

## ON THE PRODUCTION OF IRON ORE SUPERCONCENTRATES BY HIGH-INTENSITY WET MAGNETIC SEPARATION

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### ABSTRACT

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Direct reduction of iron ore to produce electric furnace feed for steelmaking is becoming economically important on a worldwide scale. For this application an iron ore superconcentrate containing less than 2% silica is demanded. Pilot plant and commercial operations have shown that high-intensity wet magnetic separation is well adapted to meet this specification with high recovery and attractive capital and operating costs. Tests with the Jones separator have produced superconcentrates containing less than 1.5% silica with over 90% iron recovery from preconcentrates produced by sizing or by gravity or low-intensity magnetic separation. Estimated total capital and operating costs to produce a ton of superconcentrate by high-intensity wet magnetic separation are \$0.43 for retreatment of specular hematite spiral concentrate, \$0.47 for Brazilian hematite fines, and \$0.49 for magnetite.

### INTRODUCTION

Recently there has been an upsurge in interest in steelmaking by direct reduction as an alternative to the blast furnace. In the direct reduction process, iron ore, often in the form of pellets, is heated with a solid or gaseous reductant at a temperature of about 1,000° C. Some fraction of the oxygen in the ore is removed, leaving a partially metallized product called sponge iron because of its porous structure. The sponge iron is then fed to an electric furnace for steelmaking. If steel scrap is available, it is most economical to include 40–60% scrap in the furnace charge (Leary and Larwood, 1973). Although the 1973 production of pre-reduced pellets was only about 3 million tons (Lownie, 1973), it has been estimated by Miller (1972) that at least 42 million tons per year of pre-reduced iron ore materials will be consumed in electric furnaces for steel production by 1980.

A number of advantages in the direct reduction route to steelmaking have been delineated. Direct reduction eliminates the need for coke. High-quality

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coking coal has become scarce and expensive as increasing numbers of fuel burners compete for limited supplies of low-sulfur coal. In addition, it is very difficult to control air pollution from coke ovens. Direct reduction reduces dependency on supplies of steel scrap, the price of which can fluctuate widely. Pre-reduced ore also introduces lesser quantities of deleterious elements into electric furnace steel than does scrap. Blast furnace operation is most economical when carried out on a very large scale. Direct reduction, on the other hand, is adaptable to use in "miniplants", of 50–500 thousand ton per year capacity, which can use local raw materials and serve a regional market.

The advent of direct reduction poses a challenge to iron ore processing technology. The optimum silica content of blast furnace feed is generally in the range of 6–8%. For efficient operation of the electric furnace, on the other hand, the pre-reduced feed must contain less than 3% silica (Miller, 1972; Leary and Larwood, 1973). Since weight is lost as oxygen is removed in the reduction process, this requirement corresponds to a limit of 2% on the silica in the iron oxide concentrate. Iron ore concentrates meeting this requirement are known as *superconcentrates*.

Three methods of producing superconcentrates have recently received attention. Tippin (1972) reported on producing a superconcentrate by cationic flotation of quartz from a Mesabi Range magnetic concentrate. Only about 40% of the magnetic concentrate was converted into a superconcentrate with most of the remainder being recovered as a standard grade concentrate. Funk and Lawver (1970) retreated magnetic and gravity concentrates by high-tension electrostatic separation to produce superconcentrates. The third method of producing superconcentrates is by magnetic upgrading of preconcentrates produced by sizing or by gravity or low-intensity magnetic separation. For certain magnetite ores, low-intensity dry or wet separation or a combination thereof has produced high degrees of purity (Kihlstedt and Sköld, 1960). For hematite ores, high-intensity wet magnetic separation has proved to be successful. This paper will report on the application of high-intensity wet magnetic separation to the production of iron ore superconcentrates.

Since the cost of the raw materials may constitute as much as 75% of the cost of producing sponge iron (Meyer and Bongers, 1973) iron ore superconcentrates must be available at a reasonable cost in order to make direct reduction economically attractive. In this paper, cost analyses will be given for the production of superconcentrates by high-intensity wet magnetic separation from three types of iron ores. The economic feasibility of this method of producing superconcentrates will be demonstrated.

## PRINCIPLES

The theory and practice of high-intensity wet magnetic separation has recently been reviewed by Lawver and Hopstock (1974). They showed that because of the nature of the forces acting on particles in the separator, a high-intensity wet magnetic separator that recovers 25-micron diameter pure

hematite particles in the concentrate will also recover locked 100-micron particles containing only 10% iron. They also showed that the magnetic field necessary to recover a paramagnetic particle is inversely proportional to the particle size. Since the capital and operating costs increase with increasing magnetic field strength, the key to economical superconcentrate production by high-intensity wet magnetic separation is starting with an ore for which the iron minerals liberate at a relatively coarse size. It is essential that a minimum of locked particles be present. For a hematite ore, 100-micron particles should be well liberated. Since it is much easier to recover ferromagnetic particles, magnetite particles as small as one micron being recovered by the Jones separator, it is only necessary that 25-micron particles be liberated in a magnetite ore.

In addition to good liberation characteristics of the ore, the second requirement for superconcentrate production is minimal entrainment of gangue particles in the concentrate. For the tests described in this paper, a matrix of grooved plates, of the type introduced by Jones (1955, 1960) was used in the high-intensity magnetic separators. Grooved plates are particularly well adapted to obtaining minimal entrainment of gangue in the magnetic concentrate. Since the plates are aligned parallel to the direction of wash-water flow, the wash water flows through freely at a high velocity, giving maximum extraction of nonmagnetic material. The plates can be set far enough apart to prevent the formation of chains or bridges of magnetic particles between magnetic poles. Such clusters are responsible for much of the entrainment of gangue in magnetic separation. The free access of wash water to the plates prevents the build-up within the separation matrix of magnetite and foreign material such as grass or straw, all which have been known to cause cleaning problems in other machines.

## EQUIPMENT

The metallurgical data presented in this survey are based on commercial and pilot plant operations using the continuous Jones high-intensity wet magnetic separator, manufactured by the Humboldt division of Kloeckner-Humboldt-Deutz AG of Cologne, West Germany (Wenz and Zabel, 1973). A schematic drawing illustrating the magnetic circuit of the Jones machine is given in Fig.1. There are two rotating annular rings or carousels containing the plate boxes. Each carousel passes through two gaps in the magnetic circuits. Thus there are four regions where separation takes place. The double rotor design reduces the floor space requirements of the machine.

The largest Jones machine presently being manufactured, the DP-317, is 3.5 m high, 6.3 m wide, and weighs 96 metric tons. For single stage operation on Brazilian hematite it has a capacity of 120 tons per hour or one million tons per year. Nine smaller Jones machines are available down to a single-rotor laboratory/pilot plant model which can treat 0.5 ton per hour.

The capital and operation cost calculation for a single DP-317 Jones sepa-

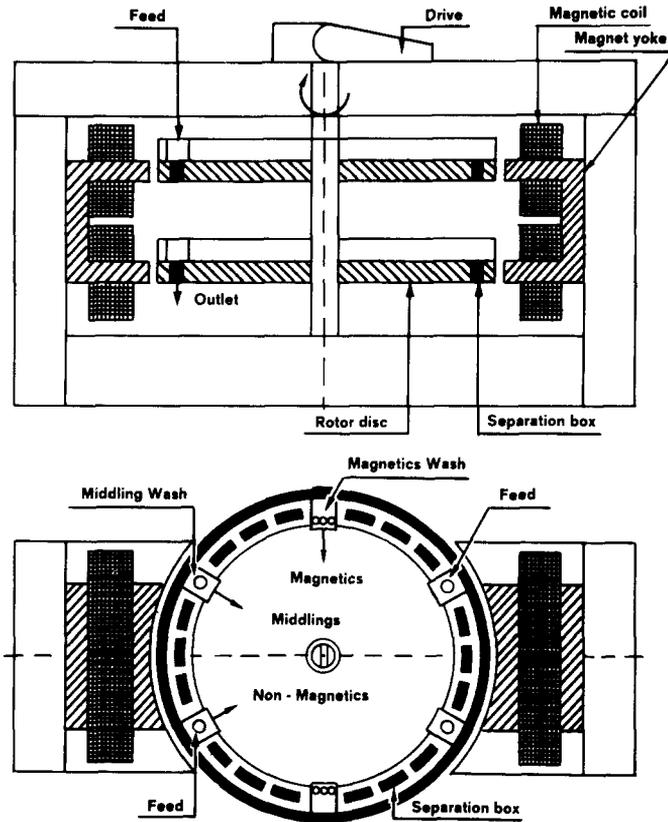


Fig.1. Schematic drawing of the double rotor Jones high-intensity wet magnetic separator, illustrating the magnetic circuit.

erator is given in the Appendix pp. 125–126. The costs are given in American dollars and are valid for the vicinity of Quebec, Canada in the year 1974. The capital cost of the machine — including installation cost, building space, and auxiliary pumps, agitators, and power controls — is \$545,000. Based on a 15-year service life and a 10% interest rate, the annual cost for depreciation and interest is \$71,700. The annual operating cost — including labor, power, water, supplies, and maintenance — is \$75,000. Thus the total capital and operating cost is \$146,700 per year.

#### SUPERCONCENTRATE FROM SPECULAR HEMATITE SPIRAL CONCENTRATE

There are a number of mines in Canada producing a specular hematite ore with excellent liberation characteristics. Traces of magnetite associated with the specularite give the iron-bearing mineral an apparent magnetic susceptibility much greater than that of reagent-grade hematite, making 10-micron particles easily recoverable. Thus, this type of ore is an excellent candidate

for the production of superconcentrate by high-intensity wet magnetic separation. In fact, Ferro Iron Ltd. of Prescott, Ontario, has been producing an iron superconcentrate from an ore of this type since 1965. Spiral concentrate purchased from Quebec Cartier Mining Company is ground to minus 35 mesh and fed to a Jones separator. The silica content is reduced from 6 to less than 0.3% and the insoluble content to about 0.4%. The plant produces about 20 tons per day of ferric oxide to be used in the production of barium ferrite. More recently a similar plant was built by Fina Metal Ltd. of Montreal, Quebec to produce an iron oxide product containing less than 0.2% insoluble. The 100 tons of ferric oxide produced each day in this plant is reduced in a hydrogen atmosphere to iron powder.

With this technical background, it will be possible to build much larger plants as the demand for superconcentrates increases for use in the production of electric furnace feed by direct reduction. A flowsheet to retreat specularite spiral concentrate, or other materials, to produce a superconcentrate containing 0.5% insolubles is given in Fig.2 along with typical metallurgical results. For this application a Jones DP-317 Separator would have a capacity of 400,000 tons per year. If a lower grade concentrate containing about 1.5%  $\text{SiO}_2$  were satisfactory, instead of two passes a single pass could be used and the capacity could be doubled. From the capacity and the cost calculation in the Appendix, the capital and operating costs per ton of feed and per hour of concentrate were calculated as given in Table II. The overall capital and operating cost to produce a ton of superconcentrate is \$0.43. The costs of reducing the feed to minus 35 mesh, filtering and drying the concentrate, and disposing of the tailings would be in addition to this basic concentration cost.

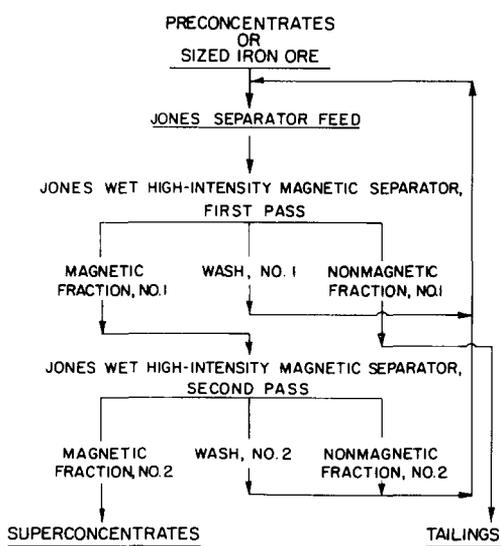


Fig.2. Flowsheet for production of superconcentrate from preconcentrates or sized iron ore

Plans have already been developed by Sidbec-Dosco to construct the first large superconcentrate plant in Canada by 1976. Jones separators will be used to produce three million tons per year of superconcentrate from Fire Lake Mine spiral concentrate (minus 14 mesh). This superconcentrate will be pelletized and then shipped to the Sidbec-Dosco direct-reduction plant at Contrecoeur, Quebec. Single-pass pilot plant tests with recirculation of wash water have shown a 96.3% iron recovery in a superconcentrate containing 68.7% iron and 1.45% silica.

#### SUPERCONCENTRATE FROM BRAZILIAN HEMATITE FINES

The first demonstration that high-intensity wet magnetic separation is technically and economically feasible on a very large scale has taken place at Itabira, Brazil. In 1970 a Jones DP-317 separator was installed by Companhia Vale do Rio Doce to treat the finer fractions of its hematite ore. Successful production of a high-grade concentrate led to the purchase of an additional 27 separators, giving the magnetic separation plant a capacity of 28 million tons per year.

Further studies of high-intensity wet magnetic separation of the Itabira ore showed that a flowsheet could be developed to produce a superconcentrate containing about 1.5% silica from minus 100 mesh material. The metallurgical results obtained with the flowsheet given in Fig.2 are presented in Table I and the cost analysis in Table II. The capital and operating cost of superconcentrate production is estimated to be \$0.47 per ton of superconcentrate produced. The economics are favorable enough that a plant for the production of superconcentrate will be in operation by this year.

#### SUPERCONCENTRATE FROM A MAGNETITE ORE

Although the Jones separator was designed for high-intensity magnetic separation, tests have shown that with reduced current it is also a very effective separator for finely ground magnetite. Because of the intense washing action, cleaner concentrates are obtained in fewer stages than are necessary on conventional wet drum separators. For this reason the Jones separator is well suited to the production of superconcentrates.

One possible method of superconcentrate production is by recleaning the concentrate from conventional wet drums. However, as illustrated by the results summarized in Table I, it is possible to produce a 70.8% iron concentrate from a 35.9% iron crude ore ground to minus 325 mesh by only two stages of separation on a double-rotor Jones machine. The high capacity of the machines for magnetite gives a treatment cost of \$0.49 per ton of superconcentrate, as shown in Table II.

TABLE I

Summary of metallurgical results for producing superconcentrates with high-intensity wet magnetic separation

	Superconcentrate production from spiral concentrate			Superconcentrate production from Brazilian hematite ore			Superconcentrate production from magnetite ore		
	% wt.	% Fe	Fe dist. (%)	% wt.	% Fe	Fe dist. (%)	% wt.	% Fe	Fe dist. (%)
Preconcentrate	100.0	65.2	100.0	100.0	39.7	100.0	100.0	35.9	100.0
Jones feed	106.6	64.3	105.2	115.9	39.0	113.8	111.7	34.7	108.1
First pass Jones magnetics No.1	89.3	68.8* <sup>1</sup>	94.2	55.8	67.9	95.5	50.9	67.1	95.1
wash No.1	2.1	48.9	1.6	12.6	29.6	9.4	6.6	34.3	5.3
nonmagnetics No.1	15.2	40.3	9.4	47.5	7.4	8.9	54.2	6.4	9.7
Second pass Jones magnetics No.2	84.8	69.7	90.6	52.5	68.9	91.1	45.8	70.8	90.3
wash No.2	1.4	55.9	1.2	1.1	61.4	1.7	1.7	64.2	3.0
nonmagnetics No.2	3.1	50.5	2.4	2.2	48.7	2.7	3.4	19.2	1.8
Super concentrates	84.8	69.7* <sup>2</sup>	90.6	52.5	68.9* <sup>1</sup>	91.1	45.8	70.8* <sup>1</sup>	90.3
Final tailings	15.2	40.3	9.4	47.5	7.4	8.9	54.2	6.4	9.7

\*<sup>1</sup>Superconcentrate of approximately 1.5% SiO<sub>2</sub>.\*\*<sup>2</sup>Superconcentrates containing 0.5% insoluble.



## APPENDIX

Cost analysis (U.S.\$), 1974)

**Capital Investment***A. Equipment:*

1 Jones Separator Model DP-317 (with four agitators and power controls)	386,000	
6 centrifugal pumps (free delivery to German border)	<u>24,000</u>	
Total equipment	410,000	
Freight charge to Montreal, Canada	<u>20,000</u>	
Equipment cost (duty free) fob Montreal		430,000

*B. Building and installation:*

Ground area = 9 m × 6 m = 54 m <sup>2</sup>		
Space = 54 m <sup>2</sup> × 13 m = 700 m <sup>3</sup>		
Subject to 56 kg of steel/m <sup>3</sup>		
40 tons of steel at about \$500/ton	20,000	
Construction work, electrical installation, erection, planning, supervision and start-up cost	<u>95,000</u>	
Building and installation cost		<u>115,000</u>

*C. Total capital investment:*545,000*D. Annual capital cost (depreciation and interest):*

Calculated by the compound interest formula:

$$K = \frac{Ar}{1 - (1+r)^{-n}}$$

where:

A = capital investment = \$545,000

r = annual interest rate = 10% = 0.10

n = service life = 15 years

K = annual depreciation and interest cost

So, annual depreciation and interest cost

71,653**Annual Operating Cost***A. Labor:*20% man day - 20% × 3 × \$15,000 9,000*B. Power:*1,800,000 kWh at an electricity price of \$0.01/kWh 18,000

(Appendix cont.)

*C. Water:*

Total water consumption with feed at 40% solids, wash water and scour water is 4,000,000 m<sup>3</sup>/yr  
 Portion of recycled water amounts to 90%  
 (Cost \$7,000/year)  
 Consequently, about 400,000 m<sup>3</sup>/yr. of make up water is required  
 (Cost at \$0.025/m<sup>3</sup> = \$10,000) 17,000

*D. Supplies:*

Mainly cost of grooved plates of which average life is 2 years 20,000

*E. Maintenance:*

Mechanical and electrical equipment and building 11,000

*F. Total operating cost per year:* 75,000

**Capital And Operating Cost Per Year**

A. Depreciation and interest cost per year	71,653
B. Operating cost per year	75,000
C. Total capital and operating cost per year	<u>146,653</u>

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