DEPARTMENT OF MINES
SOUTH AUSTRALIA

RESEARCH AND DEVELOPMENT BRANCH

R.D. 97

BENEFICIATION OF LOW GRADE IRON ORES

PART I

BRAEMER IRONSTONE

by

L.J. WEIR

P.K. HOSKING

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Abstract.

Preliminary laboratory beneficiation tests were carried out on a fine-grained siliceous iron ore. Magnetic treatment of ground ore recovered approximately half the iron in a concentrate assaying 65.5 per cent. Fe. Magnetic treatment of ore roasted in a reducing atmosphere and then ground, recovered approximately 90 per cent. of the iron in a concentrate assaying 49 per cent. Fe. The ratio of concentration was 1.6:1. Flotation tests were not encouraging. A tall oil collector emulsion showed some promise.

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1. SUMMARY.

The two major iron minerals in the ore were identified as relatively coarse-grained magnetite and finer hematite.

Magnetic treatment of ground ore assaying 33.1 per cent. Fe produced a concentrate assaying 65.5 per cent. Fe with a recovery of 47.8 per cent.

Treatment of ore ground after roasting in a reducing atmosphere produced a magnetic concentrate assaying 49.1 per cent. Fe with a recovery of 89.2 per cent.

No significant difference in grinding characteristics of reduced ore with those of the original ore was noticed.

The best result from flotation was obtained on ground raw feed using a tall oil emulsion, when a concentrate assaying 47.9 per cent. Fe was produced with a recovery of 53.6 per cent.

Further investigation of magnetic and flotation concentration methods on a sample more representative of the orebody is recommended.

2. INTRODUCTION.

An extensive range of hills, consisting mainly of low grade iron ore, approximately fifty miles north of Morgan has been known for many years. The ores, of various types, mode of occurrence, and grade, have for convenience been grouped under the general title of "Braemar ironstones".

A ground survey of the area late in 1958 by the Geological Branch indicated a tonnage and grade of material worthy of more detailed examination.

It was estimated that 50 million tons of ore occur in an easily mined orebody, with a further 59 million tons above plain level.

Surface samples for mineral identification and analysis were taken from the deposit.

The two main ore types encountered were:-

(a) A thinly-bedded ironstone assaying about 40 per cent. Fe.

(b) A tillitic ironstone assaying about 15 per cent. Fe.

Reject portions of assay samples were made available to the Metallurgical Section and preliminary testing was requested pending the receipt of drill core samples from the deposit.

3. MATERIAL EXAMINED.

The Geological Branch submitted hand-picked surface samples from the Southern ore body of the deposit for assay. The reject portions of these samples were used to produce a sample expected to approximate the mineralogy and grade of the "main ore horizon".

Samples bulked were:-

Section.	Line.	Assay No.
BB	2	A 1311/58
FF	7	A 1356/58
EE	8	A 1359/58
DD	9	A 1362/58
	10	A 1486-87/58
	11	A 1488-92/58.

Total weight of the composite sample was approximately 50 pounds.

4. EQUIPMENT USED.

The following equipment was used in test work:-

(a) Tyler series laboratory screens.

(b) Infrasizer.

(c) Laboratory batch ball mill.

(d) Davis tube magnetic separator.

(e) Electric muffle furnace.

(f) Laboratory attrition conditioner.

(g) Laboratory Fagergren flotation cell.

(h) Carpco laboratory electrostatic separator.

5. EXPERIMENTAL PROCEDURE.

The head sample was crushed to minus 10 mesh and further sampled.

Magnetic separation tests were carried out on finely ground raw feed, and on material ground after reduction roasting.

Flotation tests were carried out on finely ground raw feed, on material deslimed after grinding and on non-magnetic fractions from the Davis tube machine. Two reagent combinations were used.

An electrostatic separation test was carried out on a closely sized fraction of ground raw feed.

6. CONDITIONS AND RESULTS.

6.1 Mineralogical Examination of Head Sample:

Microscopic examination of a briquetted sample of crushed material showed that the iron minerals occur as aggregates of grains. About 50 per cent. by volume consists of grains coarser than 20 microns and up to 70 microns in diameter.

The coarser particles consist mainly of magnetite, which shows some martitisation. The finer grains, which are mostly in the 3 to 10 micron range, consist mainly of haematite with a little magnetite.

Silica is the principle gangue mineral.

6.2 Sizing of Head Sample:

Sizing analysis, with iron assays and distributions, is given in Table 1.

Table 1.

Screen	Weight %.	Assay Fe %.	Distribution Fe %.
+ 10	3.8	32.9	27.9
+ 14	23.6		
+ 20	20.4	32.5	32.9
+ 28	12.9		
+ 35	8.3	32.1	13.4
+ 48	5.4		
+ 65	3.9	31.6	6.3
+ 100	2.6		
+ 150	1.8	32.9	3.1
+ 200	1.3		
Infrasizer.			
+ 49 microns	2.1	57.6*	6.6
+ 35 "	1.7		
+ 25 "	2.0	39.6	4.4
+ 18 "	1.7		
+ 12 "	1.7	21.9	2.0
+ 9 "	1.4		
- 9 "	5.4	23.9	3.9
	100.0	32.9 (calc.) 33.1 (assay)	100.0

Infrasizer fraction sizes are based on a specific gravity of 3.5.

* The high assay figure is probably entirely due to a concentration effected by the changed method of sizing.

6.3 Magnetic Separation Tests:

6.3.1 Treatment of Raw Feed:

Ground material was treated in the Davis Tube magnetic separator. Conditions for test 1 are given in Table 2.

Table 2.

Conditions for Magnetic Separation Test 1.

Fineness of Grind (% -325 mesh)	69
Coil Current (amps)	3.0
Stroke Frequency (cycles/min.)	50
Water Flow Rate (gallons/min.)	0.3

Results of the test are given in Table 3.

Table 3.

Results of Magnetic Separation Test 1.

Product	Weight %.	Assay Fe %.	Distribution Fe %.
Magnetics	40.0	50.8	61.5
Non-magnetics ..	60.0	21.1	38.5
		33.0 (calc.)	100.0

Feed for Test 2 was ground finer, the sizing as determined in the infrasizer being given in Table 4.

Table 4.

Sizing of Magnetic Separation Test 2 Feed.

Cone	Size (microns)	Weight %.
1	+ 49	0.5
2	+ 35	2.5
3	+ 25	10.5
4	+ 18	17.0
5	+ 12	12.0
6	+ 9	9.0
7	- 9	48.5
		100.0

The material was treated in the Davis tube machine, non-magnetics being repassed twice. Conditions are given in Table 5.

Table 5.

Conditions for Magnetic Separation Test 2.

	Pass		
	1	2	3
Coil Current (Amps)	1.0	2.0	3.0
Stroke Frequency (cycles/min.)	50	40	30
Water Flow Rate (gallons/min.)	0.3	0.3	0.3

Results are given in Table 6.

Table 6.

Results of Magnetic Separation Test 2.

Product	Weight %.		Assay Fe %.		Distribution Fe %.	
Magnetics 1	16.2		67.4		33.0	
" 2	6.1	24.1	66.1	65.5	12.2	47.8
" 3	1.8		48.7		2.6	
Non-magnetics	75.9		22.8		52.2	
			33.1 (calc.)		100.0	

Size fractions of the sample were also treated in the Davis tube under conditions given in Table 7.

Table 7.

Conditions for Magnetic Separation Test 3.

Coil Current (Amps)	3.0
Stroke Frequency (cycles/min.)..	80
Water Flow Rate (gallons/min.)..	0.3

Results are given in Table 8.

Table 8.

Results of Magnetic Separation Test 3.

Size Fraction	Weight %.	Magnetic Separation				
		Product	Weight %.	Assay Fe %.	Distribution % of Size Fraction	Distribution % of Feed
Cones 1, 2, 3 and 4 (+ 18 micron)	30.5	Magnetics	38.7	66.4	65.5	21.2
		Non-magnetics	61.3	22.0	34.5	11.2
			100.0	39.1 (calc.)	100.0	32.4
Cones 5 and 6 (+ 9 micron)	21.0	Magnetics	17.6	67.1	39.8	18.9
		Non-magnetics	82.4	21.7	60.2	28.2
			100.0	29.7 (calc.)	100.0	47.1
Cone 7 (- 9 micron)	48.5	Magnetics	5.2	68.2	12.6	2.6
		Non-magnetics	94.8	26.0	87.4	17.9
			100.0	28.2 (calc.)	100.0	20.5
Feed	100.0			33.1		100.0

Material for Test 4 was ground to the sizing given in Table 9.

Table 9.

Sizing of Magnetic Separation Test 4 Feed.

Cone	Size (microns)	Weight %.
1	+ 49	0.3
2	+ 35	1.0
3	+ 25	5.2
4	+ 18	9.5
5	+ 12	13.5
6	+ 9	13.0
7	- 9	57.5
		100.0

The ground material was fed to the Davis tube machine under the conditions given in Table 7.

Results of the test are given in Table 10.

Table 10.

Results of Magnetic Separation Test 4.

Product	Weight %.	Assay Fe %.	Distribution Fe %.
Magnetics	19.0	64.3	36.7
Non-magnetics ...	81.0	25.8	63.3
	100.0	33.1 (calc.)	100.0

Two charges of the original feed, each of 1,000 g., were ground and treated under conditions identical for Test 3. The non-magnetic fractions after desliming were used as feed for flotation tests 2 and 5.

Results of the magnetic treatment are given in Table 11.

Table 11.

Results of Magnetic Separation Tests 5 and 6.

Test	Product	Weight %.	Assay Fe %.	Distribution Fe %.
5	Magnetics	23.7	64.5	46.3
	Slime	5.8	26.7 (calc.)	4.7
	Non-magnetics ...	70.5	23.0	49.0
		100.0	33.1	100.0
6	Magnetics	25.2	63.6	48.4
	Slime	7.0	19.7(calc.)	4.2
	Non-magnetics ...	67.8	23.2	47.4
		100.0	33.1	100.0

6.3.2 Mineralogical Examination of Magnetic Products:

Samples of magnetic and non-magnetic products from Test 6 were examined microscopically to determine the efficiency of magnetic treatment.

Extracts from the mineralogical report are as follows:-

Magnetic Fraction:-

The product contains 90-95 per cent. by volume of iron oxide minerals, the 5-10 per cent. of gangue mineral consisting mainly

of quartz, with some felspar and traces of apatite. Some of the larger quartz grains are composites with iron ore.

The grain size varies from 1 to 70 microns, about 30 per cent. being coarser than 30 microns and 90 per cent. coarser than 10 microns.

Non-Magnetic Fraction:-

The product contains about 65 per cent. by volume of gangue minerals, mainly quartz, with some felspar, dolomite, muscovite, chlorite and apatite.

Hematite is the main iron mineral present, and there are minor amounts of goethite. There is less than 1 per cent. of magnetite present.

The grain size varies from 1 to 35 microns, 90 per cent. being smaller than 10 microns.

6.3.3 Treatment of Reduced Feed:

A 500 g. charge of minus 10 mesh ore was roasted at 600° C. in a coal gas atmosphere for two hours and then cooled in the reducing atmosphere.

The reduced material was ground to the sizing shown in Table 12.

Table 12.

Sizing of Magnetic Separation Test 5 Feed.

Cone	Size (microns)	Weight %.
1	+ 49	5.2
2	+ 35	8.8
3	+ 25	13.1
4	+ 18	12.2
5	+ 12	13.0
6	+ 9	12.0
7	- 9	35.7
		100.0

The ground material was treated in the Davis tube separator under the conditions given in Table 7.

Results are given in Table 13.

Table 13.

Results of Magnetic Separation Test 5.

Product	Weight %.	Assay Fe %.	Distribution Fe %.
Magnetics	56.5	49.5	85.0
Non-magnetics ...	43.5	11.3	15.0
	100.0	32.9 (calc.)	100.0

Roasting of a second 500 g. charge of ore was carried out at 650° C. for two hours in a coal gas atmosphere which was also maintained during cooling.

The reduced charge was ground under conditions identical to those of Test 2.

Sizing of the ground material is given in Table 14.

Table 14.

Sizing of Magnetic Separation Test 6 Feed.

Cone	Size (microns)	Weight %.
1	+ 49	0.8
2	+ 35	4.2
3	+ 25	10.0
4	+ 18	12.0
5	+ 12	14.5
6	+ 9	12.7
7	- 9	45.8
		100.0

The ground material was treated in the Davis tube separator under the conditions given in Table 15.

Table 15.

Conditions for Magnetic Separation Test 6.

Coil Current (Amps)	1.0
Stroke Frequency (cycles/min.)	80
Water Flow Rate(gallons/min.)	0.3

Results of the test are given in Table 16.

Table 16.

Results of Magnetic Separation Test 6.

Product	Weight %.	Assay Fe %.	Distribution Fe %.
Magnetics	62.2	49.1	89.2
Non-magnetics ...	37.8	9.8	10.8
	100.0	34.3 (calc.)	100.0

6.4 Flotation Tests:

Separate charges, each of 500 g., of raw feed, deslimed feed and deslimed non-magnetic fractions from Davis tube separations were tested using two reagent combinations. All charges were ground at 60 per cent. solids to give a product approximately 92 per cent. minus 325 mesh.

Desliming, where carried out, was done on ground material. Charges were then conditioned with reagents in the attrition conditioner for 20 minutes at 60 per cent. solids, and floated at 25 per cent. solids. Rougher flotation was carried to completion in each case, and the rougher concentrate cleaned twice.

Adelaide tap water was used in all tests.

6.4.1 Tests with Radium Hill Type Collector Emulsion:

Reagents used in this series are given in Table 17.

Table 17.

Reagents - Flotation Series 1.

Reagent	Addition, lb./ton.
Peltogen	0.75
Linseed Fatty Acid	1.0
Fuel Oil	3.0
Napthenic Acid ...	0.25
	5.0

Test 7 was carried out on raw feed and Test 8 on deslimed non-magnetics from Davis tube Test 5.

Results are given in Table 18.

Table 18.

Results of Flotation Tests 7 and 8.

Test and Feed	Product	Weight %.	Assay Fe %.	Distribution Fe %.
7 Raw Feed	Rougher tailings	23.5	25.8	18.7
	1st cleaner tailings.	19.3	28.0	16.7
	2nd cleaner tailings.	15.3	31.8	15.0
	Cleaner concentrate..	41.9	38.5	49.6
		100.0	33.1(calc.)	100.0
8 Deslimed Non-magnetics	Rougher tailings	14.8	13.1	5.9
	1st cleaner tailings.	11.4	17.1	5.9
	2nd cleaner tailings.	9.2	20.3	5.6
	Cleaner concentrate..	35.1	29.7	31.6
		70.5	23.0	49.0
	Magnetics	23.7	64.5	46.3
	Slime	5.8	26.7(calc.)	4.7
		100.0	33.1	100.0

6.4.2 Test with Tall Oil Collector Emulsion:

An emulsion which gave promising results on Middleback Range jaspilite was used in this series of tests.

The reagents used are given in Table 19.

Table 19.

Reagents - Flotation Series 2.

Reagent	Addition, lbs./ton.
Pamak 1	2.0
Fuel Oil	4.0
Napthenic Acid	0.2
P.100	0.1
	6.3

Test 9 was carried out on raw feed, Test 10 on deslimed feed, and Test 11 on deslimed non-magnetics from David tube Test 6.

Results are given in Table 20.

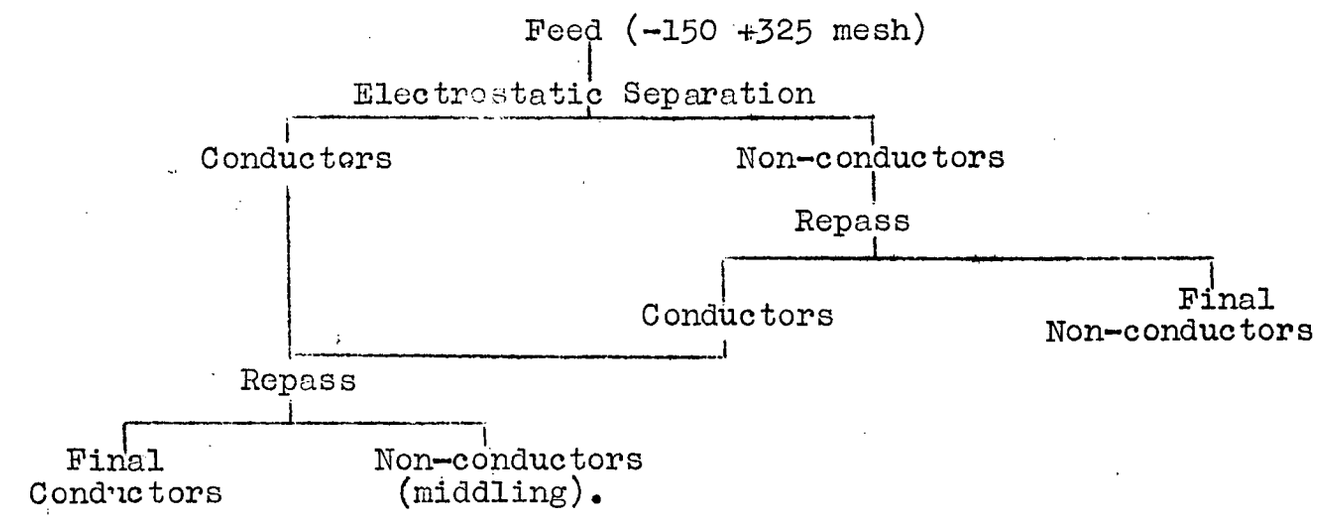
Table 20.

Results of Flotation Tests 3, 4, and 5.

Test and Feed.	Product.	Weight %.	Assay Fe %.	Distribution Fe %.
9 Raw Feed	Rougher tailings	30.3	20.0	18.3
	1st cleaner tailings ...	18.2	25.2	13.8
	2nd cleaner tailings ...	14.3	33.4	14.3
	Cleaner concentrate	37.2	47.9	53.6
		100.0	33.2(calc.)	100.0
10 Deslimed Feed.	Slime	12.2	10.0	3.7
	Rougher tailings	18.9	28.6	16.6
	1st cleaner tailings ...	17.8	31.5	17.3
	2nd cleaner tailings ...	18.3	35.1	19.8
	Cleaner concentrate	32.8	42.2	42.6
		100.0	32.6(calc.)	100.0
11 Deslimed Non-magnetics	Rougher tailings	22.7	14.5	10.0
	1st cleaner tailings ...	14.8	20.5	9.1
	2nd cleaner tailings ...	11.9	27.9	10.0
	Cleaner concentrate	18.4	32.8	18.3
		67.8	23.2	47.4
	Magnetics	25.2	63.6	48.4
	Slime	7.0	19.7(calc.)	4.2
		100.0	33.1	100.0

6.5 Electrostatic Separation Tests:

A sample of raw feed ground to approximately 80 per cent. minus 325 mesh was treated in the laboratory electrostatic separator. However, the fine nature of the sample made feeding difficult and erratic, and no separation could be made. The plus 325 fraction was screened off and treated separately in the following manner:-



A positive electrode potential of 20 KV was used for each stage, but the electrode position was varied to obtain best separation.

Results of this test are given in Table 21.

Table 21.

Product	Weight %.	Assay Fe %.	Distribution Fe %.
Conductors	43.3	53.4	56.1
Middling	29.0	34.8	24.6
Non-conductors	27.7	28.6	19.3
	100.0	41.1 (calc.)	100.0

The distribution of 56.1 per cent. in the concentrate represents about 16 per cent. recovery from the raw feed.

7. DISCUSSION OF RESULTS.

Assays made on sized fractions of the crushed ore showed a fairly even distribution of iron, with one notable exception, namely in the first infrasizer fraction, where the grade is high. This is probably due to the air elutriator effecting a gravity separation of similarly sized particles rather than a true size separation.

Petrological examination of the head sample shows that the iron occurs in two main forms, namely a relatively coarse magnetite and a fine hematite.

Magnetic separation of raw feed ground to approximately 70 per cent. minus 325 mesh gave a concentrate grade of 50.8 per cent. Fe with a recovery of 61.5 per cent. (Table 3). Treatment of raw feed ground to virtually all passing 325 mesh (48.5 per cent. minus 9 microns) produced concentrates ranging in grade from 63.6 to 65.5 per cent. Fe with recoveries from 47.8 to 48.4 per cent. of the total iron (Tables 6 and 11). Treatment of material ground to 57.5 per cent. minus 9 microns gave a concentrate grade of 64.3 per cent. Fe with a recovery of 36.7 per cent. The lower recovery is apparently due to mechanical losses of over-ground material (Table 10).

Mineralogical examination of magnetic products indicated that separation was efficient, there being less than 1 per cent. magnetite remaining in the non-magnetic fraction.

Material roasted in a reducing atmosphere was ground under conditions identical to those used for raw feed, no significant difference in grinding characteristics being noted.

Magnetic treatment of reduced ore ground to 35.7 per cent. minus 9 microns gave a concentrate grade of 49.5 per cent. with a recovery of 85 per cent. Treatment of a sample ground to 45.8 per cent. minus 9 microns gave a concentrate grade of 49.1 per cent. Fe with a recovery of 89.2 per cent. (Tables 13 and 16).

Flotation tests were disappointing, selectivity of the two reagent combinations tried being poor. Tall oil emulsion shows some promise.

An electrostatic separation test on a size fraction of ground ore gave poor concentrate grade and low recovery.

8. CONCLUSIONS.

Magnetic separation is effective on ground raw feed in that virtually all the magnetite can be recovered in a concentrate which would be acceptable blast furnace grade.

However, this represents only about half of the iron in the feed, the balance being present principally as hematite.

Magnetic separation of reduced material will recover approximately 90 per cent. of the iron, but the grade of concentrate produced is low. Higher grade concentrates may be obtained by grinding the reduced ore finer.

Although flotation tests were not encouraging, concentration by this method should be possible if the mineral can be liberated. Adjustment of the ratio of active component to carrier in the reagent emulsions may enhance selectivity.

Further work on electrostatic separation is not recommended because of the finely disseminated nature of the ore.

It is recommended that any further test work be carried out on a sample more representative of the ore-body, preferably diamond drill core material.
