 3.82 | 4.00 | 6.93 | nil | 1.18 |
| % $Fe_2O_3$ * | 56.84 | 94.66 | 43.00 | 4.75 | 75.86 | 75.35 | 74.33 | 97.22 | 91.67 |
| % $Fe_3O_4$ ++ | 36.94 | nil | 52.24 | 80.46 | 12.31 | 12.85 | 22.35 | nil | 3.81 |
| % $SiO_2$ | 3.70 | 2.18 | 2.30 | 0.74 | 4.98 | 4.91 | 3.16 | 1.21 | 2.23 |
| % S | 0.007 | 0.004 | 0.17 | 0.012 | 0.04 | 0.008 | 0.009 | 0.003 | 0.004 |
| % $P_2O_5$ | 0.38 | 0.52 | 0.05 | 0.01 | 0.01 | 0.03 | 0.25 | 0.008 | 0.19 |
| % Gangue | 2.13 | 2.64 | 2.24 | 5.03 | 6.80 | 6.85 | nil | 1.56 | 2.10 |

The above chemical analysis tests were conducted on -100 mesh oven-dried samples.

++ Calculated assuming that FeO is unstable and each FeO mole would tie with it $Fe_2O_3$ mole to form $Fe_3O_4$.

* Hematite, does not include the $Fe_2O_3$ tied up with FeO in the magnetite.

## IV - SINGLE PARTICLE GASEOUS REDUCTION TESTS

These reduction experiments were conducted in a Stanton thermogravimetric apparatus (Model HT), modified to operate with reducing gases. The reduction conditions are:

| | |
|---|---|
| R-Gas Composition | 61.5% $H_2$ |
| | 15.7% CO |
| | 7.1% $CO_2$ |
| | 15.7% $N_2$ |
| R-Gas Flow Rate | 0.28 liters/$cm^2$/min |
| Average Pellet Diameter | 1.32 cm |
| Pellet Weight Range | 4.0 - 5.0 g |
| Lump Weight Range | 5.0 - 6.0 g |
| Reduction Temperatures | 800 - 900 - 1000°C |

Each particle was heated to the desired temperature level in a stream of nitrogen and reduced under isothermal conditions. The data obtained from a test were evaluated by plotting the percent reduction fraction (R)* vs time (t) and comparing such curve with the standard reduction curve for Alzada pellets or Encino lump. Also, the temperature dependence of the chemical reaction rate constant (i.e., the energy of activation "ΔH" of chemical kinetic rate constant) was computed from the slope of the tangent to the R vs t curve at time t <2.5 minutes (when gas diffusion resistance is negligible).

The results of the single particle reduction experiments are shown in the attached figures.

$$*(R) = \frac{\text{Oxygen removed (or weight loss)} \times 100}{\text{total reducible oxygen available}}$$

## V - BATCH REDUCTION TESTS

In each experiment, one kilo batch of -1/2 inch + 3/8 inch (-12.7mm + 9.51mm) lump particles was reduced in a 5 inch I.D. stainless steel capsule placed in an electrically heated furnace. The reducing gas flow rate was 20 l/min (at room temperature). The gas composition was similar to that used in the single particle reduction tests. The reducing gas was passed through an alumina preheater before it reached the ore bed. The reduction was done isothermally for 45 minutes with the ore bed at about 900°C. The bed was heated and cooled in a stream of nitrogen.

Samples (8 - 10 particles) were removed from the top and bottom portions of each reduced batch and analysed for percent metallisation. Nevertheless, spot checking analyses were frequently done on particles removed from the middle of the bed. The remainder of the batch was then pulverised and also analysed for percent metallisation. The results obtained are listed on the following page.

## METALLIZATIONS - ONE KILO REDUCTION RUNS

| Sample | Batch Position | Total Fe % | Metallic Fe % | Metallization % |
|---|---|---|---|---|
| Encino | Top | 71.23 | 17.27 | 24.25 |
| | Bottom | 81.42 | 54.22 | 66.59 |
| | Composite | 75.37 | 21.04 | 27.92 |
| Alzada Pelets | Top | 73.51 | 4.40 | 5.99 |
| | Middle | 77.61 | 25.38 | 32.70 |
| | Bottom | 88.25 | 74.94 | 84.92 |
| | Composite | 76.50 | 28.37 | 37.05 |
| 50487-A-1 Niassar Kashan | Top | 76.27 | 1.99 | 2.59 |
| | Middle | 78.12 | 22.14 | 28.34 |
| | Bottom | 84.71 | 51.84 | 61.30 |
| | Composite | 78.83 | 30.43 | 38.60 |
| 50487-A-2-1 North of Semnan | Top | 78.30 | 19.33 | 24.69 |
| | Bottom | 92.84 | 81.25 | 87.52 |
| | Composite | 77.83 | 25.63 | 32.93 |
| 50487-A-2-2 Hamyard Semnan | Top | 70.84 | 13.79 | 19.47 |
| | Middle | 73.48 | 17.81 | 24.24 |
| | Bottom | 82.86 | 64.76 | 78.16 |
| | Composite | 74.20 | 23.33 | 31.44 |
| 50487-A-3 Shams Abad | Top | 66.97 | 9.07 | 13.54 |
| | Middle | 71.70 | 32.37 | 45.44 |
| | Bottom | 77.80 | 59.79 | 76.85 |
| | Composite | 72.73 | 39.90 | 54.86 |
| 50487-B-1 Hospet | Top | 80.69 | 28.59 | 35.43 |
| | Bottom | 90.83 | 73.35 | 80.78 |
| | Composite | 78.00 | 24.47 | 31.75 |
| 50487-B-2 Donimalai | Top | 75.43 | 4.20 | 5.57 |
| | Middle | 84.49 | 41.52 | 56.24 |
| | Bottom | 88.44 | 62.22 | 70.35 |
| | Composite | 75.53 | 29.13 | 38.56 |
| 50487-B-3 GOA Pellets | Top | 77.62 | 20.23 | 26.06 |
| | Bottom | 91.12 | 85.42 | 93.74 |
| | Composite | 77.83 | 26.63 | 34.22 |

## VI - DISCUSSION

### A. Raw Ore and Pellet Analyses

The Donimalai sample (50487-B-2) is a composite of five different ores which were found to vary, among other things, in hardness. The amount of each ore received was in proportion to its estimated percent by weight present in the overall deposit. However, one type (with dark blue tint) was observed to be fragile and could be pulverized quite easily, so a fairly small amount actually remained in the composite sample tested.

The North of Semnan sample (50487-A-2-1) was comprised of two different ores. One type was light, grey in color, while the other was dense, with dark blue tint. Of the 19.3 kilos retained for bench scale testing, 17.5% by weight was from the greyish ore that contained a large amount of $SiO_2$, but only 7.54% total Fe (which was present as $FeCO_3$). The analysis of the "bluish" ore, which was used in the single particle and batch reduction tests, is listed in Table III.

The results of the screen analyses of the pellet samples (20 kilos) show that 3.24% of the Shams Abad pellets and 13.73% of the GOA pellets are not within the specified HyL size range of 12.7 mm to 9.53 mm.

Also, the Shams Abad pellets had noticeable "surface cracks," resulting, perhaps, from the sudden exposure to steep temperature gradient during the drying and thermal treatment processes.

### B. Single Particle and Batch Reduction Runs

The reduction characteristics of the UNIDO pellet samples were evaluated using Alsada pellets as the standard. In the following table, the percent reduction attained by GOA and Shams Abad pellets after 10, 20 and 30 minutes at each of the three temperature levels used, are compared with the results of the Standard Alzada pellets. The comparison factor (F) is the ratio between the percent reduction of an ore pellet to that of an Alzada pellet reduced under the same conditions of time and temperature.

| | | Alzada | | GOA | | Shams Abad |
|---|---|---|---|---|---|---|
| 1000°C | F | % Reduction | F | % Reduction | F | % Reduction |
| 10 min. | 1.00 | 77.0 | 0.90 | 70.5 | 0.78 | 60.0 |
| 20 | 1.00 | 96.0 | 1.00 | 96.7 | 0.94 | 89.8 |
| 30 | 1.00 | 99.0 | 1.00 | 99.5 | 0.97 | 95.6 |
| 900°C | | | | | | |
| 10 min. | 1.00 | 47 | 1.05 | 49.5 | 0.75 | 35.0 |
| 25 | 1.00 | 76 | 1.11 | 86.0 | 0.84 | 63.6 |
| 45 | 1.00 | 94 | 1.04 | 97.5 | 0.89 | 83.9 |
| 800°C | | | | | | |
| 10 min. | 1.00 | 41 | 0.93 | 38.0 | 0.73 | 27.8 |
| 30 | 1.00 | 77 | 0.96 | 74.0 | 0.76 | 56.3 |
| 50 | 1.00 | 93 | 0.97 | 90.5 | 0.80 | 72.0 |

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

Also, the reducibility curves (% Fraction Reduction vs Time) of the GOA and Shams Abad pellets at the three reduction temperature levels are plotted on the attached figures 1G thru 3G and 1SA thru 3SA.

It can be seen from these curves and from the above F factors, that the reduction characteristics of single GOA pellets are very similar to those of Alzada, while single Shams Abad pellets are less reducible than Alzada pellets.

If the chemical reaction rate constants (computed from the slopes of R vs t curves as: $t \to 0$) are plotted against the reciprocal of the absolute temperature (i.e., according to Arrhenius equation), the slope of the straight line obtained for each ore is an indication of the temperature dependency of the chemical reaction step of the ore reduction mechanism, from which the activation energies could be calculated (Figures 4G and 4SA). Results show the similarity between Alzada and Shams Abad ores dependence on temperature. However, the dependence of the chemical reaction rate of reduction, of the GOA ore pellets, on temperature seems to be higher than that of the Alzada Standard, which confirms the trend of the F factors.

The behavior of the UNIDO pellet samples in a packed bed as,compared to Alzada pellets,is shown on page 6. It can be seen that the metallization of the Shams Abad pellets was more uniform, because of its less reactivity, than the Alzada pellets which reduces, in packed beds, in a "reduction wave front" pattern.

It can also be noticed that the metallization of the GOA pellets in a packed bed seems to proceed, like Alzada, in a "reduction wave front pattern." However, the average metallization is approximately the same as that of the Alzada pellet bed.

Single particle data was not obtained for two of the lump ores:

(1) Particles of Hospet ore (50487-B-1) split during heat up to the reduction temperature and also during reduction. As a result, portions of each lump tested were lost and it was not possible to obtain continuous weight loss vs time curves.

(2) The Donimalai sample (50487-B-2) was a composite of five ores and since it was not possible to run single particle tests and know which type was used at each temperature level, no single particle tests were done for that sample.

The behavior of the Hospet and Donimalai ores in packed beds as compared to Encino ore is shown on page 6.

The metallization of the Donimalai packed bed was found to be of the "reduction wave front" pattern. The overall behavior of the Donimalai ore was found to be better than the Encino ore from packed bed reduction point of view.

The metallization of the Hospet composite was found to be low, relative to the analyzed top and bottom samples of the reduced batch (caused by gas channelling). However, the composite metallization is higher than that of the Encino standard. Many of the Hospet particles split into distinct layers during reduction and, as a result, underwent appreciable expansion. This splitting behavior seems to have improved the reduction process (exposes more area for reduction).

There was no difficulty in running single particle tests on the Niessar Kashan (50487-A-1), North of Semnan (50487-A-2-1) and Hamyard Semnan (50487-A-2-2) UNIDO lump ores. In the table on the next page, the percent reduction attained after various time intervals by each ore particle at the indicated temperature level was compared with the results obtained for the Encino ore particles.

| 1000°C | F | Encino % Reduction | Niassar Kashan F | Niassar Kashan % Reduction | North of Semnan F | North of Semnan % Reduction | Hamyard Semnan F | Hamyard Semnan % Reduction |
|---|---|---|---|---|---|---|---|---|
| 10 min. | 1.00 | 64 | 0.76 | 48.4 | 0.66 | 42.2 | 0.83 | 53 |
| 20 | 1.00 | 88 | 0.84 | 73.6 | 0.77 | 68.1 | 0.88 | 77 |
| 30 | 1.00 | 96 | 0.93 | 88.9 | 0.88 | 84.8 | 0.95 | 91 |
| **900°C** | | | | | | | | |
| 10 min. | 1.00 | 57 | 0.62 | 35.1 | 0.74 | 42.1 | 0.70 | 40 |
| 25 | 1.00 | 93 | 0.68 | 63.3 | 0.72 | 66.9 | 0.74 | 69 |
| 45 | 1.00 | 99 | 0.87 | 86.0 | 0.89 | 88.5 | 0.89 | 88 |
| **800°C** | | | | | | | | |
| 10 min | 1.00 | 49 | 0.43 | 21.1 | 0.88 | 42.9 | 0.65 | 32 |
| 30 | 1.00 | 89 | 0.55 | 49.2 | 0.87 | 77.3 | 0.67 | 60 |
| 50 | 1.00 | 99 | 0.68 | 67.3 | 0.92 | 90.9 | 0.75 | 74 |

Note: $F = \text{Reduction Fraction} = \dfrac{\text{\% Reduction, Test Particle}}{\text{\% Reduction, Encino Particle}}$

Also, the reducibility curves (% Fraction Reduction vs Time) of these ores at the three reduction temperature levels are plotted on the attached figures 1NK thru 3NK; 1NS thru 3NS and 1HS thru 3HS.

It can be seen from these curves and from the above F factors that, over the 800 - 900 - 1000°C reduction temperature range, the single Niassar Kashan, North of Semnan and Hamyard Semnan ore lumps are less reducible than single Encino ore particles.

Moreover, if the chemical reaction rate constants (computed from the slopes of R vs t as $t \rightarrow 0$) are plotted according to Arrhenius equation to obtain the temperature dependence (or the energy of activation) of the chemical reaction step of the reduction mechanism, Figures 4NS, 4NK and 4HS are obtained. One could conclude that the effect of temperature on the chemical reaction step of Niassar Kashan and Hamyard Semnan are more pronounced than that of North of Semnan.

Finally, the behavior of these ores in a packed bed, as compared to Encino, is shown on page 6.

A comparison of the composite metallization with the metallizations of the top and bottom portions, indicates that the packed beds of Niassar Kashan, North of Semnan, Hamyard Semnan and Encino ores did not reduce uniformly (gas channeling). However, the overall batch metallization of these three ores were higher than that of the Encino standard.

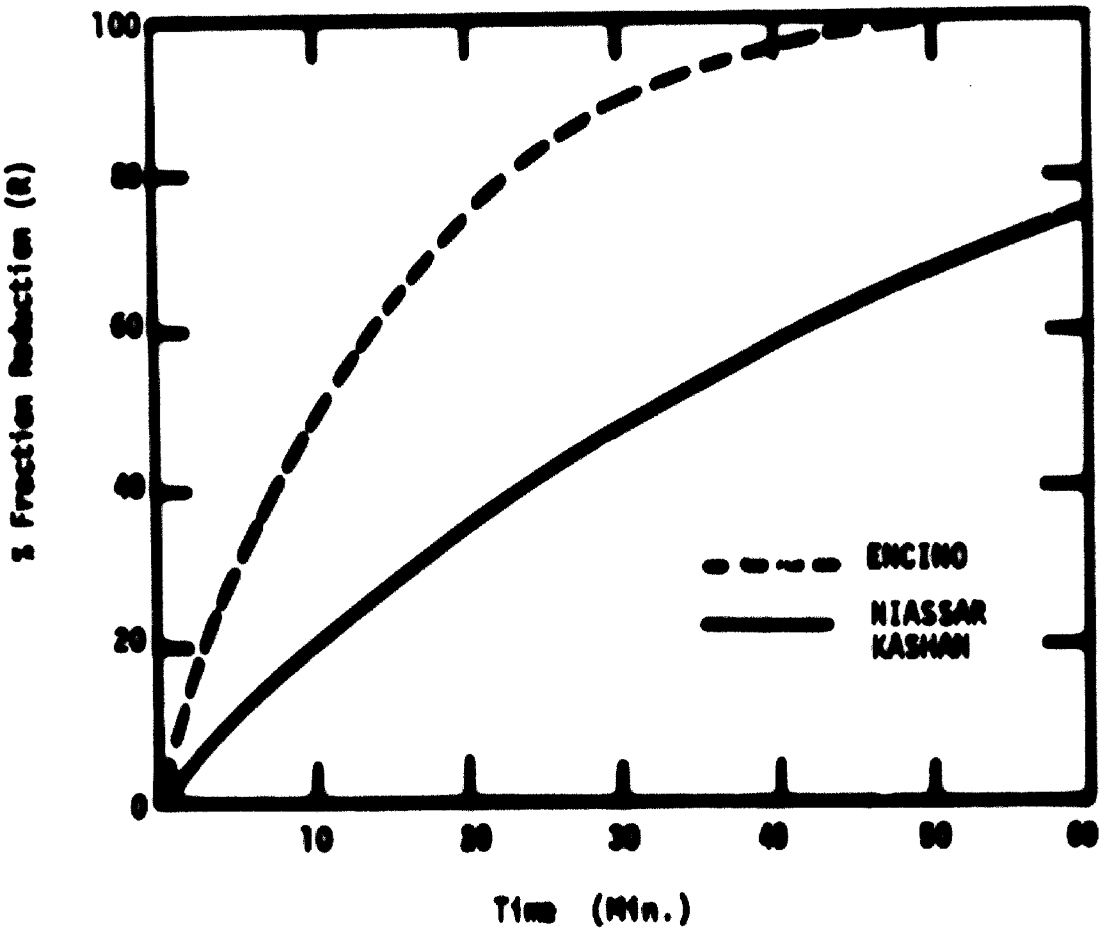
UNIDO

50487-A-1 - NIASSAR KASHAN ORE

SINGLE PARTICLE REDUCTION RATE

at 800°C

AS COMPARED TO ENCINO ORE




| | |
|---|---|
| R-Gas Flow Rate | 0.28 l/cm$^2$-min. |
| R-Gas Composition | 61.8% $H_2$ |
| | 15.7% CO |
| | 7.1% $CO_2$ |
| | 15.7% $N_2$ |

Fig: 10K

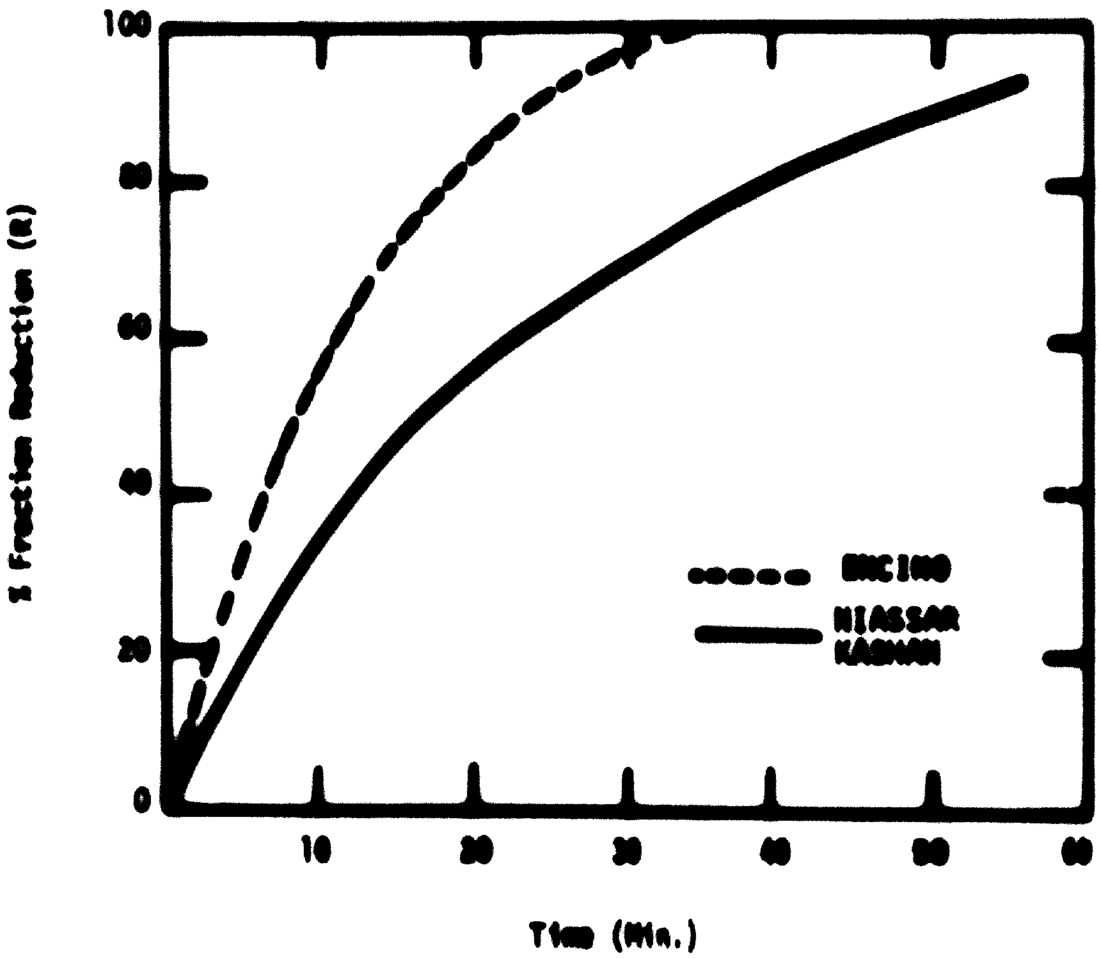
UNIDO

80487-A-1 - NIASSAR KASHAN ORE

SINGLE PARTICLE REDUCTION RATE

at 900°C

AS COMPARED TO ENCINO ORE




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.26 l/cm$^2$-min. | |
| R-Gas Composition | 61.5% | $H_2$ |
| | 15.7% | $CO$ |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig: [illegible]

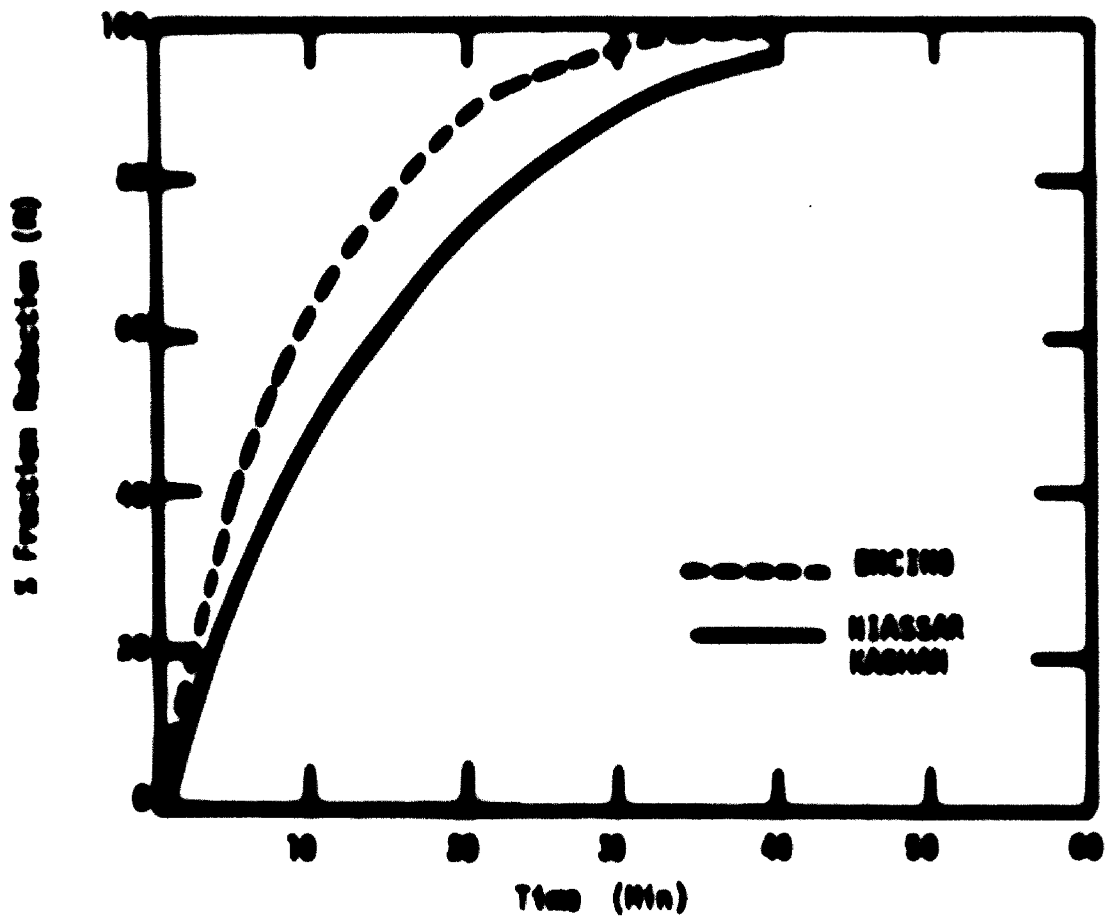
## UNIDO

## 80087-A-1 - NIASSAR KASHAN ORE

### SINGLE PARTICLE REDUCTION RATE

### at 1000°C

### AS COMPARED TO ENCINO ORE




| | |
|---|---|
| R-Gas Flow Rate | 0.20 l/cm$^2$-min. |
| R-Gas Composition | 61.5% $H_2$ |
| | 16.7% CO |
| | 7.1% $CO_2$ |
| | 16.7% $N_2$ |

Fig. [illegible]

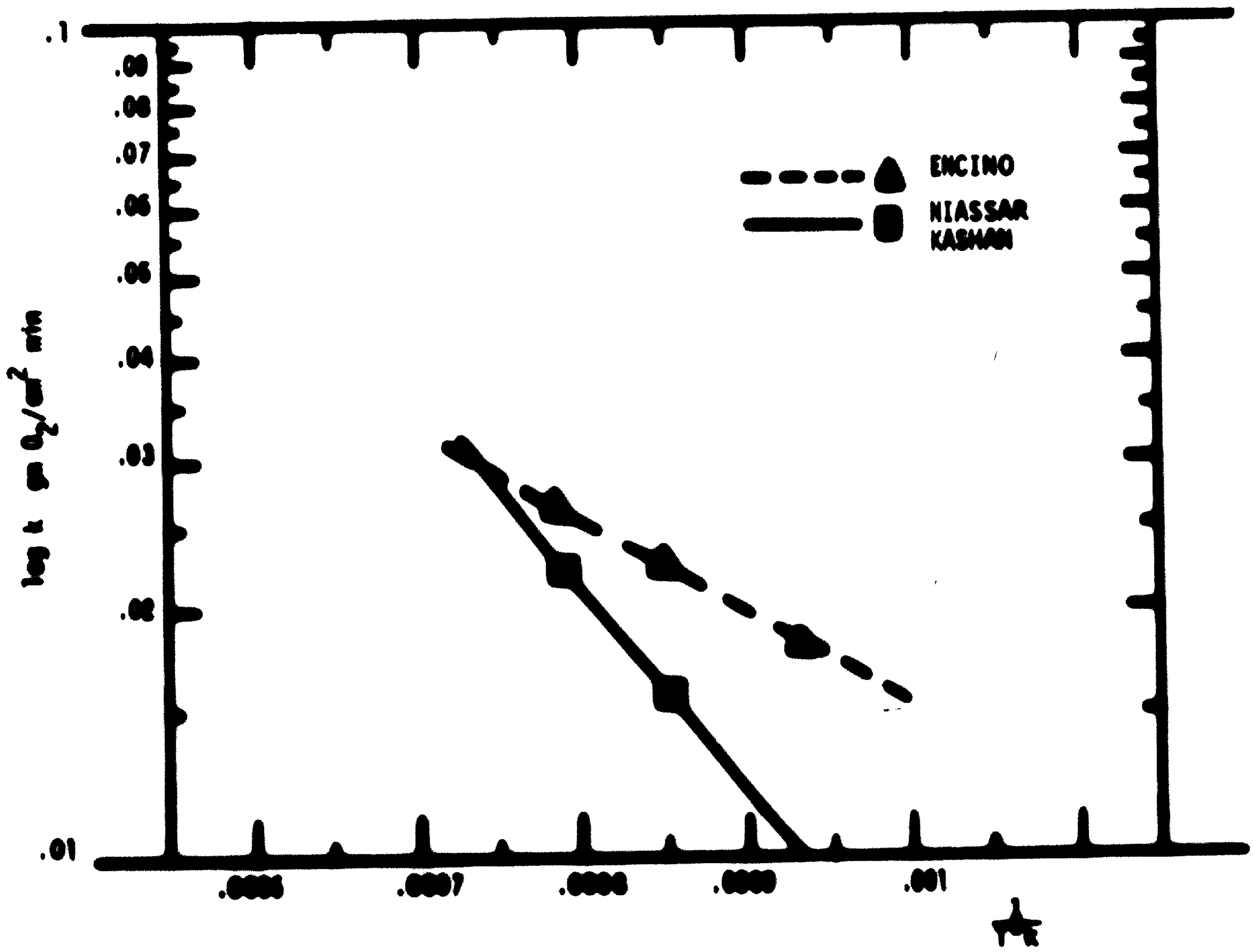
UNIDO

50407-A-1 - NIASSAR KASHAN ORE

TEMPERATURE DEPENDENCE COEFFICIENT

OF SINGLE PARTICLE KINETIC CONSTANT

AS COMPARED TO ENCINO ORE PARTICLES




ENCINO ORE $\Delta H$ = 4.9 k-cal/g mole
NIASSAR KASHAN $\Delta H$ = 10.5 k-cal/g mole

Fig: [illegible]

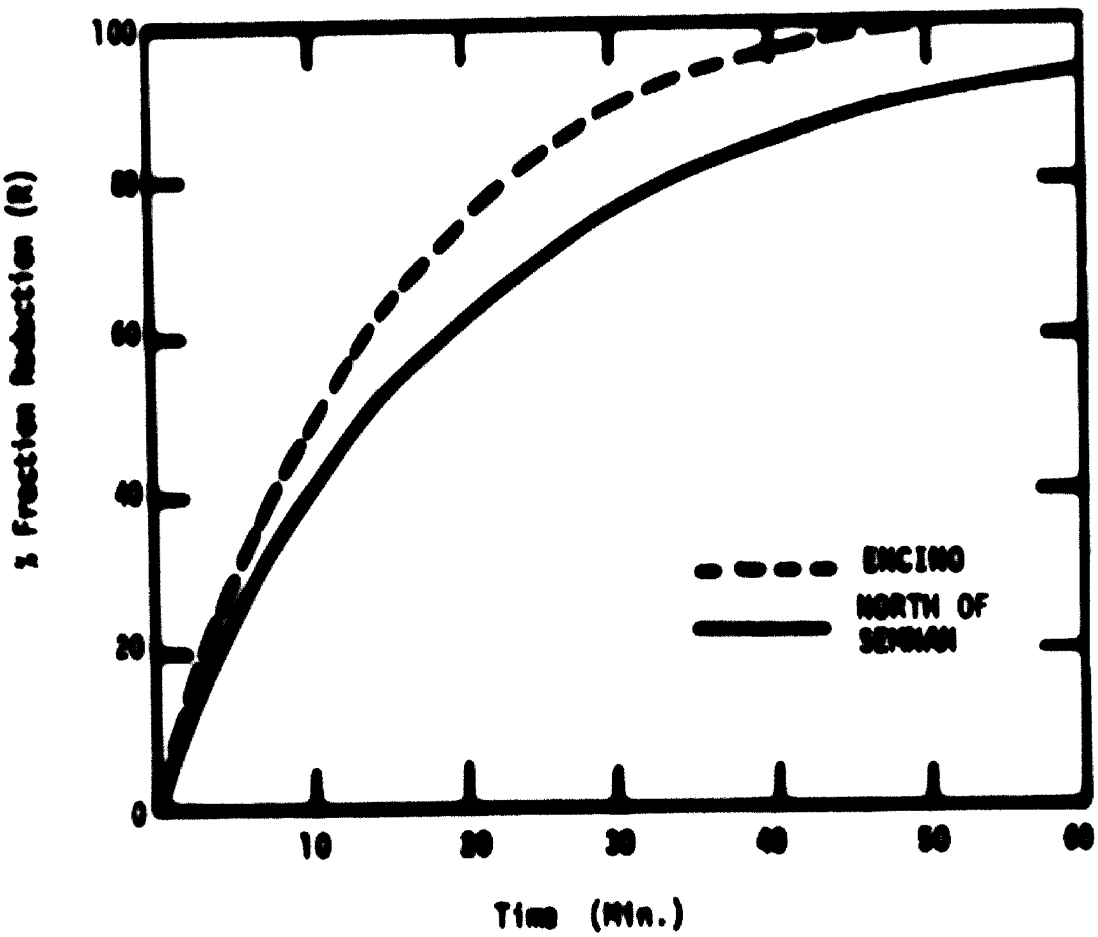
**UNIDO**

**50487-A-2-1 - NORTH OF SEMNAN ORE**

**SINGLE PARTICLE REDUCTION RATE**

**at 800°C**

**AS COMPARED TO ENCINO ORE**




| | |
|---|---|
| R-Gas Flow Rate | 0.20 l/cm$^2$-min. |
| R-Gas Composition | 61.8% $H_2$ |
| | 15.7% CO |
| | 7.1% $CO_2$ |
| | 15.7% $N_2$ |

**Fig. 10B**

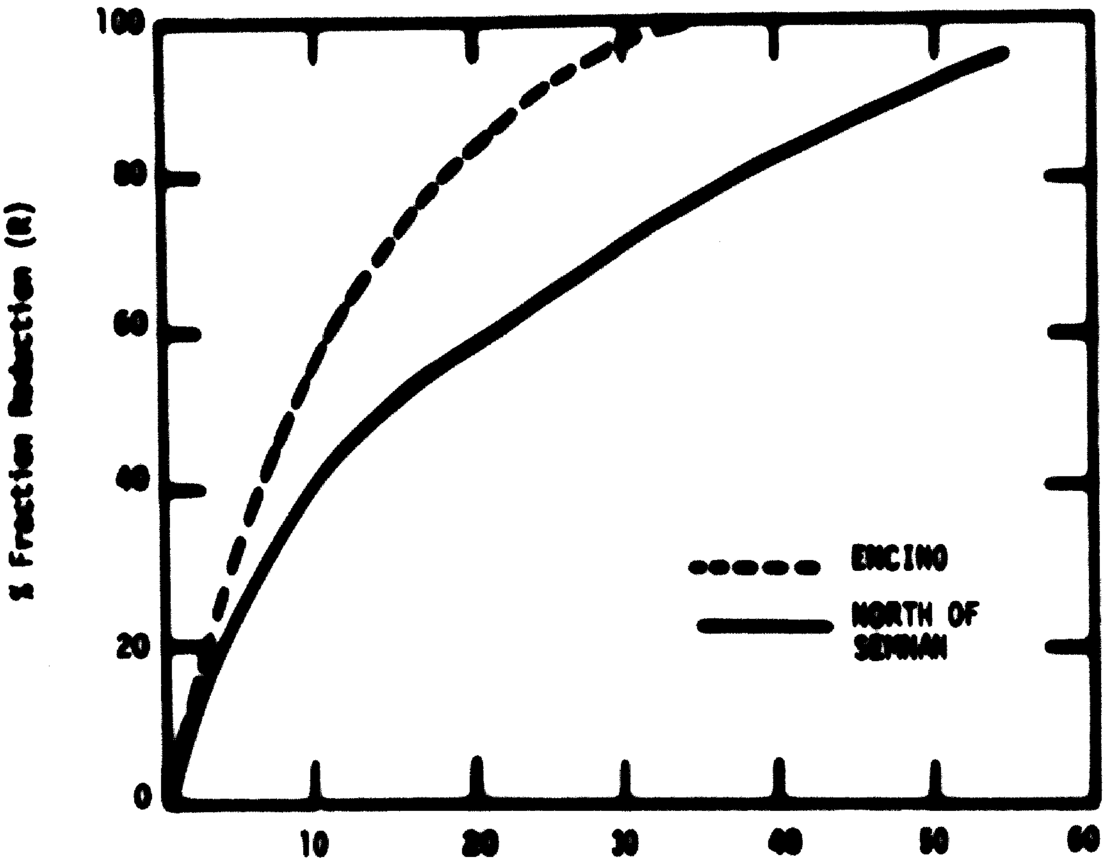
## UNIDO

## 50487-A-2-1 - NORTH OF SEMNAN ORE

### SINGLE PARTICLE REDUCTION RATE

### at 900°C

### AS COMPARED TO ENCINO ORE




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.28 1/cm²-min. | |
| R-Gas Composition | 61.5% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig: 2015

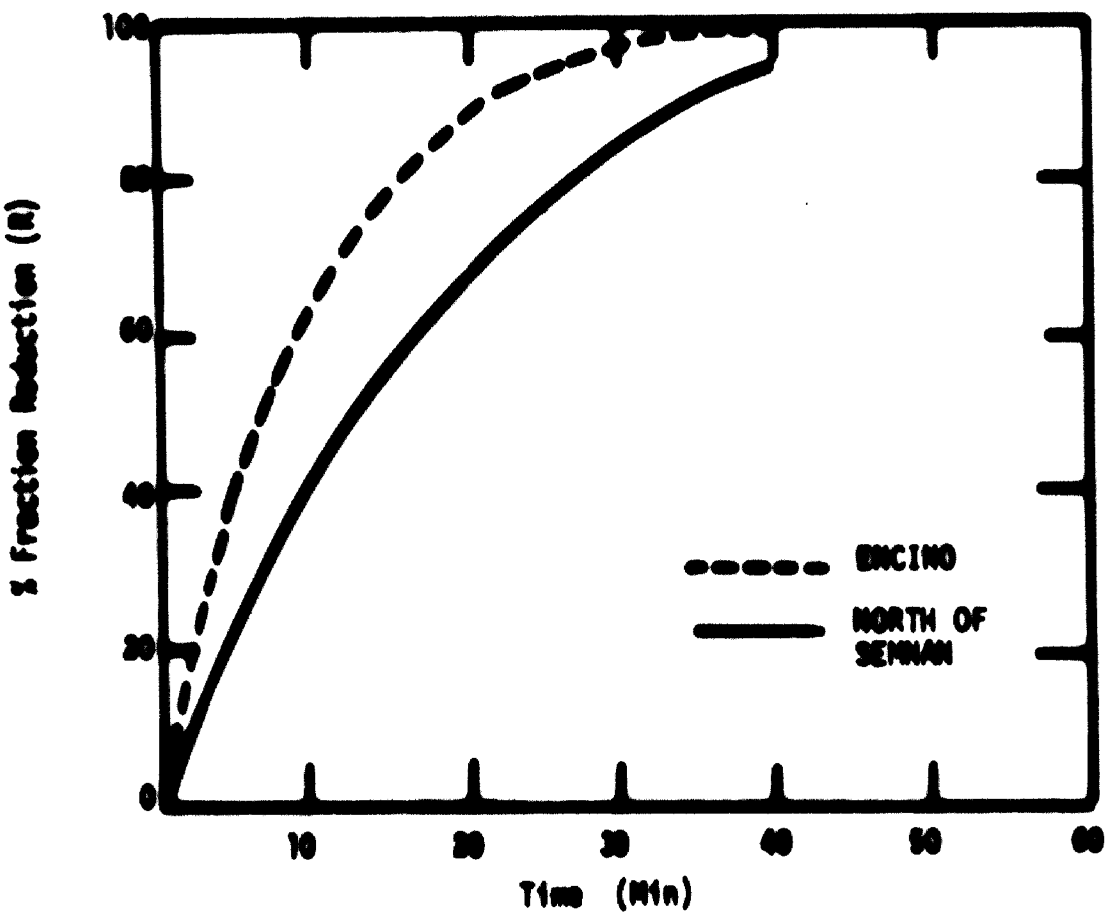
UNIDO

50487-A-2-1 - NORTH OF SEMNAN ORE

SINGLE PARTICLE REDUCTION RATE

at 1000°C

AS COMPARED TO ENCINO ORE



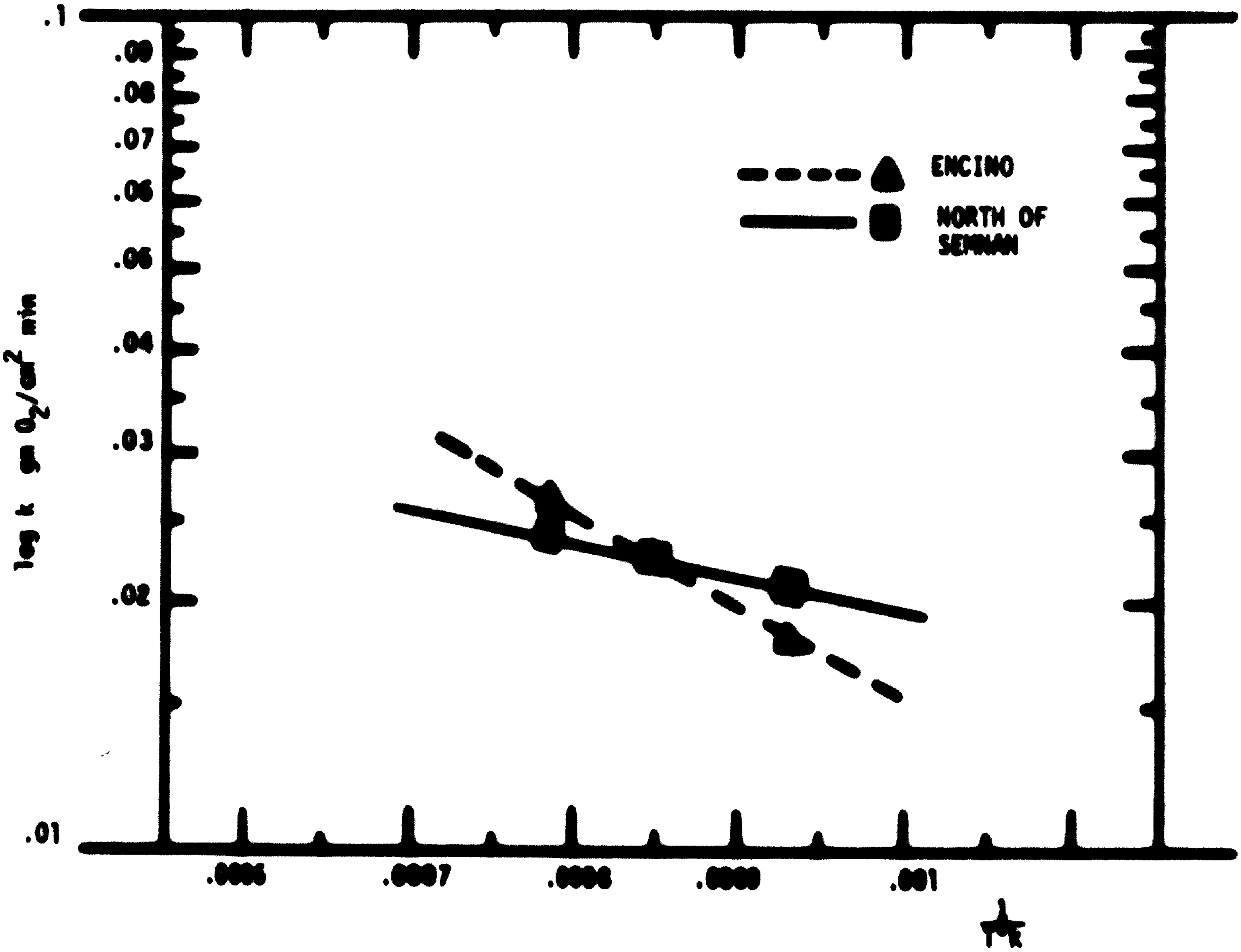

| | |
|---|---|
| R-Gas Flow Rate | 0.28 1/cm$^2$-min. |
| R-Gas Composition | 61.5% $H_2$ |
| | 15.7% CO |
| | 7.1% $CO_2$ |
| | 15.7% $N_2$ |

Fig: [illegible]

UNIDO

50487-A-2-1 - NORTH OF SEMNAN ORE

TEMPERATURE DEPENDENCE COEFFICIENT
OF SINGLE PARTICLE KINETIC CONSTANT
AS COMPARED TO ENCINO ORE PARTICLES




ENCINO ORE $\Delta H$ = 4.9 k-cal/g mole
NORTH OF SEMNAN $\Delta H$ = 1.85 k-cal/g mole

Fig: 0NS

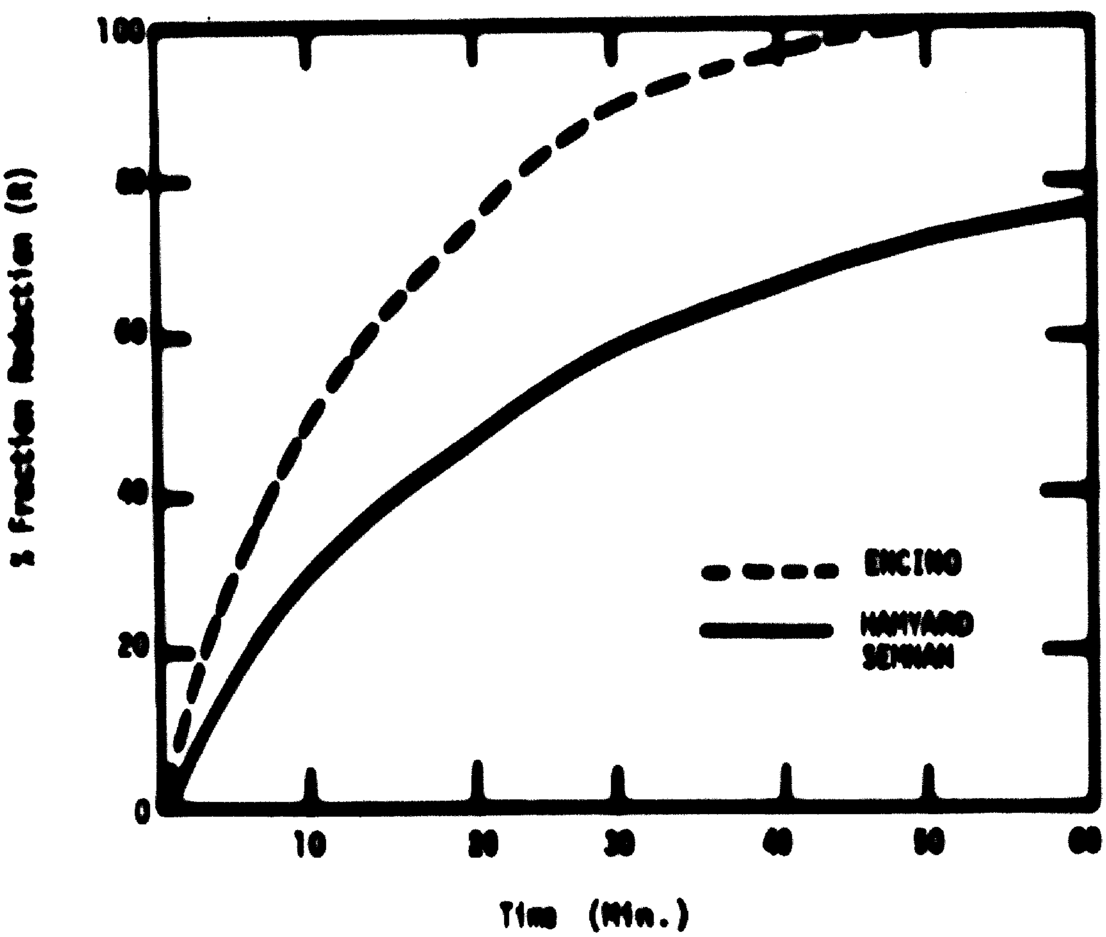
UNIDO

50487-A-2-2 - HAMYARD SEMNAN ORE

SINGLE PARTICLE REDUCTION RATE

at 800°C

AS COMPARED TO ENCINO ORE




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.28 | l/cm²-min. |
| R-Gas Composition | 61.8% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig. 1HS

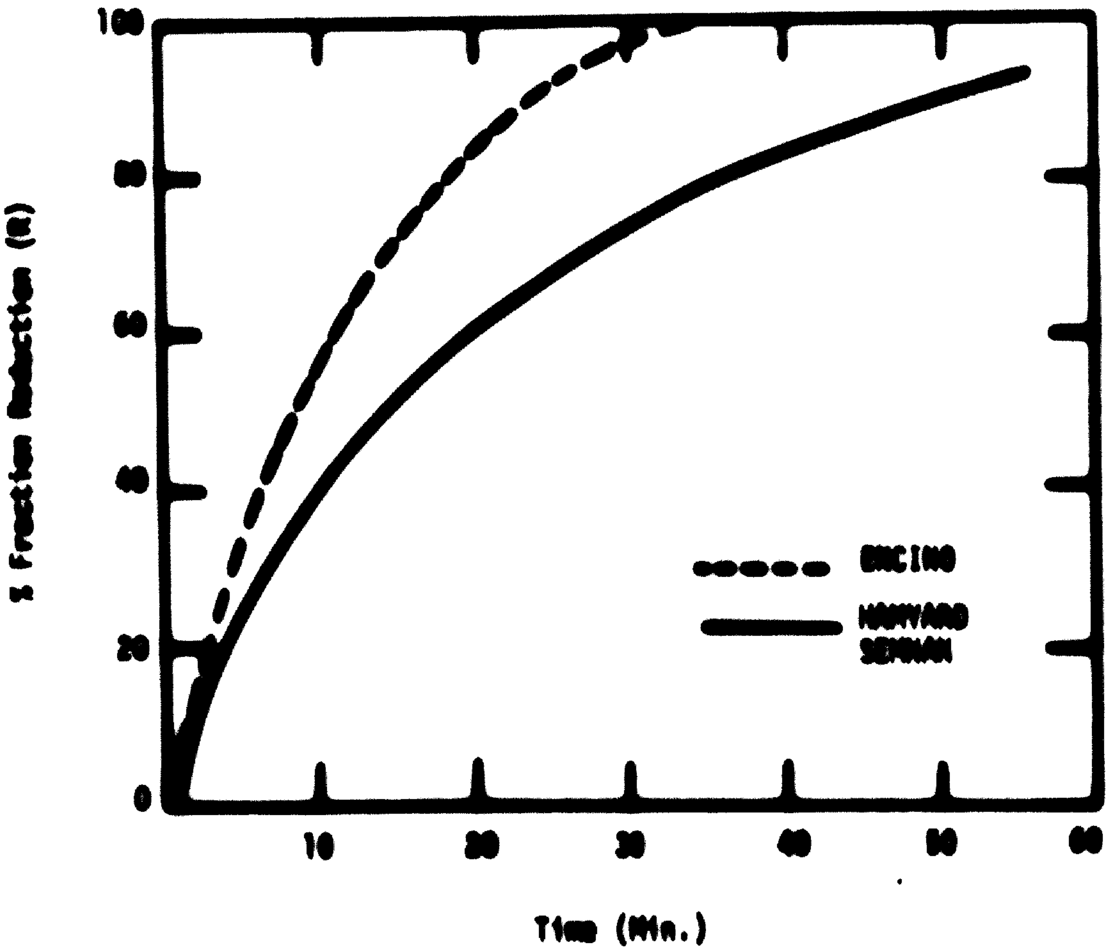
UNIDO

50007-A-2-2 - HAMYARD SEMNAN ORE

SINGLE PARTICLE REDUCTION RATE

at 900°C

AS COMPARED TO ENCINO ORE




| | |
|---|---|
| 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: 2HS

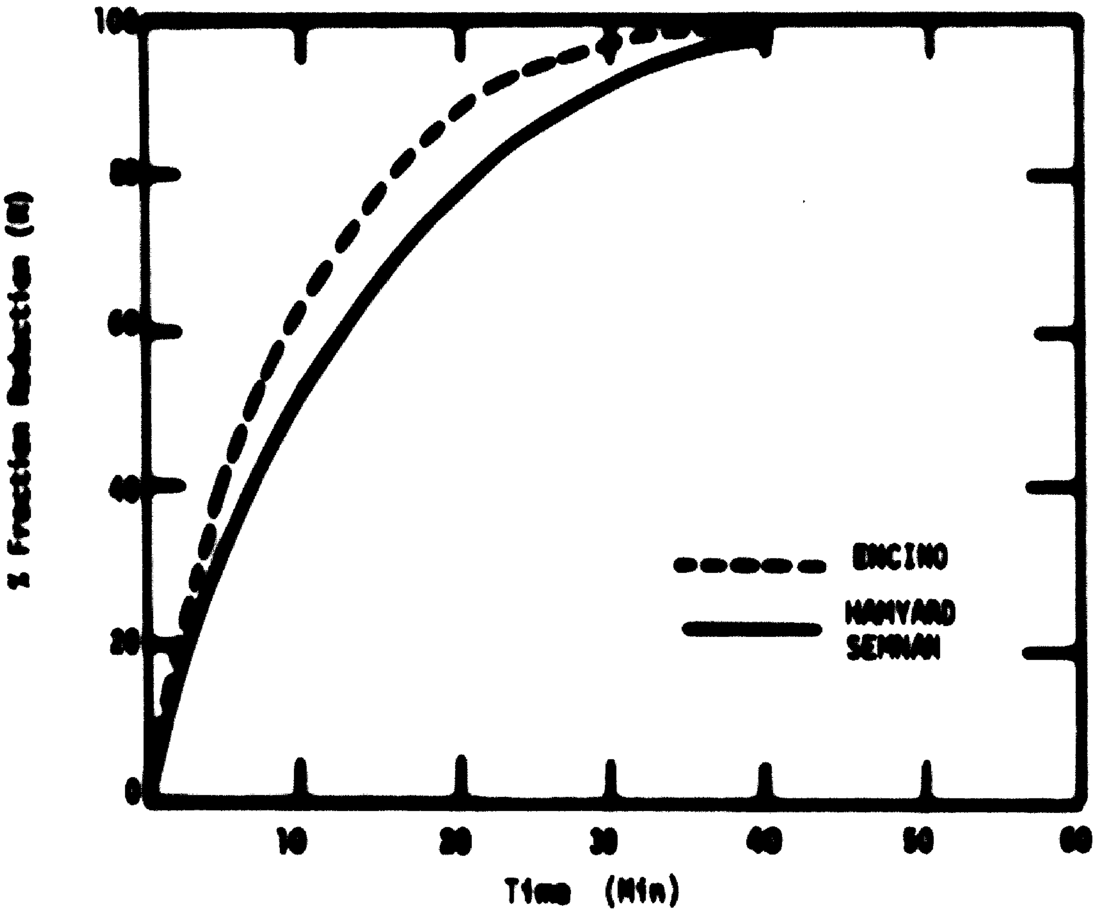
**UNIDO**

**10487-A-2-2 - HAMYARD SEMNAN ORE**

**SINGLE PARTICLE REDUCTION RATE**

**at 1000°C**

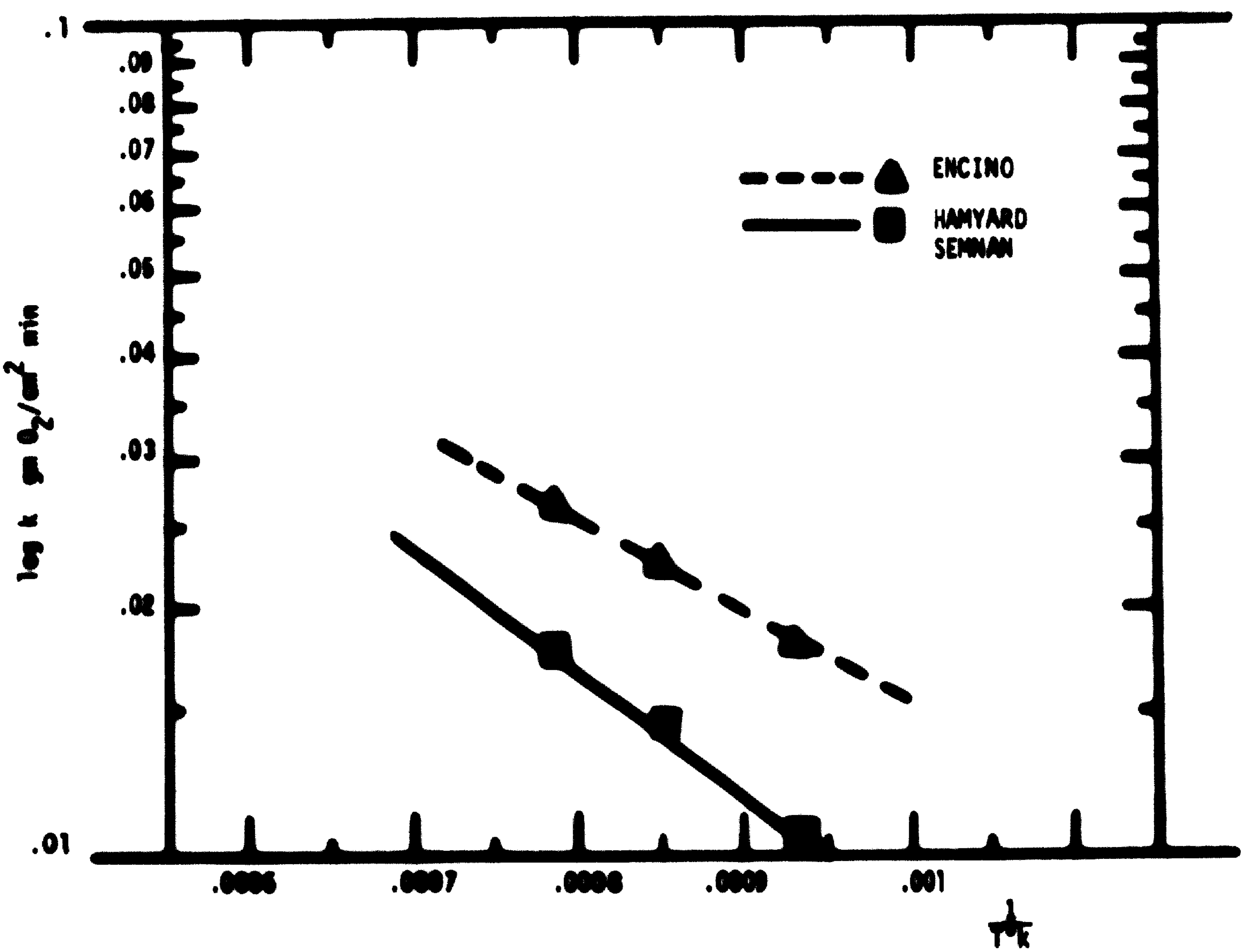
**AS COMPARED TO ENCINO ORE**




| | |
|---|---|
| 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: [illegible]

TEMPERATURE DEPENDENCE COEFFICIENT
OF SINGLE PARTICLE KINETIC CONSTANT
AS COMPARED TO ENCINO ORE PARTICLES




ENCINO ORE $\Delta H$ = 4.9 k-cal/g mole
HAMYARD SEMNAN $\Delta H$ = 7.5 K-cal/g mole

Fig: 4HS

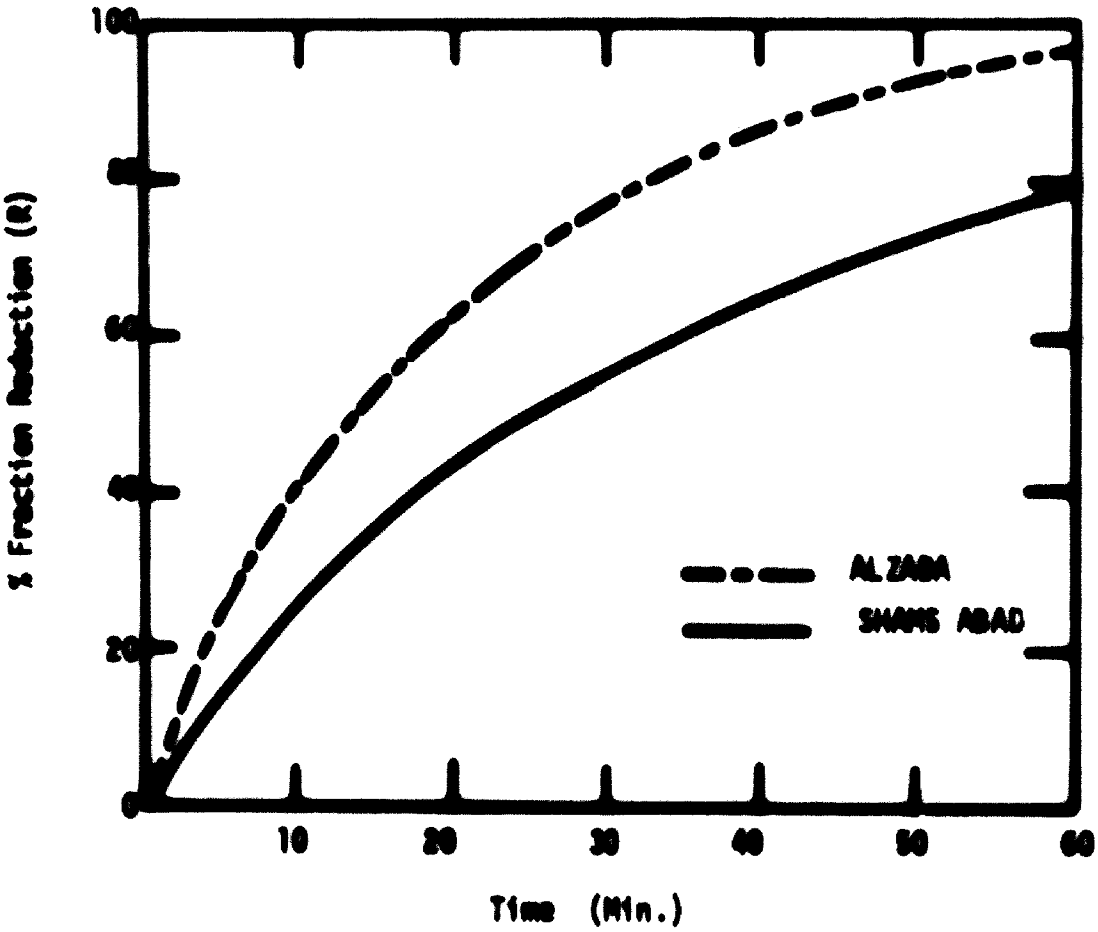
**UNIDO**

**50487-A-3 - SHAMS ABAD ORE**

**SINGLE PARTICLE REDUCTION RATE**

**at 800°C**

**AS COMPARED TO ALZADA PELLETS**




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.28 | 1/cm²-min. |
| R-Gas Composition | 61.5% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig: 15A

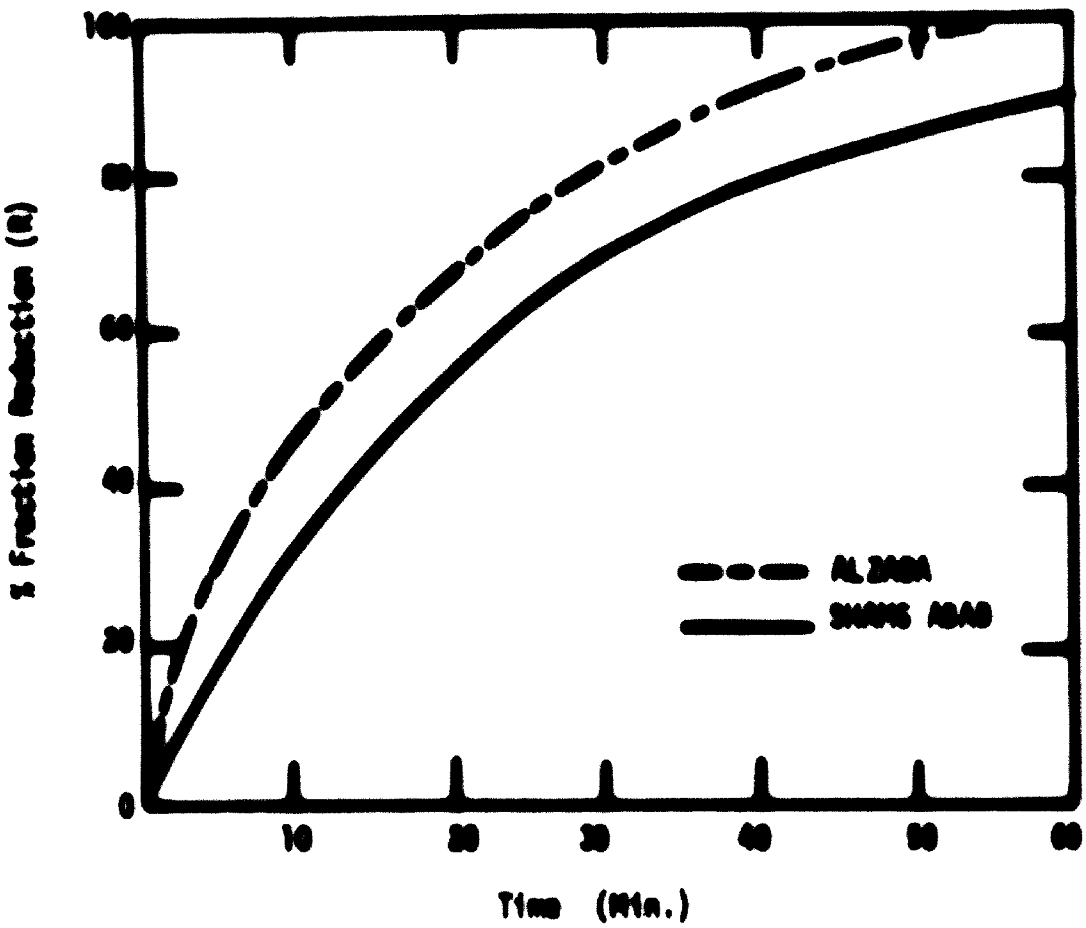
**[illegible]**

**50407-A-3 - SHAMS ABAD ORE**

**SINGLE PARTICLE REDUCTION RATE**

**at 900°C**

**AS COMPARED TO ALZADA PELLETS**




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.28 | 1/cm$^2$-min. |
| R-Gas Composition | 61.5% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig. 28A

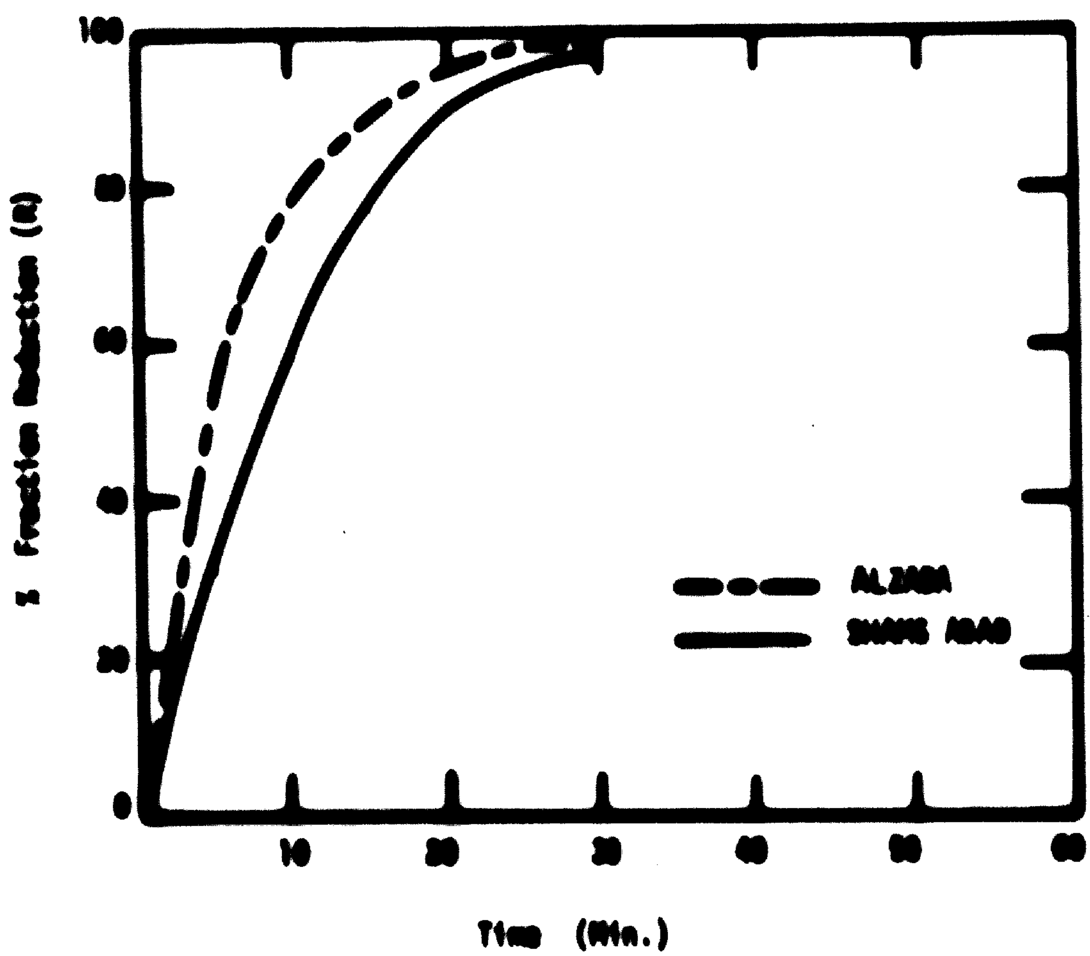
## UNIDO

## SOA07-A-3 - SHAMS ABAD ORE

SINGLE PARTICLE REDUCTION RATE

at 1000°C

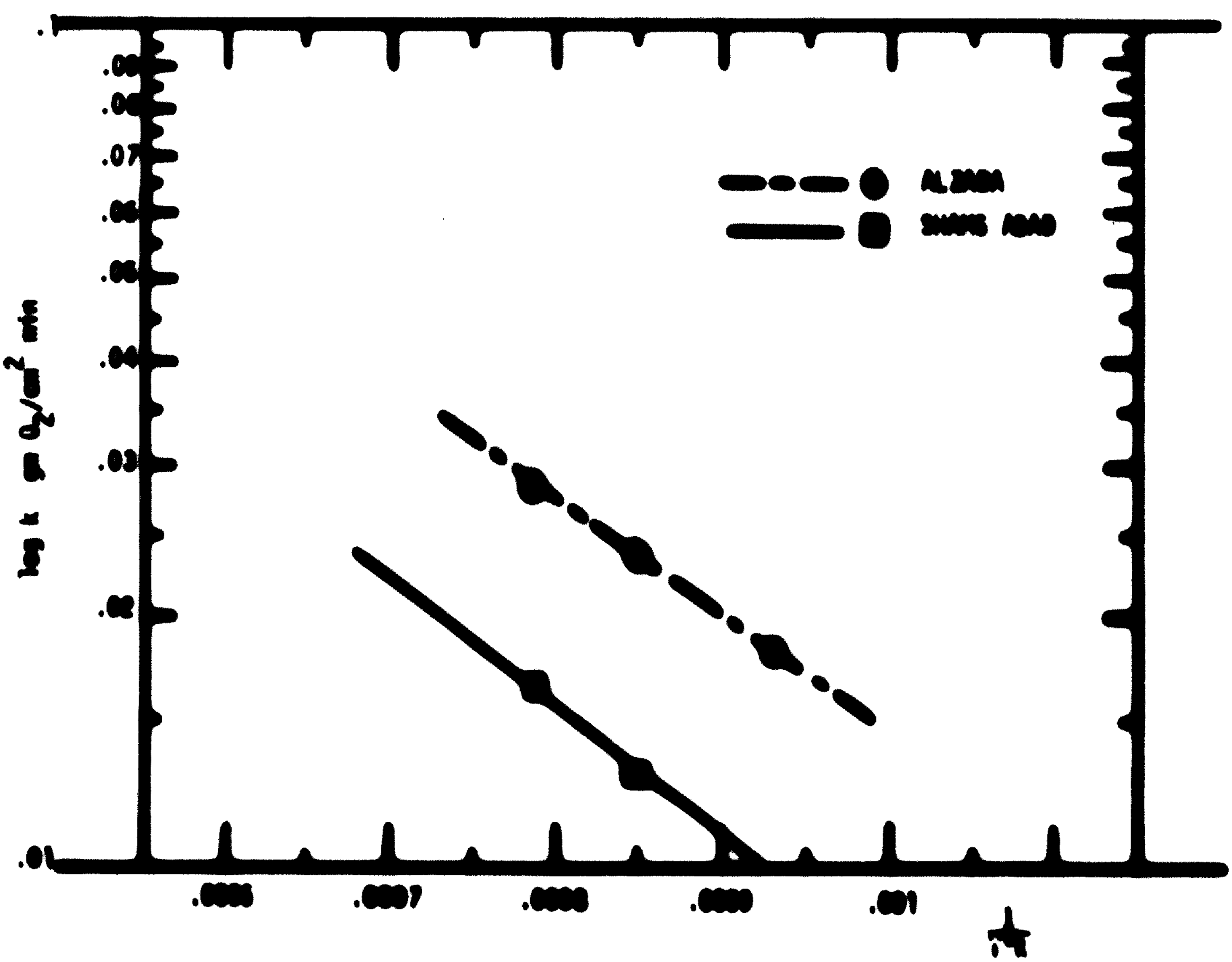
AS COMPARED TO ALZADA PELLETS




| | | |
|---|---|---|
| R-Gas Flow Rate | 6.20 l/cm²-min. | |
| R-Gas Composition | 61.0% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig. 20A

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




ALZADA PELLETS ΔH = 6.7 k-cal/g mole
SHAMS ABAD PELLETS ΔH = 6.7 k-cal/g mole

Fig. 

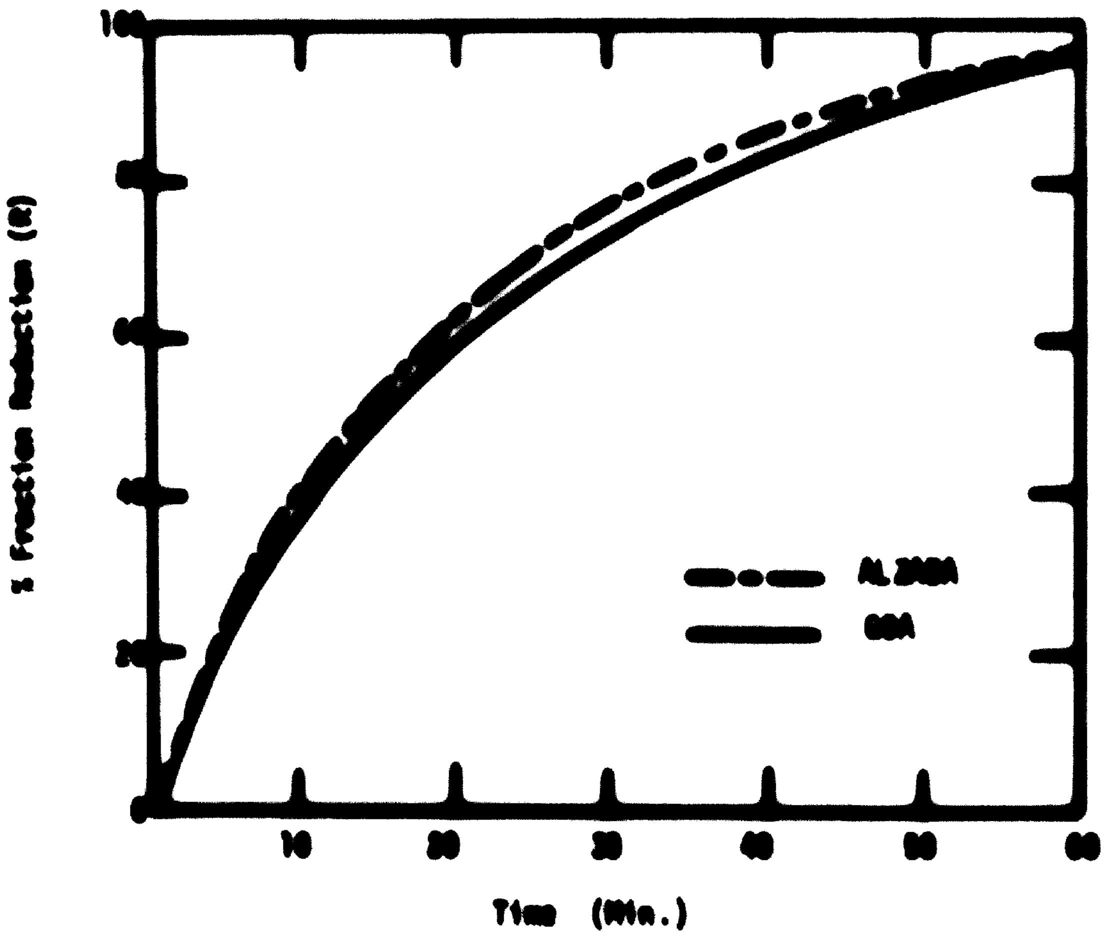
UNIDO

00007-0-3 - 00A PELLET

SINGLE PARTICLE REDUCTION RATE

at 800°C

AS COMPARED TO ALZADA PELLETS




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.20 | 1/cm²-min. |
| R-Gas Composition | 61.8% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig. 16

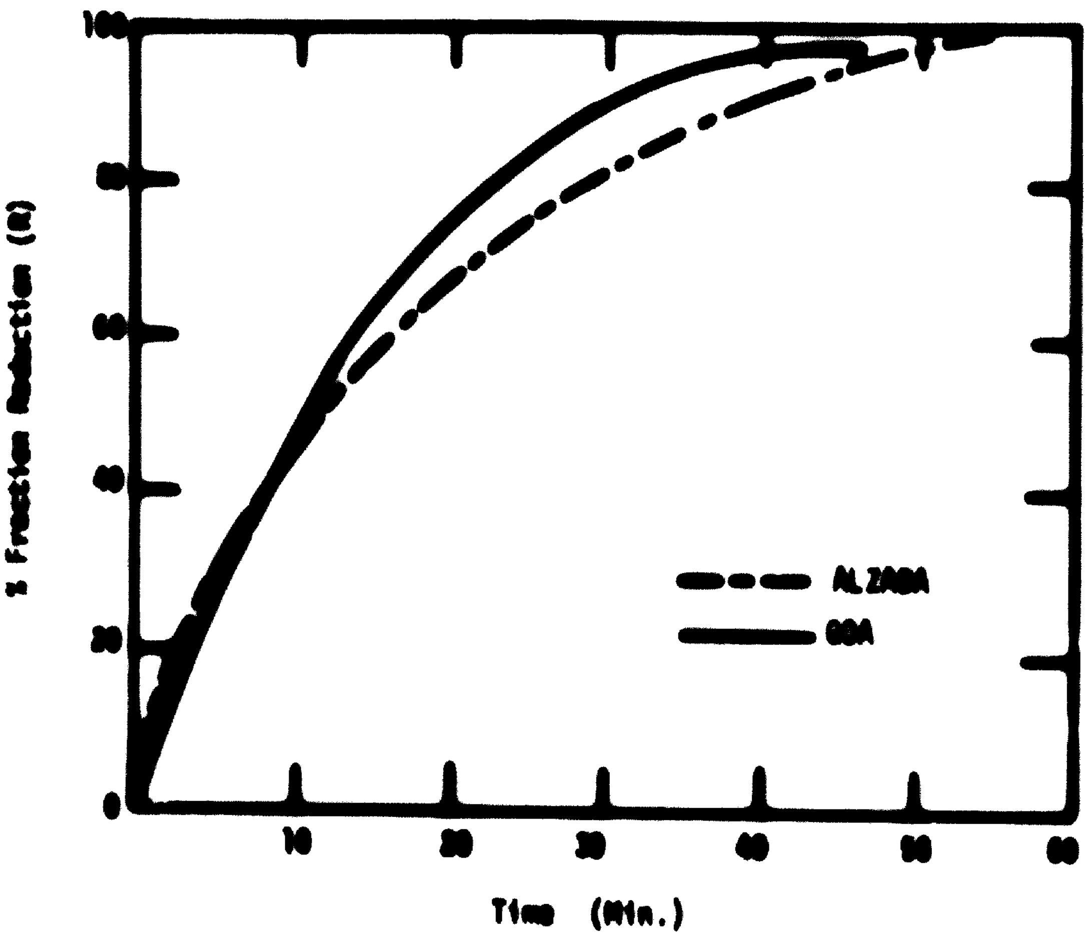
UNIDO

50087-B-3 - GOA PELLET

SINGLE PARTICLE REDUCTION RATE

at 900°C

AS COMPARED TO ALZADA PELLETS




| | | |
|---|---|---|
| R-Gas Flow Rate | 0.20 | $1/cm^2$-min. |
| R-Gas Composition | 61.5% | $H_2$ |
| | 15.7% | CO |
| | 7.1% | $CO_2$ |
| | 15.7% | $N_2$ |

Fig. 20

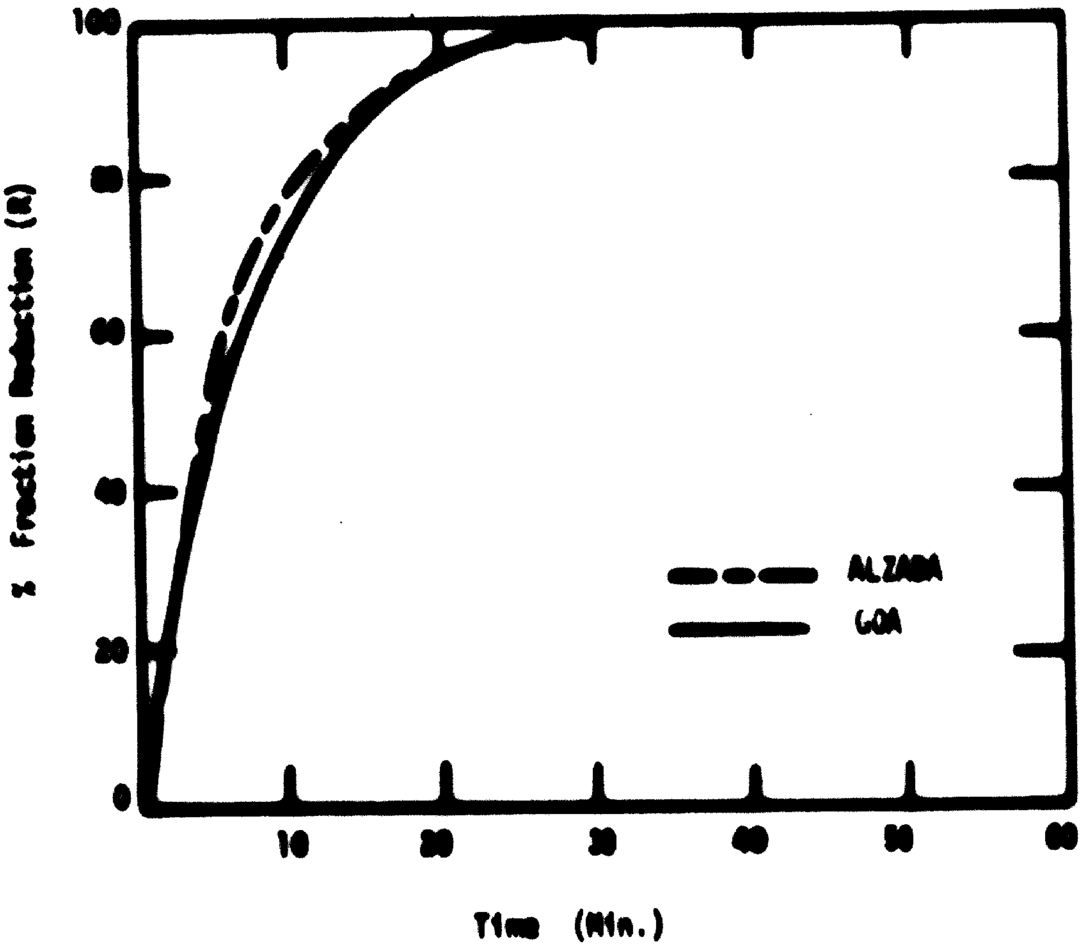
UNIDO

50407-B-3 - GOA PELLET

SINGLE PARTICLE REDUCTION RATE

at 1000°C

AS COMPARED TO ALZADA PELLETS




R-Gas Flow Rate 0.28 1/cm$^2$-min.

R-Gas Composition 61.5% $H_2$
15.7% CO
7.1% $CO_2$
15.7% $N_2$

Fig. 28

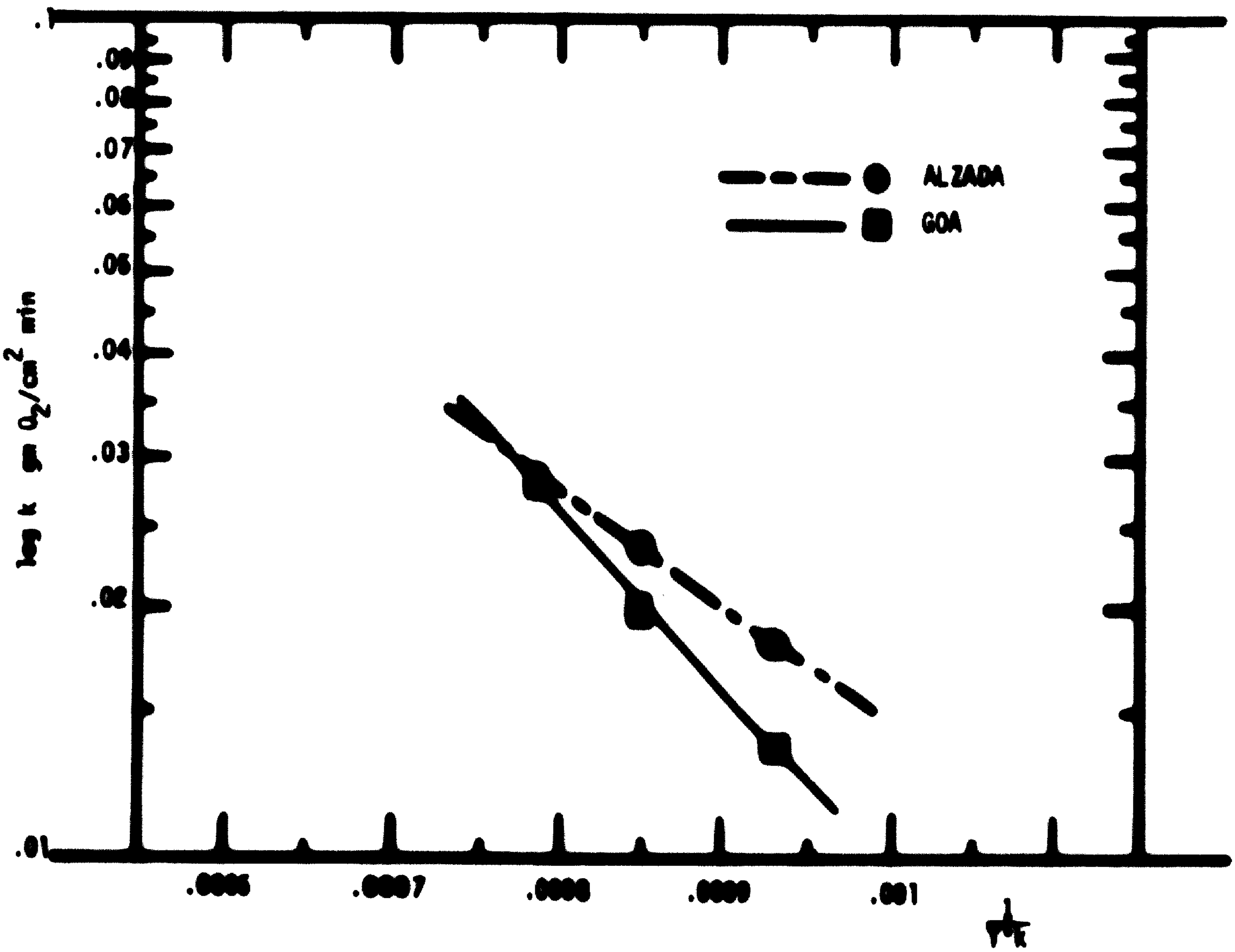
UNIDO

50487-B-3 - GOA PELLET

TEMPERATURE DEPENDENCE COEFFICIENT

OF SINGLE PARTICLE KINETIC CONSTANT

AS COMPARED TO ALZADA PELLETS




ALZADA PELLETS ΔH = 6.7 k-cal/g mole

GOA PELLETS ΔH = 9.0 k-cal/g mole

Fig: 46

# REPORT ON BAG SCALE TESTS.

UNIDO CONTRACT 70 - 50
S/D JOB No. 50487

Conducted by

Hojalata y Lámina, S.A.
Research and Development
Monterrey, N.L., México

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**Presented to:**

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Manager,
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Hojalata y Lámina, S.A.

August 5, 1971

**Transmitted to:**

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

# REPORT ON BAG SCALE TESTS.

UNIDO CONTRACT 70 - 50

S/D JOB No. 50487

The bag scale tests for seven Iranian and Indian iron ores on contract 50487 have been carried out at Monterrey Pilot Plant.

Three wire mesh bags, containing 5 Kg. each one, for each sample were prepared. These samples were grouped with samples of Alzada Pellets. Groups of 8 bags 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 (this test was made only for the pellets, samples A-3, B-3 and Alzada).

Tables I. thru VIII. disclose a summary of the results for each sample. Figures 1 thru 8 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 such bag, and comments on the reducibility of each of the seven iron ore samples compared with the Alzada pellets. In figure 9 is shown the charge diagram for the pilot plant reactor. In table IX are shown the operating conditions for the bag test run in the Pilot Plant.

## TABLE I.

### RESULTS FOR SAMPLE No. 90407 - A - 1

#### CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 65.3 |
| % FeO (Det.) | 13.6 |
| % $Fe_2O_3$ (Calc.) | 78.2 |
| % Hematite | 48.0 |
| % Magnetite | 43.8 |
| % Sulfur | 0.258 |
| % Phosphorus | 0.030 |
| % Red. Oxygen | 26.51 |
| % Gangue | 7.9 |

#### CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 92.2 | 81.8 | 73.2 |
| % Fe Metal | 81.7 | 52.5 | 6.7 |
| % Metallization | 88.6 | 64.2 | 9.2 |
| % Carbon | 0.61 | 0.52 | 0.33 |
| % Sulfur | 0.010 | 0.030 | 0.050 |
| % Phosphorus | 0.112 | 0.126 | 0.020 |
| % Gangue | 4.1 | 9.1 | 7.3 |

#### POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 50.00 | 38.62 | 26.03 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | - | - | - |

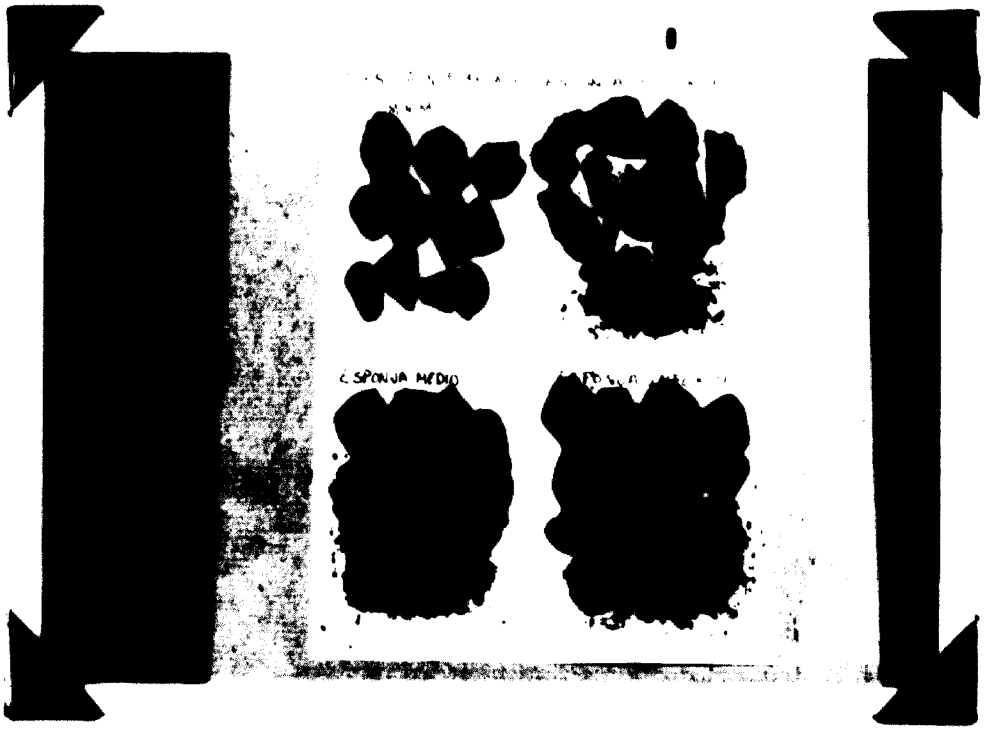

FIGURE 1

SAMPLE No. 50487-A-1

INSPECTION OF SPONGE IRON SAMPLES

TOP: No fusion. Some size reduction takes place during reduction. No fines.

MIDDLE: Considerable size reduction. Some fines.

BOTTOM: Considerable size reduction. Some fines.

COMMENTS ON THE REDUCIBILITY.

Average Metallization Sample 50487-A-1 = 54.00%

Average Metallization Alzada Pellets (bags) = 71.10%

The low metallization and the considerable size reduction of sample 50487-A-1 seem to indicate that this iron ore is not so ideally suited for the production of sponge iron by the HyL Process as some of the others.

TABLE II.

RESULTS FOR SAMPLE No. 50487 - A - 2 - 1

CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 62.8 |
| % FeO (Det.) | 18.5 |
| % $Fe_2O_3$ (Calc.) | 69.2 |
| % Hematite | 28.1 |
| % Magnetite | 59.6 |
| % Sulfur | 2.568 |
| % Phosphorus | 0.019 |
| % Red. Oxygen | 24.90 |
| % Gangue | 9.7 |

CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 92.7 | 82.3 | 69.5 |
| % Fe Metal | 85.4 | 51.8 | 7.7 |
| % Metallization | 92.1 | 62.9 | 11.1 |
| % Carbon | 0.43 | 0.28 | 0.38 |
| % Sulfur | 0.372 | 0.572 | 0.636 |
| % Phosphorus | 0.012 | 0.109 | 0.111 |
| % Gangue | 4.4 | 8.0 | 11.7 |

POROSITY AND RESISTENCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 50.48 | 43.37 | 27.08 |
| Resistence to compression (Kg./pellet). Average of 10 pellets. | - | - | - |

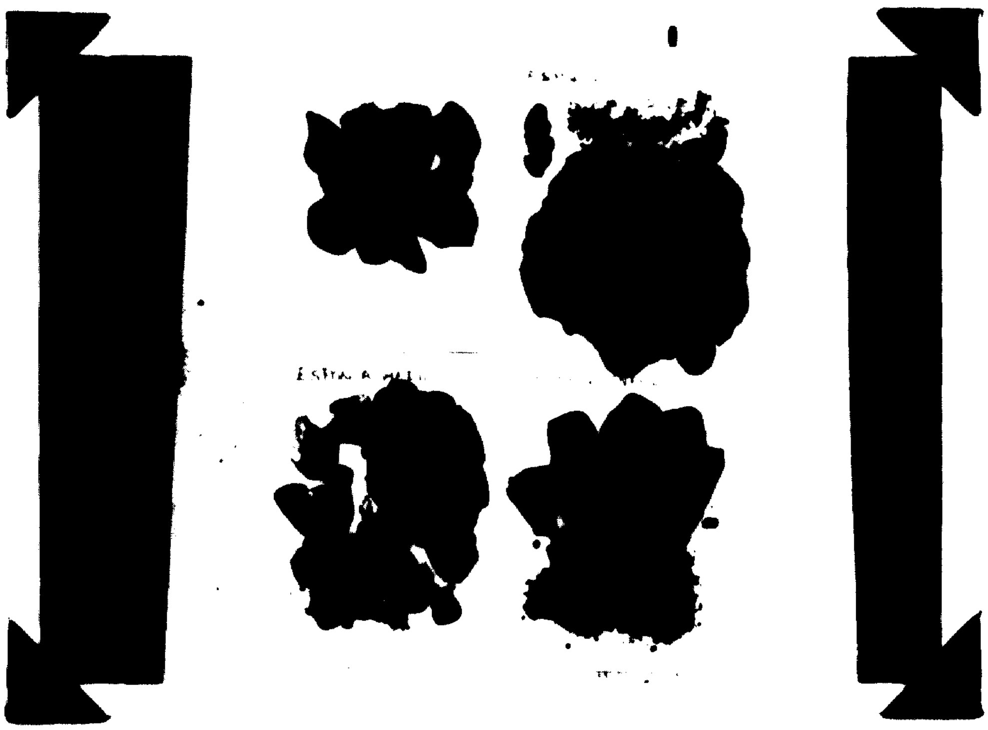

FIGURE 2

SAMPLE No. 50487-A-2-1

INSPECTION OF SPONGE IRON SAMPLES.

TOP: The entire sample was agglomerated. Some size reduction.

MIDDLE: Some brittle agglomeration. Some size reduction.

BOTTOM: Some surface cracks. No fusion. Some size reduction and fines.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-A-2-1 = 55.37%

Average Metallization of Alzada Pellets (bags) = 71.10%

The tendency to fuse, the low metallization the size reduction and the fines production makes this iron ore not so ideally suitable for the production of sponge iron by the HyL Process.

TABLE III.

RESULTS FOR SAMPLE No. 50487 - A - 2 - 2.

CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 61.6 |
| % FeO (Det.) | 3.7 |
| % $Fe_2O_3$ (Calc.) | 83.9 |
| % Hematite | 75.7 |
| % Magnetite | 11.9 |
| % Sulfur | 0.128 |
| % Phosphorus | 0.010 |
| % Red. Oxygen | 26.12 |
| % Gangue | 12.3 |

CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 88.7 | 79.3 | 72.0 |
| % Fe Metal | 86.5 | 59.7 | 8.5 |
| % Metallization | 97.5 | 75.3 | 11.8 |
| % Carbon | 0.77 | 1.47 | 0.48 |
| % Sulfur | 0.023 | 0.013 | 0.012 |
| % Phosphorus | 0.017 | 0.017 | 0.108 |
| % Gangue | 9.9 | 13.6 | 9.2 |

POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 51.42 | 48.57 | 22.22 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | - | - | - |

FIGURE 3

SAMPLE No. 50487-A-2-2

INSPECTION OF SPONGE IRON SAMPLES

TOP: No fusion. Some size reduction. No fines.

MIDDLE: Some Cracks. No fusión. Some size reduction and fines.

BOTTOM: Considerable size reduction. No cracks.

COMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-A-2-2 = 61.53%

Average Metallization of Alzada Pellets (bags) = 71.10%

This iron ore has regular metallization compared with the Alzada Pellets, the size reduction specially at the bottom could be a disadvantage for the use of this material in the HyL process.

TABLE IV.

RESULTS FOR SAMPLE No. 30407 - A - 3

## CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 62.3 |
| % FeO (Det.) | 1.7 |
| % $Fe_2O_3$ (Calc.) | 86.8 |
| % Hematite | 83.0 |
| % Magnetite | 5.5 |
| % Sulfur | 0.005 |
| % Phosphorus | 0.058 |
| % Red. Oxygen | 26.47 |
| % Gangue | 11.4 |

## CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 79.3 | 79.3 | 64.2 |
| % Fe Metal | 71.1 | 69.1 | 2.2 |
| % Metallization | 89.7 | 87.1 | 3.4 |
| % Carbon | 0.79 | 0.70 | 0.23 |
| % Sulfur | 0.024 | 0.005 | 0.008 |
| % Phosphorus | 0.023 | 0.108 | 0.113 |
| % Gangue | 17.6 | 17.0 | 17.6 |

## POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 48.71 | 44.73 | 19.35 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | 110 | 171 | 97 |

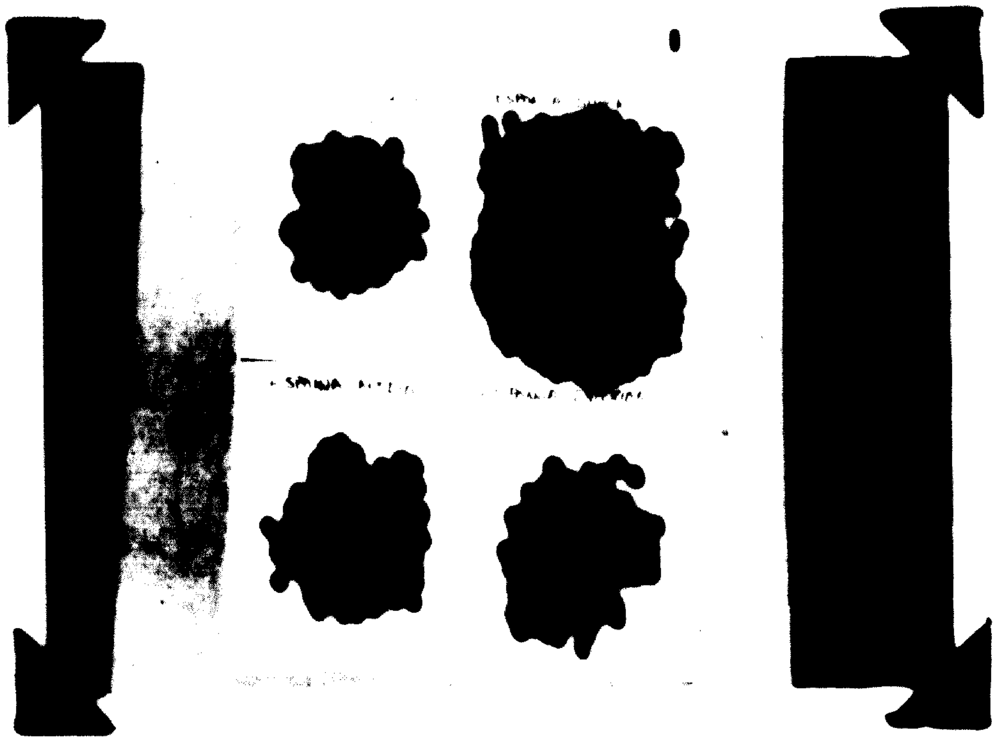

FIGURE 4

SAMPLE No. 50487-A-3

INSPECTION OF SPONGE IRON SAMPLES

TOP: All the sample was agglomerated. No size reduction No fines. Cracked (the cracks were already present in the raw pellets).

MIDDLE: No fusion. No size reduction. No fines. Cracked.

BOTTOM: No fusion. No size reduction. No fines. Cracked.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-A-3 = 60.07%

Average Metallization of Alzada Pellets (bags) = 71.10%

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

## T A B L E V.

### RESULTS FOR SAMPLE No. 90407 - B - 1

### CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 67.3 |
| % FeO (Det.) | 1.8 |
| % $Fe_2O_3$ (Calc.) | 94.2 |
| % Hematite | 90.2 |
| % Magnetite | 5.8 |
| % Sulfur | 0.064 |
| % Phosphorus | 0.053 |
| % Red. Oxygen | 28.76 |
| % Gangue | 3.9 |

### CHEMICAL ANALYSIS OF SPONGE IRON

| | T O P | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 93.5 | 89.5 | 75.3 |
| % Fe Metal | 92.0 | 81.8 | 12.0 |
| % Metallization | 98.4 | 91.4 | 15.9 |
| % Carbon | 0.80 | 1.94 | 0.48 |
| % Sulfur | 0.015 | 0.010 | 0.004 |
| % Phosphorus | 0.058 | 0.108 | 0.063 |
| % Gangue | 5.2 | 6.2 | 6.1 |

### POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | T O P | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 55.88 | 49.20 | 36.66 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | - | - | - |

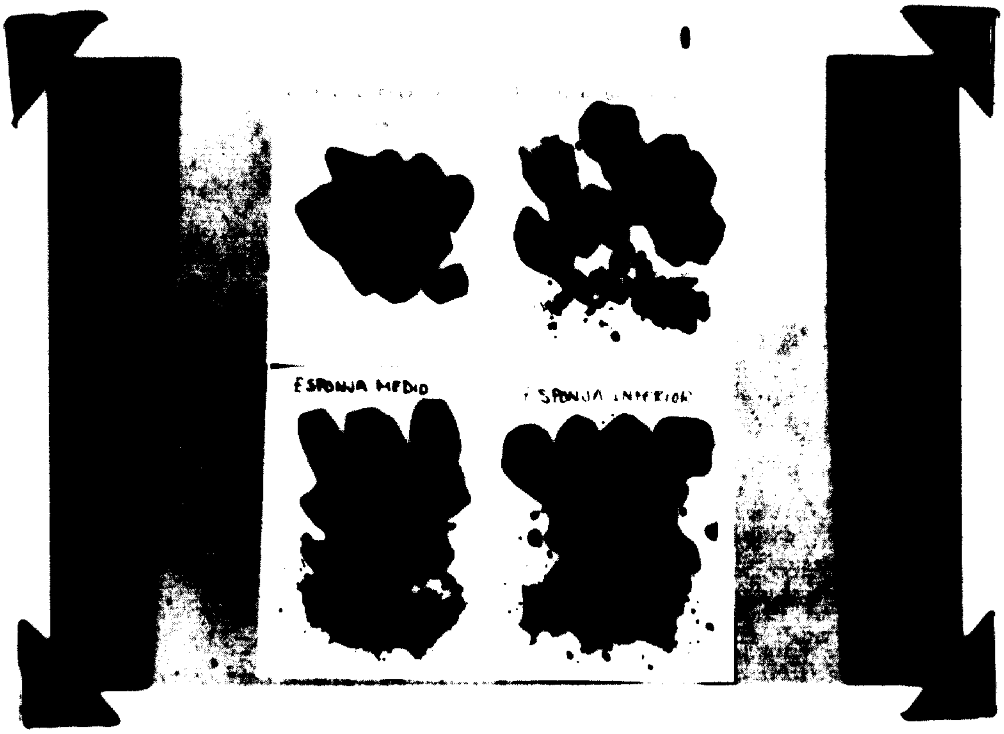


FIGURE 5

SAMPLE No. 50487-B-1

INSPECTION OF SPONGE IRON SAMPLES.

TOP: Cracked. A part of the sample was agglomerated. Some size reduction.

MIDDLE: Considerable size reduction. Cracked. No fusion. Some fines.

BOTTOM: Considerable size reduction. Cracked. Fines.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-B-1 = 68.57%

Average Metallization of Alzada Pellets (bags) = 71.10%

Good Metallization, but the physical characteristics of this ore could be a problem for the production of sponge iron by the HyL Process.

TABLE VI.

RESULTS FOR SAMPLE No. 30487 - B - 2

CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 68.2 |
| % FeO (Det.) | 1.7 |
| % $Fe_2O_3$ (Calc.) | 95.6 |
| % Hematite | 91.8 |
| % Magnetite | 5.5 |
| % Sulfur | 0.032 |
| % Phosphorus | 0.113 |
| % Red. Oxygen | 29.14 |
| % Gangue | 2.6 |

CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 97.0 | 94.2 | 75.7 |
| % Fe Metal | 96.4 | 88.7 | 12.7 |
| % Metallization | 99.4 | 94.2 | 16.8 |
| % Carbon | 0.65 | 1.34 | 0.47 |
| % Sulfur | 0.016 | 0.005 | 0.006 |
| % Phosphorus | 0.076 | 0.093 | 0.093 |
| % Gangue | 2.0 | 2.8 | 5.7 |

POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 59.45 | 54.54 | 34.37 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | - | - | - |

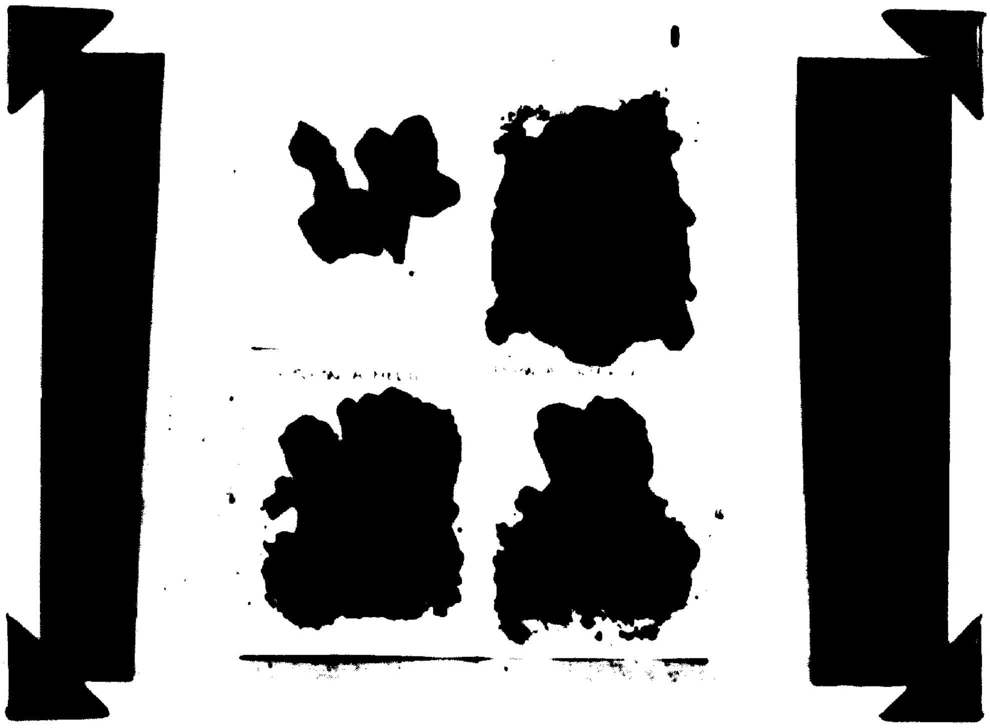

FIGURE 6

SAMPLE No. 50487-B-2

INSPECTION OF THE SPONGE IRON SAMPLES.

TOP: The entire sample was agglomerated. Cracked. Some size reduction.

MIDDLE: Brittle agglomerations. Considerable size reduction. Cracked.

BOTTOM: No fusion. Considerable size reduction and fines.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-B-2 = 70.13%

Average Metallization of Alzada Pellets (bags) = 71.10%

This iron ore has very good metallization, but it has the following disadvantages: tendency to fuse, considerable size reduction and fines generation.

TABLE VII.

RESULTS FOR SAMPLE No. 30487 - B - 3

## CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 68.1 |
| % FeO (Det.) | 1.4 |
| % $Fe_2O_3$ (Calc.) | 95.8 |
| % Hematite | 92.7 |
| % Magnetite | 4.5 |
| % Sulfur | 0.032 |
| % Phosphorus | 0.097 |
| % Red. Oxygen | 29.10 |
| % Gangue | 2.8 |

## CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 90.7 | 89.1 | 75.1 |
| % Fe Metal | 87.8 | 85.7 | 12.7 |
| % Metallization | 96.8 | 96.2 | 16.9 |
| % Carbon | 0.93 | 2.60 | 0.98 |
| % Sulfur | 0.026 | 0.013 | 0.004 |
| % Phosphorus | 0.103 | 0.128 | 0.112 |
| % Gangue | 7.4 | 7.2 | 6.0 |

## POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 60.25 | 55.26 | 35.29 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | 43 | 28 | 16 |

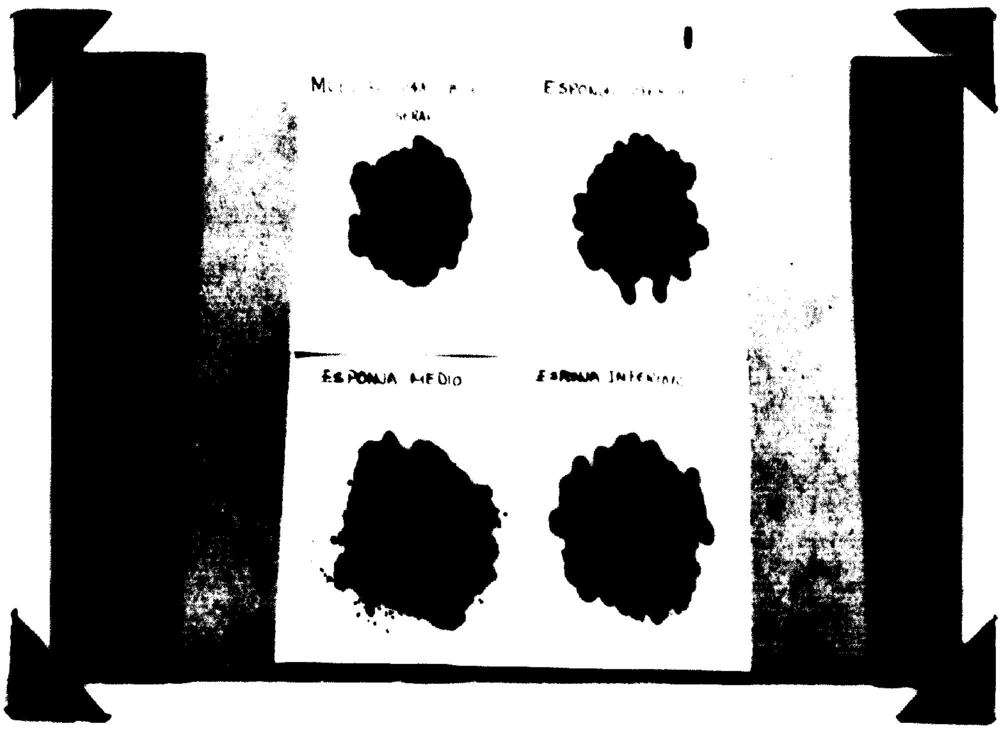


FIGURE 7

SAMPLE No. 50487-B-3

INSPECTION OF THE SPONGE IRON SAMPLE

TOP: No fusion. Some cracks. No fines.

MIDDLE: Some size reduction and fines.

BOTTOM: Practically no size reduction and no fines.

COMMENTS ON REDUCIBILITY

Average Metallization of Sample 50487-B-3 = 69.97%

Average Metallization of Alzada Pellets (bags) = 71.10%

This iron ore seems to be the best suitable for the production of sponge iron by the HyL process, the metallization is very similar to the Alzada Pellets and also its physical characteristics are very good.

## TABLE VIII.

### RESULTS FOR ALZADA PELLETS.

#### CHEMICAL ANALYSIS OF IRON ORE

| | |
|---|---|
| % Fe Total | 68.0 |
| % FeO (Det.) | 1.7 |
| % $Fe_2O_3$ (Calc.) | 95.4 |
| % Hematite | 91.6 |
| % Magnetite | 5.5 |
| % Sulfur | 0.006 |
| % Phosphorus | 0.242 |
| % Red. Oxygen | 29.06 |
| % Gangue | 2.6 |

#### CHEMICAL ANALYSIS OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Fe Total | 91.8 | 89.9 | 75.9 |
| % Fe Metal | 87.6 | 84.0 | 18.6 |
| % Metallization | 95.4 | 93.4 | 24.5 |
| % Carbon | 0.88 | 2.64 | 1.00 |
| % Sulfur | 0.025 | 0.007 | 0.008 |
| % Phosphorus | 0.397 | 0.318 | 0.267 |
| % Gangue | 5.7 | 5.4 | 6.4 |

#### POROSITY AND RESISTANCE TO COMPRESSION OF SPONGE IRON

| | TOP | MIDDLE | BOTTOM |
|---|---|---|---|
| % Porosity | 52.94 | 51.42 | 32.81 |
| Resistance to compression (Kg./pellet). Average of 10 pellets. | 180 | 41 | 64 |

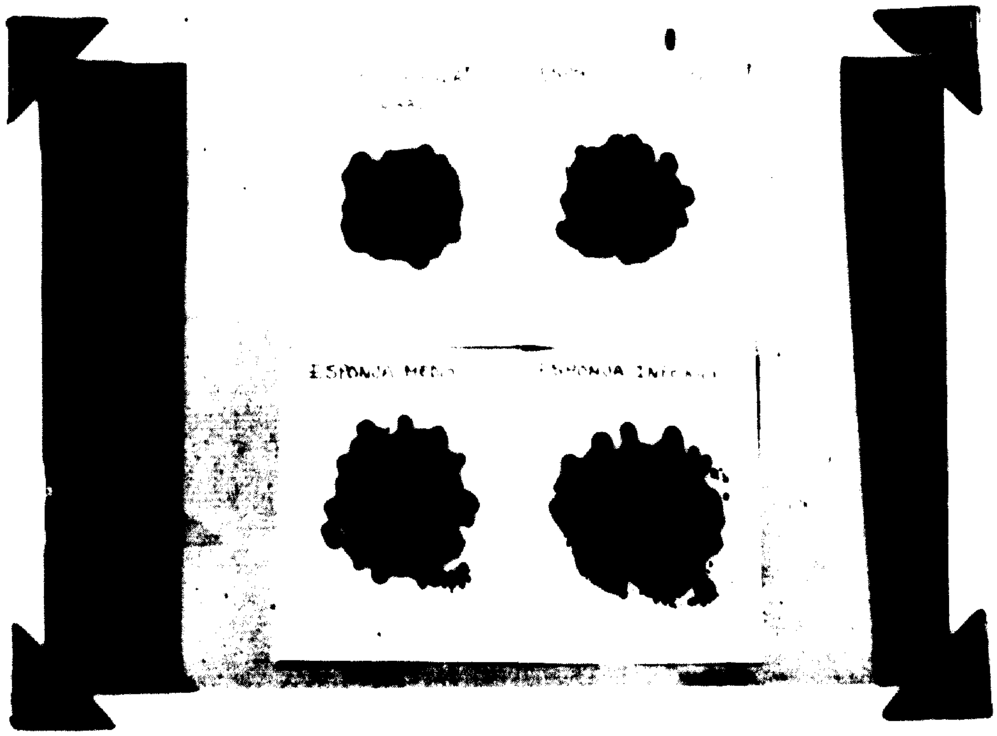

FIGURE 8

ALZADA PELLETS

**TOP:** No fusion. No size reduction

**MIDDLE:** Slight size reduction. Some fines. Cracked.

**BOTTOM:** Slight size reduction. Fines.

## T A B L E   I X

### OPERATING CONDITIONS

REFORMER GAS ANALYSIS

| | |
|---|---|
| $H_2$ | 73.30% |
| CO | 11.50% |
| $CO_2$ | 9.53% |
| $CH_4$ | 5.67% |

| | | |
|---|---|---|
| R-GAS PREHEAT TEMPERATURE | = | 730°C |
| AIR PREHEAT TEMPERATURE | = | 700°C |
| COMB. CHAMBER TEMPERATURE | = | 1050°C |
| METALLIZATION OF REACTOR CHARGE | = | 77.73% * |
| GAS CONSUMPTION, REFORMED GAS | = | 1249.38 N $M^3$/Ton.Fe. |

* For this Pilot Plant test the reactor was not preheated as usually, becsuse the reactor was manually charged in order to place the bags at the 3 different levels. So the metallization is slightly lower than the normal value for Alzada Pellets. The metallization of the charge is within standard variance for production reactors in the HyL process, though on the low side of the variance.

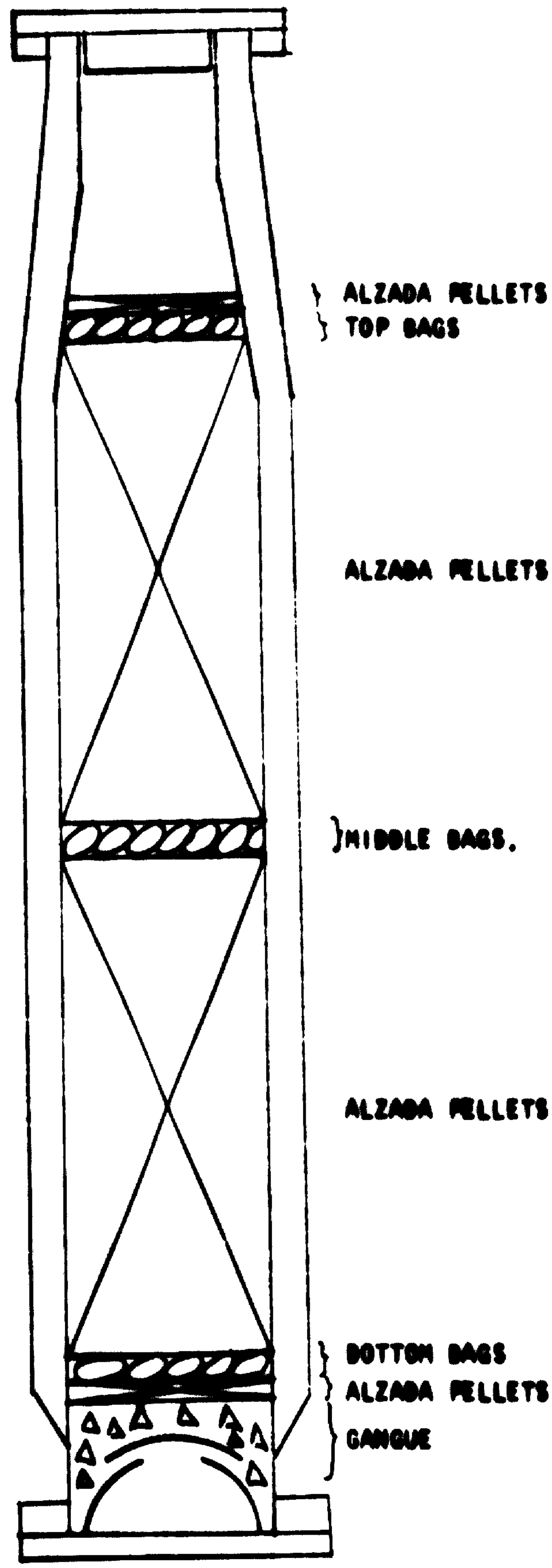


FIGURE 9.

CHARGE DIAGRAM

Final Report

# BENCH-SCALE AND PILOT-PLANT TESTING OF IRANIAN IRON ORE

For

SWINDELL-DRESSLER COMPANY

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Approved by

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May 28, 1971

## SUMMARY

A sample of Iranian iron ore provided by Swindell-Dressler Company was subjected to bench-scale testing following microscopic examination and preliminary liberation study. These results indicated that although anionic silica flotation of the crude material ground to a fine size was not effective, fine grinding and magnetic concentration of the crude, roasted to convert the iron oxides to magnetite, did give concentrate grades in the range of 60 to 62% Fe at iron recoveries in excess of 95%.

This concentrate did not meet the requirements set by Swindell-Dressler Company of 64% Fe, 0.15% S, 4% $SiO_2$, due to the presence of 3% manganese in the magnetic concentrate and inclusions of gangue in the iron oxide matrix. However, in conversations with Mr. G. F. Johnson of that company approval was given for the production of 100 kilograms of pellets using a roast - magnetic concentration - pelletizing process, with the expectation of producing a concentrate with the following chemistry: 61% Fe, 3% Mn, 7% $SiO_2$, 1% $Al_2O_3$, at 90% iron recovery.

The concentration results of the pilot plant run did agree quite well with those estimated from the bench-scale data: 60.5% Fe, 2.9% Mn, 6.7% $SiO_2$, 1.1% $Al_2O_3$, and 0.028% S at 94% iron recovery.

The concentrate was balled and fired in a pot grate furnace producing pellets which had a rough appearance and many shallow surface cracks, probably due to a rather large shrinkage in the pellets. These pellets had adequate crushing strength but produced only a 92.2% plus 1/4 inch tumble strength, again probably due to the rough texture of the pellet surface. Additional tests on larger quantities of material would lead to improvement and perhaps elimination of this problem. Pellet chemistry was as follows: 59.69% Fe, 6.5% $SiO_2$, 2.5% Mn, and 0.08% $Fe^{++}$.

The fired pellet product was split into two shipments, 20 pounds to Swindell-Dressler Company, Etna, Pennsylvania, and the remaining 200 pounds to Fierro Esponja, S.A.

## DESIGNATION OF SAMPLES

On October 14, 1970 a small sample of Iranian iron ore was received for preliminary testing. The sample, which was labeled 50487-A-3 by Swindell-Dressler was given the NRRC designation of Ore No. 1757, Lot No. 1, Project No. 175.

On December 3, 1970 an ore shipment was received which weighed 2075 pounds. The sample was contained in twelve drums numbered 1, 3, 4, 5, 6, 7, 8, 9, 11, 12, 13, and 14, and was labeled Sample 50487-A-3. This sample was given the NRRC label of Ore No. 1757, Lot No. 2, Project No. 175.

## BENCH-SCALE TESTING

### Preliminary Mineralogical Examination

The small sample, Lot No. 1, which had been labeled 50487-A-3 by Swindell-Dressler, was used in making a preliminary examination prior to the preparation of a proposal outlining a program of concentrating and pelletizing tests.

The sample analyzed 46.04% Fe, 0.08% $Fe^{++}$, 2.76% Mn, 0.018% P, 0.019% S, 12.78% $SiO_2$, 1.04% $Al_2O_3$, and 10.90% LOI.

Three briquets were made from hand specimens of the sample and examined under a reflecting microscope. In the first briquet goethite was the dominant iron mineral, filling spaces between grains of quartz, cementing them together, and presenting a pseudo-polygonal structure. The average size of the quartz grains was 50 microns. In the second briquet the principal iron mineral was again goethite, this time more massive with some colloform structure. Some goethite occurred as veins in cracks of the quartz. Pyrolusite was present as lens-shaped crystals and as intersected irregular prisms scattered in the goethite. In the third briquet siderite was the main iron mineral, but goethite was also present, occurring as very thin rims around the siderite grains. (Probably the goethite observed in the first two briquets was formed by the alteration of original siderite).

Ten grams of the sample was ground for 10 minutes in a Spex mill and then x-ray analyzed. The results showed that quartz was predominant, but that a fair amount of siderite and some calcite were also present.

The size of the gangue grains varied considerably but most of the goethite can be liberated by a 270/325-mesh grind.

About 150 grams of the sample was crushed through 8 mesh and roasted for one hour at 650° C in an atmosphere of 16% water vapor, 8.4% $H_2$, 16.8% $CO_2$, and 58.8% $N_2$. After the roasted product had been pulverized through 150 mesh, 10 grams of the product was concentrated in a Davis magnetic tube. Nearly 97 percent of the iron in the tube feed was recovered in a concentrate containing 60.85% Fe and 6.97% Insol.

TABLE 1. DAVIS TUBE TEST RESULTS IN PRELIMINARY SAMPLE

| Material | % Wt | % Fe | % $Fe^{++}$ | % Insol | % Fe Rec |
|---|---|---|---|---|---|
| Feed | 100.00 | 52.48 | 16.88 | 14.74 | 100.00 |
| Concentrate | 83.33 | 60.85 | 17.56 | 6.97 | 96.62 |
| Tailing | 16.67 | 10.63 | 4.02 | 45.69 | 3.38 |

## Preliminary Flotation Tests

On December 3, 1970 the Mineral Resources Research Center received 12 drums of Iranian iron ore weighing 2075 pounds from the Swindell-Dressler Company and labeled them Ore No. 1757, Lot No. 2. The ore was to be used in bench-scale tests to determine a suitable flowsheet and to prepare a 200-kilogram sample of fired pellets for further testing by Swindell-Dressler.

Two cursory flotation tests were conducted on a sample of Lot 2. The object of the tests was to produce an iron concentrate containing about 4 percent silica. The first test used direct anionic silica flotation and the second test used selective desliming followed by anionic silica flotation. Although the latter method was more effective than the former method in upgrading the sample, neither method was able to produce a concentrate containing 4 percent silica.

### Test Procedure

A 50-pound representative sample of Lot 2 Ore 1757 was crushed and ground to minus 10 mesh. For each flotation test a 500-gram charge of the minus 10-mesh material was ground in a small rod mill for 20 minutes at 50 percent solids. Table 2 shows screen analyses of the rod-mill feed and product.

In the first test the ground 500-gram charge was transferred to a batch conditioner and pulped at 40 percent solids. A specified amount of causticized tapioca flour was added. The pH of the pulp was adjusted to 11.7 with caustic soda and the pulp was conditioned for 2 minutes. Next the pulp was conditioned for one minute with $CaCl_2$ and finally for two minutes with Acintol FA-2. The conditioned pulp was transferred to a Fagergren laboratory flotation cell, diluted to volume, and floated until barren of froth, or for about 5 minutes. The froth was returned to the cell and scavenged for 3 minutes with the supernatant water from the roughing operation.

In the second test the 500-gram charge (which had been ground with $Na_2SiO_3$) was transferred to a fiberglass cell and diluted to volume of 6 liters. Causticized tapioca flour was added and the pulp was conditioned for one minute. At this point the agitation was stopped, the suspension was allowed to settle, and the supernatant water was siphoned off. Then distilled water was added to the cell and the pulp was agitated for 10 seconds. Again the suspension was allowed to settle and the superantant water was siphoned off. The sedimentation-decantation procedure was repeated four times. The deslimed pulp was then treated by flotation in the same manner as was followed during the first test.

The reagent schedule and the metallurgical results for each test are summarized in Table 3.

TABLE 2. SCREEN ANALYSIS OF THE MINUS 10-MESH ORE AND GROUND FLOTATION FEED.

| Size Mesh | Minus 10-mesh Rod-Mill Feed | | 20-minute Ground Rod-Mill Product | |
|---|---|---|---|---|
| | % Wt | % Cum | % Wt | % Cum |
| -10+48 | 65.99 | 65.99 | - | - |
| + 65 | 5.95 | 71.94 | - | - |
| +100 | 4.74 | 76.68 | - | - |
| +150 | 3.43 | 80.11 | - | - |
| +200 | 3.02 | 83.13 | - | - |
| +270 | 1.92 | 85.05 | 2.23 | 2.23 |
| +325 | 1.62 | 86.67 | 2.63 | 4.86 |
| -325 | 13.33 | 100.00 | 95.14 | 100.00 |
| Total | 100.00 | | 100.00 | |

TABLE 3. METALLURGICAL RESULTS OF FLOTATION TESTS ON LOT 2 ORE 1757

| Test No. | Desliming* $Na_2SiO_3$** | Desliming* Causticized Tapioca | Flotation* pH | Flotation* Caust. Tapioca | Flotation* $CaCl_2$ | Flotation* FA-2 | Products | % Wt | % Fe | % Insol | % Distribution Fe | % Distribution Insol |
|---|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | --- | --- | 11.7 | 4.0 | 2.0 | 1.0 | R Cell Prod | 62.48 | 49.26 | 10.88 | 69.69 | 50.82 |
| | | | | | | | Scav Cell Prod | 20.69 | 45.88 | 13.35 | 21.49 | 20.63 |
| | | | | | | | Scav Froth | 16.83 | 23.17 | 22.73 | 8.82 | 28.55 |
| | | | | | | | Composite | 100.00 | 44.17 | 13.88 | 100.00 | 100.00 |
| 2 | 3.0 | 1.5 | 11.7 | 4.0 | 2.0 | 1.0 | R Cell Prod | 79.18 | 48.94 | 8.80 | 87.93 | 52.17 |
| | | | | | | | Scav Cell Prod | 8.57 | 36.38 | 17.63 | 7.08 | 11.30 |
| | | | | | | | Scav Froth | 7.76 | 8.05 | 46.92 | 1.41 | 27.25 |
| | | | | | | | Slimes | 4.49 | 35.26 | 27.65 | 3.58 | 9.28 |
| | | | | | | | Composite | 100.00 | 44.07 | 13.36 | 100.00 | 100.00 |

* Reagent in pounds per ton of ore

** Added in rod mill

**Magnetic Concentration Following Roasting Crude to Magnetite**

Approximately 50 pounds of Lot 2 crude ore was crushed through 10 mesh, balled and roasted in a pot-type batch roaster at 650° C for one hour with a reducing gas containing 6% $H_2$ and CO.

Roasted samples were subjected to batch ball-mill grinding for selected periods of time and concentrated in a Davis tube to indicate liberation and response to magnetic concentration. These results, shown in Table 4, indicate grinding beyond 150 mesh has little effect on liberation, yielding concentrate grades of 61 to 62 percent Fe at iron recoveries of 94 - 96 percent.

These tests led to several bench-scale fine grinding - magnetic separation - cationic silica flotation tests on the roasted ore to determine if higher concentrate grades could be obtained. These results, shown in Table 5, indicate that the flotation tailings eliminated are in the 40 - 50% Fe range, resulting in considerable loss in recovery with little concentrate grade improvement. These data are also shown as grade-recovery curves in Figure 1.

Microscopic examination of the magnetic concentrate showed the presence of considerable 5 - 10 micron sized gangue disseminated within the magnetite particles. Several photomicrographs of these materials are shown in Figure 2.

Since the grinding required to liberate this gangue is far beyond what is presently considered reasonable, the sponsor was asked for a decision on further testing and/or pilot-plant production of products. The Swindell-Dressler Company concluded that pilot-plant testwork should proceed to produce 100 kilograms of fired pellets for their evaluation. In view of the large iron recovery losses associated with small improvements in concentrate grade resulting from silica flotation, it was also decided that the pilot-plant process should consist only of roasting to magnetite, wet fine grinding and magnetic concentration, and pelletizing. Mr. G. F. Johnson was informed of the expected concentration results: 61% Fe, 3% Mn, 7% $SiO_2$, 1% $Al_2O_3$, at 90% iron recovery.

## PILOT TESTING PROGRAM

**Magnetic Roasting**

Five hundred pounds of ore was ground to 40 percent minus 325 mesh in a dry Hardinge batch ball mill.

The ground material was moistened and balled in a 3 1/2 foot balling disk. The material balled well and the balls averaged 1/2 inch in diameter.

A charge of about 180 pounds of wet balls was placed in a 16-inch diameter by 18-inch deep basket and roasted at 650° C in a batch roaster for one hour with a reducing gas containing a combined $H_2$ plus CO of 6 percent. The reducing gas and the heat required were produced by burning natural gas with a deficiency of air.

TABLE 4. BATCH GRINDING AND DAVIS TUBE CONCENTRATION TESTS ON MAGNETICALLY ROASTED SAMPLE

| Grind Time* (min) | | 5 | 10 | 15 | 20 |
|---|---|---|---|---|---|
| **Size Distribution--Cum % passing** | | | | | |
| 65 mesh | | 99.0 | 99.9 | -- | -- |
| 100 " | | 95.8 | 99.6 | 99.9 | -- |
| 150 " | | 89.1 | 97.4 | 99.5 | 99.9 |
| 200 " | | 79.4 | 91.7 | 97.7 | 98.7 |
| 270 " | | 71.7 | 85.2 | 94.3 | 96.2 |
| 325 " | | 65.3 | 79.1 | 90.0 | 93.1 |
| **Davis Tube Results** | | | | | |
| Head, | % Fe | 50.27 | 50.02 | 49.94 | 50.10 |
| | % DT Mag Fe | 47.99 | 47.84 | 47.34 | 47.25 |
| Conc | % Fe | 60.55 | 61.19 | 61.47 | 62.15 |
| | % Wt | 79.26 | 78.17 | 77.02 | 76.02 |
| Tail | % Fe | 11.08 | 11.00 | 11.62 | 13.18 |

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

TABLE 5. FINE GRINDING--MAGNETIC SEPARATION--CATIONIC SILICA FLOTATION TEST RESULTS ON ROASTED ORE
(Magnetic concentration in laboratory wet Sala magnetic separator and flotation by addition of 0.02 lb/T MG83 and 1 drop MIBC to each stage)

| Grind: | 40 min @ 50% solids 0.3% +325 mesh | | | 20 min @ 50% solids 6.7% +325 mesh (high frequency demagnetization between stages) | | |
|---|---|---|---|---|---|---|
| | % Wt | % Fe | % Fe Recov | % Wt | % Fe | % Fe Recov |
| Head | 100.0 | 49.86 | 100.0 | 100.0 | 50.43 | 100.0 |
| Mag Tail 1 | 15.5 | 9.72 | 3.0 | 13.3 | 9.39 | 2.5 |
| Mag Conc 1 | 84.5 | (57.2) | 97.0 | 86.7 | (55.7) | 97.5 |
| Mag Tail 2 | 5.4 | 17.19 | 1.9 | 4.9 | 18.07 | 1.8 |
| Mag Conc 2 | 79.1 | (59.9) | 95.1 | 81.8 | (58.0) | 95.7 |
| Mag Tail 3 | 1.6 | 29.87 | 1.0 | 2.7 | 25.94 | 1.4 |
| Mag Conc 3 | 77.5 | 60.58 | 94.1 | 79.1 | (59.1) | 94.3 |
| Froth 1 | 2.8 | 54.12 | 3.1 | 1.1 | 43.07 | 0.9 |
| Conc 4 | 74.7 | (60.7) | 91.0 | 78.0 | (59.5) | 93.4 |
| Froth 2 | 2.7 | 50.10 | 2.7 | 1.7 | 40.95 | 1.4 |
| Conc 5 | 72.0 | (61.1) | 88.3 | 76.3 | (59.9) | 92.0 |
| Froth 3 | 2.9 | 50.27 | 2.9 | 1.9 | 43.04 | 1.6 |
| Conc 6 | 69.1 | (61.6) | 85.4 | 74.4 | (60.4) | 90.4 |
| Froth 4 | 2.9 | 52.28 | 3.0 | 2.2 | 45.93 | 2.1 |
| Conc 7 | 66.2 | (62.1) | 82.4 | 72.2 | (60.8) | 88.3 |
| Froth 5 | 3.6 | 55.28 | 3.9 | 2.1 | 47.56 | 2.0 |
| Conc 8* | 62.6 | 62.71 | 78.5 | 70.1 | 61.19 | 86.3 |

* 3.22 Mn
4.67 $SiO_2$
1.04 $Al_2O_3$

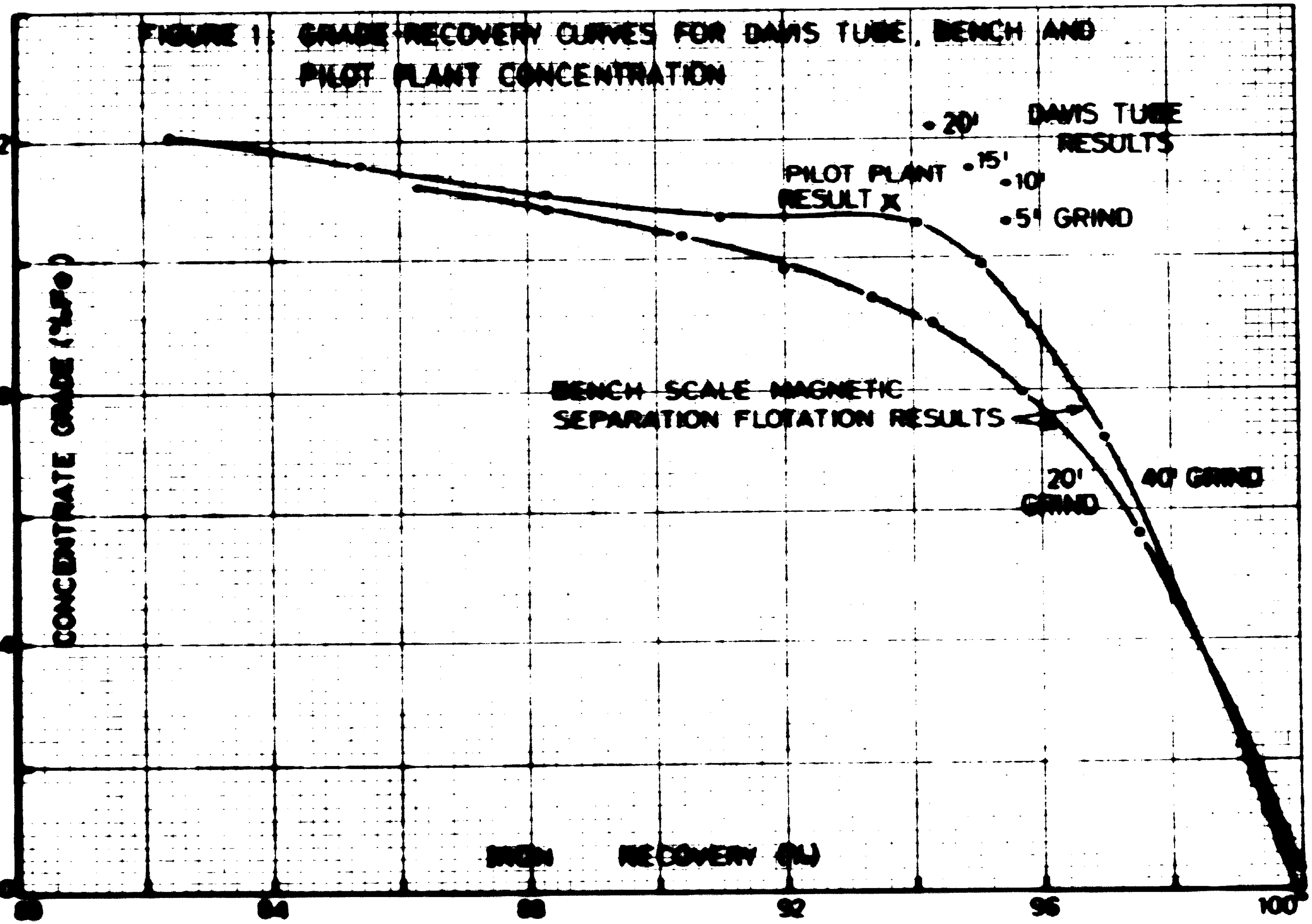
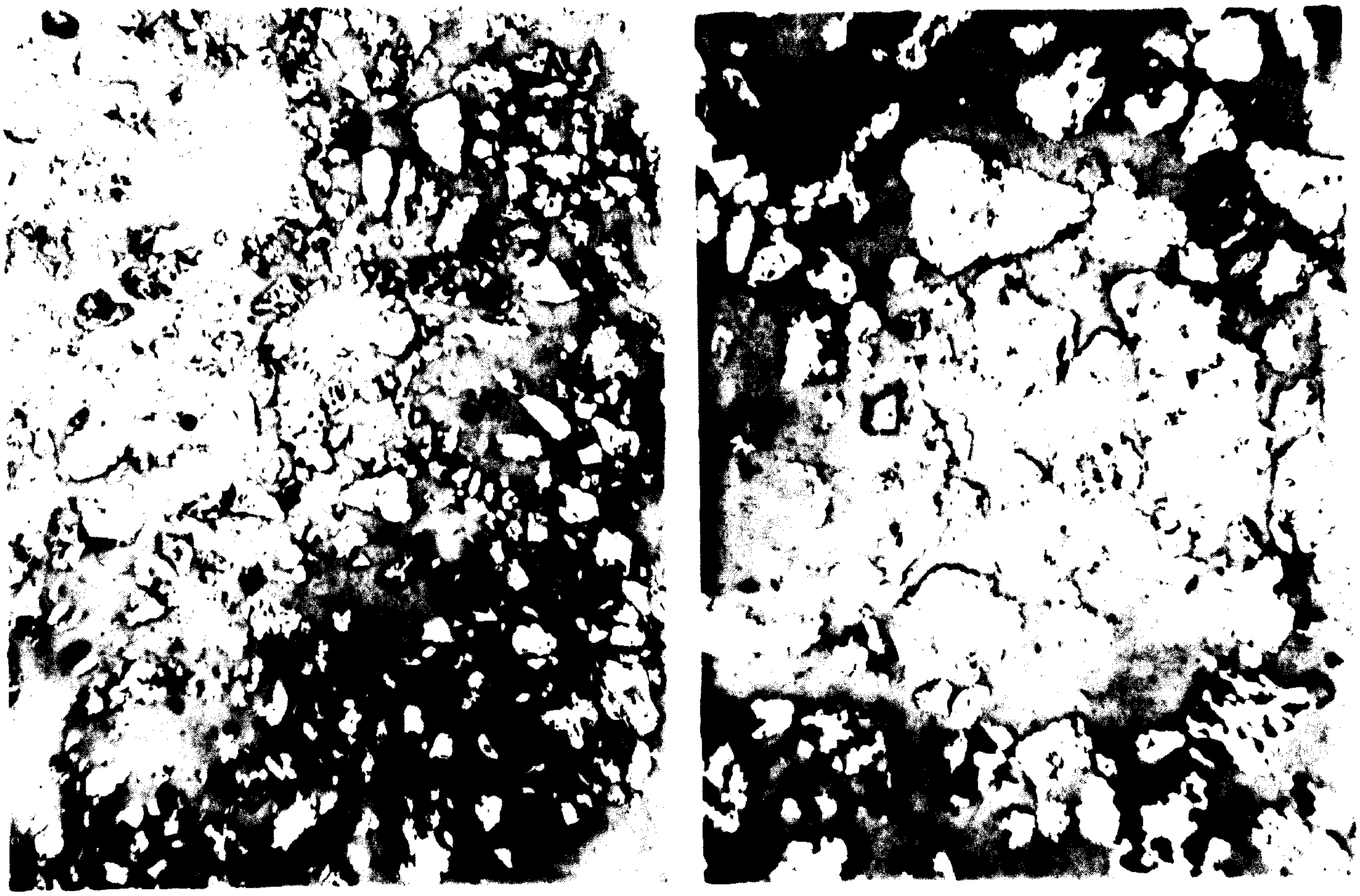


FIGURE 1: GRADE-RECOVERY CURVES FOR DAVIS TUBE, BENCH AND PILOT PLANT CONCENTRATION
CONCENTRATE GRADE (% Fe)
62
58
54
50
80
84
88
92
96
100
IRON RECOVERY (%)
•20'
•15'
•10'
•5' GRIND
DAVIS TUBE RESULTS
PILOT PLANT RESULT X
BENCH SCALE MAGNETIC SEPARATION FLOTATION RESULTS
20' GRIND
40' GRIND

FIGURE 2. PHOTOMICROGRAPHS OF PLUS 500 MESH PORTION OF MAGNETIC CONCENTRATE



2-A (50X) 2-B (150X)

These photomicrographs show the prevalence of finely disseminated gangue (5-10 microns) locked with the magnetite in the plus 500 mesh portion of the concentrate. The magnetite (white) commonly contains quartz or carbonate gangue inclusions (gray) as shown in 2-B. There is a small amount of free quartz (gray - distinguished from matrix by grain boundaries) in this size fraction as shown in 2-A, but not enough to account for the high insoluble content of the concentrate (6.7% $SiO_2$, 61.4% Fe).

The roasted product was cooled to room temperature with the same gas mixture which had been precooled by passing it through a cooling tower.

The 500 pounds of ore were roasted in three batches and the products combined. The roasting time used was over double that which would ordinarily be required but was used to assure uniformity of roast in all three batches. The small balls broke up readily into discrete particles following roasting.

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 Figures 3 and 4.

Roasted ore was fed at the rate of about 75 pounds per hour to this circuit, with a total of about 380 pounds of ore being consumed. Following 100 minutes 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 Fe and size distributions were determined. The primary data are shown in Table 6. 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, plus 325 mesh and minus 500 mesh screen analyses were used in the calculations. The resulting metallurgical balance is shown in Table 7 and indicates a weight recovery of 76.7% and an iron recovery of 93.7%.

Since it was felt that the sampling of Sweco screen oversize would unduly disturb the process, the calculations were made without these data. The minimum weight of the screen oversize and ball mill discharge were calculated based on the assumption that the screen oversize contained no minus 500 mesh material. Since this is a recirculating stream its data would have had little effect on the overall process yields.

The chemical analysis of the combined concentrate was: 60.54% Fe, 2.87% Mn, 6.70% $SiO_2$, 1.09% $Al_2O_3$ and 0.028% S. This is in quite good agreement with the expected concentration results.

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.

FIGURE 3. PILOT PLANT CONCENTRATION FLOWSHEET

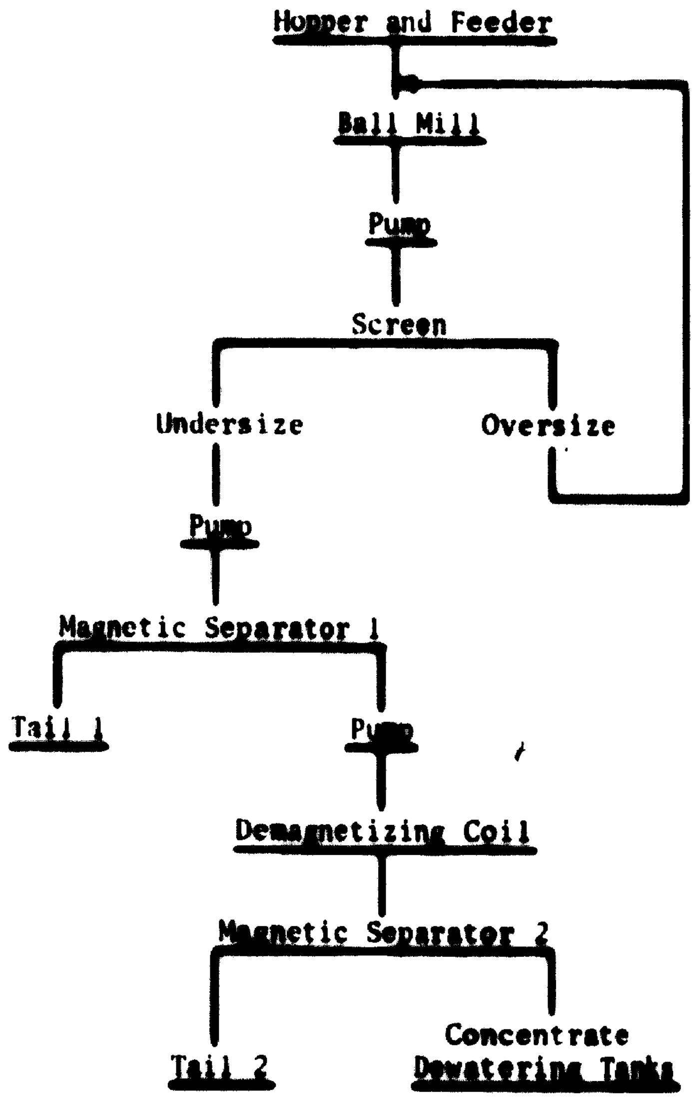


FIGURE 4. PILOT PLANT EQUIPMENT LIST

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. x 325 mesh

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

TABLE 6. ASSAYS AND SIZE DISTRIBUTIONS OF CONCENTRATION PILOT PLANT PRODUCTS.

| | Circuit Feed | Ball Mill Disch. | Screen U'size | Mag Tail 1 | Mag Conc 1 | Mag Tail 2 | Mag Conc 2 |
|---|---|---|---|---|---|---|---|
| **Sample I** | | | | | | | |
| | 49.62% Fe | 49.62% Fe | 50.19% Fe | 12.53% Fe | 57.58% Fe | 13.81% Fe | 60.30% Fe |
| (Cum % passing) 35M | 99.0 | | | | | | |
| 48 | 94.2 | | | | | | |
| 65 | 83.1 | 99.6 | | | | | |
| 100 | 71.4 | 98.3 | | | | | |
| 150 | 60.3 | 91.2 | 98.4 | | 98.9 | | 99.3 |
| 200 | 49.5 | 78.6 | 96.6 | 99.4 | 97.4 | | 98.1 |
| 270 | 42.8 | 66.2 | 94.6 | 96.6 | 95.3 | | 95.9 |
| 325 | 38.8 | 55.6 | 92.1 | 93.7 | 89.6 | | 90.5 |
| 400 | 35.7 | 49.2 | 88.9 | 90.9 | 86.5 | | 87.9 |
| 500 | 30.5 | 40.3 | 70.5 | 78.9 | 66.4 | 90.6 | 66.2 |
| **Sample II** | | | | | | | |
| | 49.78% Fe | 49.90% Fe | 49.76% Fe | 13.97% Fe | 57.73% Fe | 14.38% Fe | 61.11% Fe |
| (Cum % passing) 35M | 99.0 | | | | | | |
| 48 | 94.2 | | | | | | |
| 65 | 84.7 | 99.8 | | | | | |
| 100 | 74.3 | 98.6 | 99.6 | | | | |
| 150 | 63.1 | 95.3 | 98.8 | 99.7 | 98.8 | | 99.1 |
| 200 | 54.4 | 88.5 | 97.5 | 99.1 | 97.2 | | 97.6 |
| 270 | 48.4 | 79.0 | 95.9 | 97.8 | 95.0 | | 96.1 |
| 325 | 42.6 | 66.0 | 93.8 | 96.2 | 89.8 | | 86.5 |
| 400 | 39.7 | 57.9 | 90.5 | 93.1 | 84.8 | | 83.0 |
| 500 | 32.0 | 43.3 | 67.1 | 77.8 | 57.4 | 87.5 | 56.2 |

TABLE 7. PILOT PLANT RESULTS--MATERIAL BALANCES

| | Actual Data I | Actual Data II | Average Data | Adjusted Data | Calculated Wt lb. | Calculated Wt % | Calculated Units lb | Calculated Component Recov. % |
|---|---|---|---|---|---|---|---|---|
| | | | Total Iron % | | | | | |
| Circuit Feed | 49.62 | 49.78 | 49.70 | 49.80 | 378.97 | 100.00 | 188.71 | 100.00 |
| Ball Mill Discharge* | 49.62 | 49.90 | 49.76 | 49.76 | 599.76 | 158.26 | 298.44 | 158.15 |
| Screen Oversize* | --- | --- | --- | 49.69 | 220.80 | 58.26 | 109.73 | 58.15 |
| Screen Undersize | 50.19 | 49.76 | 49.98 | 49.80 | 378.97 | 100.00 | 188.71 | 100.00 |
| Mag Separator Tail 1 | 12.53 | 13.97 | 13.25 | 13.27 | 67.09 | 17.70 | 8.90 | 4.72 |
| Mag Separator Conc 1 | 57.58 | 57.73 | 57.65 | 57.66 | 311.87 | 82.30 | 179.81 | 95.28 |
| Mag Separator Tail 2 | 13.81 | 14.38 | 14.09 | 14.09 | 21.08 | 5.56 | 2.97 | 1.57 |
| Mag Separator Conc 2 | 60.39 | 61.11 | 60.75 | 60.81 | 290.80 | 76.73 | 176.84 | 93.71 |
| Standard Deviation | 0.24 | | | | | | | |
| | | | Plus 325 Mesh % | | | | | |
| Circuit Feed | 71.2 | 57.4 | 64.3 | 64.30 | 378.97 | 100.00 | 243.68 | 100.00 |
| Ball Mill Discharge* | 44.4 | 34.0 | 39.2 | 39.20 | 599.76 | 158.26 | 235.11 | 96.48 |
| Screen Oversize* | --- | --- | --- | 91.22 | 220.80 | 58.26 | 201.41 | 82.65 |
| Screen Undersize | 7.9 | 6.2 | 7.0 | 8.89 | 378.97 | 100.00 | 33.70 | 13.83 |
| Mag Separator Tail 1 | 6.3 | 3.8 | 5.0 | 4.66 | 67.09 | 17.70 | 3.13 | 1.28 |
| Mag Separator Conc 1 | 10.4 | 10.2 | 10.3 | 9.80 | 311.87 | 82.30 | 30.57 | 12.55 |
| Mag Separator Tail 2 | 0.0 | 0.0 | 0.0 | 0.01 | 21.08 | 5.56 | 0.00 | 0.00 |
| Mag Separator Conc 2 | 9.5 | 13.5 | 11.5 | 10.51 | 290.80 | 76.73 | 30.57 | 12.54 |
| Standard Deviation | 2.4 | | | | | | | |
| | | | Minus 500 Mesh % | | | | | |
| Circuit Feed | 30.5 | 32.0 | 31.2 | 31.20 | 378.97 | 100.00 | 118.24 | 100.00 |
| Ball Mill Discharge* | 40.3 | 43.3 | 41.8 | 41.80 | 599.76 | 158.26 | 250.70 | 212.03 |
| Screen Oversize* | --- | -- | -- | 0.00 | 220.80 | 58.26 | 0.00 | 0.00 |
| Screen Undersize | 70.5 | 67.2 | 68.5 | 66.15 | 378.97 | 100.00 | 250.70 | 212.03 |
| Mag Separator Tail 1 | 78.9 | 77.8 | 78.4 | 78.82 | 67.09 | 17.70 | 52.88 | 44.72 |
| Mag Separator Conc 1 | 66.4 | 57.4 | 61.9 | 63.43 | 311.87 | 82.30 | 197.82 | 167.31 |
| Mag Separator Tail 2 | 90.6 | 87.5 | 89.0 | 89.03 | 21.08 | 5.56 | 18.76 | 15.87 |
| Mag Separator Conc 2 | 66.2 | 56.2 | 61.2 | 61.57 | 290.80 | 76.73 | 179.06 | 151.44 |
| Standard Deviation | 1.9 | | | | | | | |

Final Concentrate Chemical Analysis 60.54% Fe, 2.87% Mn, 6.70% $SiO_2$, 1.09% $Al_2O_3$, and 0.028% S.

*Ball Mill Discharge and Screen Oversize weights calculated on basis of Screen Oversize having no minus 500 mesh material in it. This gives minimum values for these weights.

Pelletizing

Three hundred twenty five pounds of concentrate containing 15% moisture was balled in a 3 1/2 foot diameter disk using no binder addition. Finished balls had a moisture of 16.4%, gave 7 to 9 18-inch drops, and had wet and dry strengths of 4.1 and 4.5 pounds, respectively.

Preliminary bench-scale tests indicated the maximum drying temperature without decrepitation was 400° F at a gas velocity of 300 feet per minute, and fired balls had a linear shrinkage of 13 percent.

The balls were fired in a one-foot diameter by nine-inch deep pot furnace under the following conditions:

dried at 400° F at 300 ft/min for 20 min
preheated at 2250° F at 200 ft/min for 10 min
fired at 2250° F at 200 ft/min for 20 min

Bed shrinkage was approximately 35 percent and the pellets had shallow surface cracks. Compression strengths of the fired product were in the 400 to 850 pound range with an average of 636 pounds. A 600-gram tumbler test gave 92.2% plus 1/4-inch and 3.8% minus 28 mesh. The poor 1/4-inch tumble index is due to the abrasion of the rough surface, and could probably be improved with more elaborate and detailed testing. The chemical analysis of the fired product is shown in Table 8 along with the analyses of other pertinent samples from this study.

TABLE 8. CHEMICAL ANALYSIS FOR CRUDE ORE, ROASTED CRUDE, PILOT PLANT CONCENTRATE, AND FIRED PELLET

| Constituent | Preliminary Sample % | Crude % | Roasted Crude % | Concentrate % | Pellet % |
|---|---|---|---|---|---|
| Total Fe | 46.04 | 44.03 | 50.12 | 60.54 | 59.80 |
| $Fe^{++}$ | 0.08 | 0.16 | 16.84 | --- | 0.08 |
| Mn | 2.76 | 2.95 | --- | 2.87 | 2.81 |
| $SiO_2$ | 12.78 | 12.40 | 14.53 | 6.70 | 6.81 |
| $Al_2O_3$ | 1.04 | 1.42 | --- | 1.00 | --- |
| P | 0.018 | 0.016 | --- | --- | --- |
| S | 0.019 | 0.015 | --- | 0.028 | --- |
| LOI | 10.90 | 12.69 | --- | --- | --- |

## Grindability Tests

Bond ball mill grindability tests were made on the crude ore which had been roasted to magnetite at a 14-mesh grind. These grindability tests were made at both 100 and 200 mesh and work indexes were calculated as 7.3 and 7.2, respectively. Data for the tests are shown in Table 9.

An additional source of similar information is the pilot-plant data for the grinding circuit. From the dimensions and operating conditions of the 1 ft dia. x 2 ft ball mill it was possible to calculate the power input to the mill. This in conjunction with the feed rate to the ball mill - screen grinding system and the size distribution of feed and product streams permits estimation of a work index being experienced in the pilot plant. These calculations are shown in Table 10 and indicate a comparable work index of 8.3. This is in quite good agreement with the grindability results, considering the differences in feed and product sizes.

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 and coarse grinding crude can be estimated on this basis without introducing too much error.

## Process Flowsheet and Estimated Energy Requirements

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 dry autogenously grind 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 5 using 150 LTPH pellets as a basis (~ 1 MM-LTPH).

TABLE 9. RESULTS OF BOND GRINDABILITY TESTS AT 100 AND 200 MESH ON ROASTED CRUDE ORE

| Size Distribution | | Feed | 100 Mesh Product | 200 Mesh Product |
|---|---|---|---|---|
| (% Passing) | 10 Mesh | 100.0 | | |
| | 14 | 97.5 | | |
| | 20 | 83.5 | | |
| | 28 | 67.6 | | |
| | 35 | 53.2 | | |
| | 48 | 39.0 | | |
| | 65 | 31.0 | | |
| | 100 | 24.5 | | |
| | 150 | 19.3 | 74.0 | |
| | 200 | 16.0 | 53.8 | |
| | 270 | | 42.3 | 87.2 |
| | 325 | | 34.6 | 76.5 |
| $P_{80}$ (microns) | | 780 | 113 | 48 |
| $G_{bp}$ (g/rev) | | - | 4.31 | 2.47 |
| $W_i$ (KWH/MT) | | | 7.30 | 7.20 |

TABLE 10. CALCULATION OF WORK INDEX FROM PILOT PLANT DATA

| | |
|---|---|
| Dimensions | 1 ft dia. x 2 ft |
| Weight of balls | 260 lb @ 290 lb/cu ft |
| Speed | 68 rpm |
| Feed | 75 lb/hr → 0.0375 NTPH |

$V_p$ - fraction of mill occupied by balls - 0.570

$C_s$ - critical speed = 0.888

$$K_{wb} = 3.1\ D^{0.3}\ (3.2 - 3V_p)\ C_s (1 - 0.1/2^{9-10C_s})\quad \text{(KW/NT)}$$

$$= 3.73 \text{ KW/NT balls}$$

Mill power = 3.73 x 260/2000 = 0.484 KW

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

$W_{8\,ft}$ = 0.484 x 0.660/0.0375 = 8.51 KWH/NT

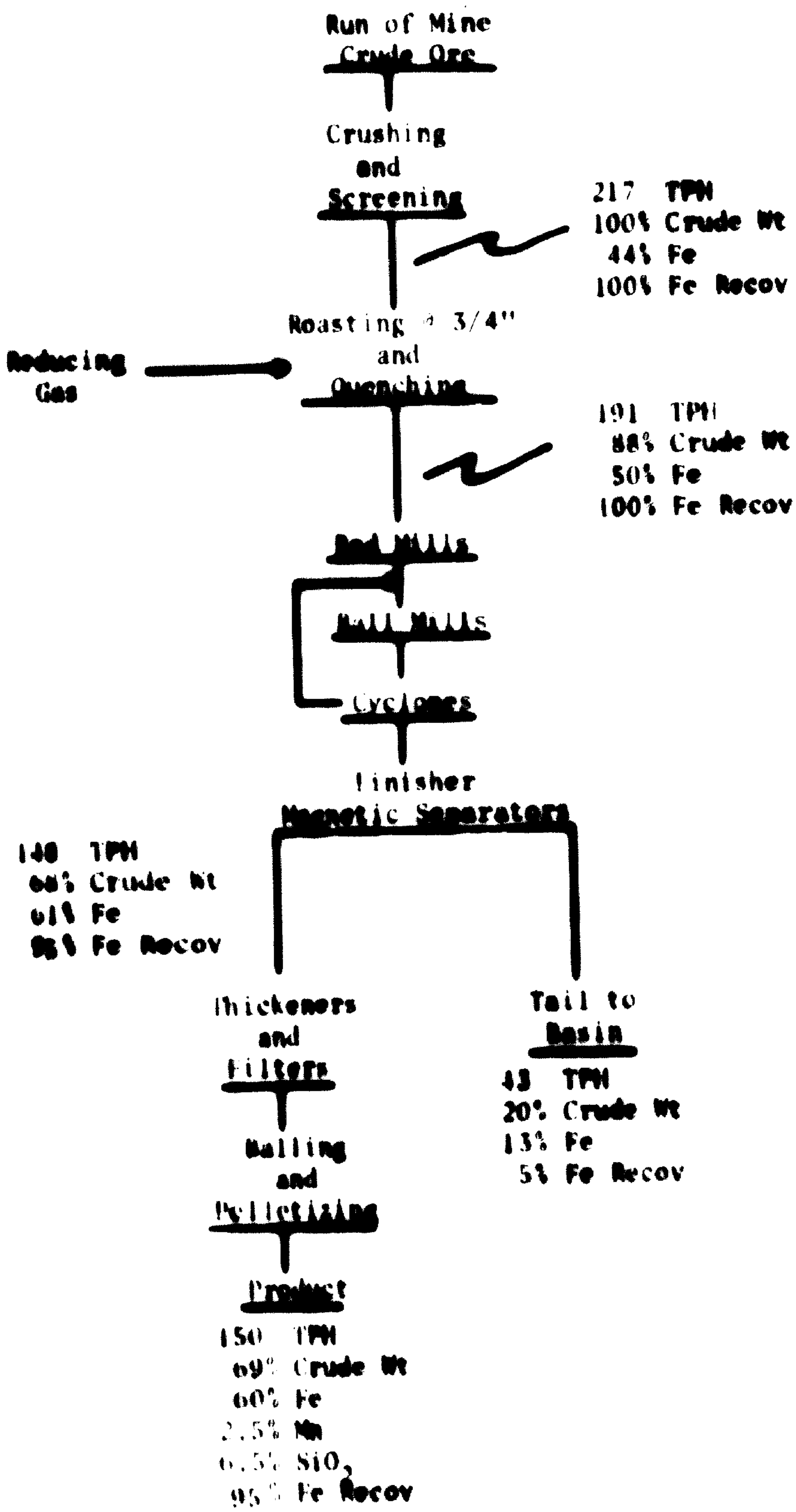
$P_{80}$ = 32 microns $\quad 10/\sqrt{P_{80}}$ = 1.768

$F_{80}$ = 180 microns $\quad 10/\sqrt{F_{80}}$ = 0.746

1.022

$$W_i = W/\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right) = \frac{8.51}{1.022} = 8.31 \text{ KWH/NT}$$

FIGURE 5. PROCESS FLOWSHEET



The estimated crushing energy requirements for attaining 80% passing 1/2 inch, which is assumed suitable for roasting, are 1.7 KWH/LT. The estimated energy requirements for rod and ball milling are 13.3 KWH/LT of crude ore, based on achieving the 80% passing 32 micron grind experienced in the pilot plant. Calculations leading to these results are shown in Table 11.

Reducing gas could be obtained by the partial combustion of oil or natural gas, and 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.

**TABLE 11. GRINDING ENERGY REQUIREMENT CALCULATIONS**

**Crushing to 80% passing 1/2"**

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

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

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

$W_i = 8$ $P_{80} = 32$ microns $F_{80} = 12{,}700$ microns

$$W = W_i\left(\frac{10}{\sqrt{P_{80}}} - \frac{10}{\sqrt{F_{80}}}\right) = 13.5 \text{ KWH/MT} = 15.1 \text{ KWH/LT roasted crude}$$

or 13.3 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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