CANADA

DEPARTMENT OF ENERGY, MINES AND RESOURCES

OTTAWA

MINES BRANCH INVESTIGATION REPORT

IR 70-65 September, 1970

A STUDY OF ALTERNATIVE FLOWSCHEMES FOR THE CONCENTRATION OF A LOW-GRADE TACONITE ORE

by

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SUMMARY OF RESULTS

Two alternative concentration flowschemes were compared on a continuous basis in the pilot plant. One involved "open-circuit roughing", the other "closed-circuit roughing". Of the two, the flowscheme involving "open-circuit roughing" appeared to have more advantages. A concentrate assaying 67.66% soluble iron and 5.42% silica was produced with a ratio of concentration of 4.35:1. The grind was 98% minus 500 mesh. The average grade of the ore in the pilot plant investigations was 26.7% soluble iron and 20.6% magnetic iron.

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INTRODUCTION

Purpose of Investigation

The purpose of this investigation was to study alternative methods for the production of a premium-grade iron concentrate, assaying over 67% iron, from a low-grade taconite ore.

Since very little mineral processing work had ever been done on the particular ore sample in question, it was necessary to conduct an extensive laboratory investigation to gather the metallurgical data fundamental in the design of any concentration flowscheme. This preliminary investigation included:

- a mineralogical examination of several samples of the ore,
- an investigation of the amenability of these samples to the production of a premium-grade concentrate, and
- a laboratory investigation of a composite sample of the ore.

From the laboratory investigation it was possible to derive two alternative concentration flowschemes which were tested on a continuous basis in the pilot plant.

Source of Ore Samples

The ore samples were taken from surface pits on the West Property of Armore Mines Limited in the Montgolfier and Orvilliers Townships of northwestern Quebec. In reviewing this property in 1969, the company reported a possible tonnage, projected to a depth of 500 feet, of 492 million tons of low-grade iron ore.

Ore Shipments

On October 28, 1969, Mr. H. E. Neal, consulting for Armore Mines Limited, submitted three samples of ore. The samples were designated A, B, and C, and each consisted of approximately 75 lb of broken rock, 4 to 6 inches in size. Mr. Neal had given consideration to dry autogenous grinding of the ore in an Aerofall mill combined with dry magnetic separation of the coarse product from the primary classifier in the mill circuit, and requested that some of the preliminary work be directed towards finding an optimum grind for coarse separation.

On March 12, 1970, samples of three products from an Aerofall mill circuit operating on a composite sample of the ore were received for further laboratory investigative work. These were a coarse concentrate, a cyclone product, and a fine filter product. The composite sample was made up of 3 parts of ore sample A, 1 part of ore sample B, and 2 parts of ore sample C.

On May 15, 1970, another shipment of these products was received from Aerofall Mills for pilot plant work. This shipment consisted of:

5850 lb of Coarse Concentrate
6850 lb of Cyclone Product
1800 lb of Filter Product

Sampling and Analysis

The ore samples A, B, and C were crushed to minus 10 mesh and split into 2000-g lots. One lot from each ore sample was selected and ground to minus 100 mesh in a batch mill, and riffled down to obtain two head samples. One head sample was submitted for analysis of total iron, soluble iron, phosphorous, and sulphur. The other was passed through a Davis Tube for the determination of magnetic iron. The magnetic iron content was calculated from the analysis of the soluble iron in the Davis Tube concentrate. Chemical analyses of the head samples were done by the Analytical Chemistry sub-division. Assays are given in Table 1.

TABLE 1

Chemical Analyses of Head Samples

Sample	Analyses, %				
	Total Fe	Sol Fe	Mag Fe	P	S
A	21.93	21.64	17.25	0.12	0.02
B	28.81	28.61	25.38	0.13	0.03
C	32.36	32.27	20.28	0.15	0.02

The analysis and distribution of the products from an Aerofall mill circuit operating on a composite sample of the ore are given in Table 2.

TABLE 2

Analysis and Distribution of Aerofall Mill Products

Product	Wt %	Soluble Fe, %		Magnetic Fe, %	
		Assay	Distn	Assay	Distn
Coarse Conc	35.32	32.3	46.0	27.3	50.1
Coarse Tail	7.42	8.2	2.5	0.65	0.3
Cyclone Product	46.80	24.0	45.3	}16.7	}49.6
Filter Product	10.46	14.8	6.2		
Total Feed*	100.00	24.8	100.0	19.3	100.0

* calculated

MINERALOGICAL EXAMINATION*

Microscopic examination of polished sections of ore samples A and B showed fine-grained magnetite in a matrix of quartz, chlorite, mica, and dolomite. Traces of feldspar, pyrite, and goethite were also found. The grain size of the magnetite was finer than 325 mesh. Microscopic examination of polished sections of ore sample C showed fine-grained magnetite and hematite in about equal proportions. The hematite occurred as elongated grains which generally ran parallel to the banded magnetite but were slightly coarser (-200 mesh) than the magnetite (-325 mesh). The gangue minerals were similar to those in ore samples A and B.

DISCUSSION OF RESULTS

Laboratory tests on ore samples A, B, and C involved a series of grinding and magnetic separation stages, each of which yielded a magnetic concentrate which was re-treated in a subsequent stage until a concentrate assaying 67% iron was produced. The final concentrates were all minus 500 mesh. This indicated that the magnetite was substantially liberated at that size. Laboratory test procedures on the Aerofall mill products included several stages of grinding followed by screening at 500 mesh to prevent overgrinding of the liberated magnetite. Subsequent tests, using a cyclone, indicated that a single stage of grinding in closed circuit would be adequate. This led to the development of a concentration flowscheme which involved the use of a single stage of grinding in closed circuit with a cyclone classifier effecting a separation at 500 mesh, followed by magnetic roughing.

This flowscheme was implemented in the first pilot plant test (Test 5), and it was found that cycloning resulted in the concentration of free gangue particles in the overflow, along with some fine magnetite. For this reason, the overflow assayed only 35.3% soluble iron, as opposed to the underflow which assayed 54.4% soluble iron. Magnetic roughing of this overflow resulted in a product assaying 62.8% soluble iron.

An alternative concentration flowscheme was investigated in the next pilot plant test (Test 6). The magnetic rougher was incorporated into the closed circuit after the grinding mill to improve the grade and reduce the amount of material fed to the cyclone. This, however, had an adverse effect on the composition of the cyclone overflow, as cycloning of the magnetic product resulted in a large proportion of fine middling particles reporting to the overflow. Considering that the minus 500-mesh fraction of the magnetic product consisted largely of free magnetite and to a smaller extent of fine middling particles, it is possible that in cycloning the fine magnetite behaved as a heavy medium forcing most of the fine middling

* Mineral Sciences Division Internal Report MS 70-5 by R. G. Pinard.

particles to be concentrated in the overflow. Thus, cycloning of the beneficiated material resulted in an overflow assaying no higher than 60.6% soluble iron.

The loss of magnetic iron incurred in "closed-circuit roughing" was 7.1%, although the efficiency of the magnetic separator operating on coarser material was slightly higher. This loss may be attributed to the field strength of the magnetic separator. In another test (Test 7), a higher field strength resulted in a loss of magnetic iron of only 0.8%, and yielded a rougher concentrate similar in composition to that of the previous test (Test 6). However, a less efficient separation of this concentrate at 500 mesh resulted in an overflow assaying 57.4% soluble iron. The lack of material made it undesirable to alter the operating conditions in cycloning once a circuit was in balance.

The overflow products from "closed-circuit roughing" proved more difficult to clean than the rougher product from "open-circuit roughing" because of the concentration of fine middling particles. For example, magnetic cleaning of an overflow product at 60.6% soluble iron to a grade of 63.7% soluble iron resulted in a loss of magnetic iron of 10.9%, while magnetic cleaning of the rougher product at 62.8% soluble iron to a grade of 63.7% soluble iron resulted in a loss of only 3.4%.

In each case, flotation was required to produce a concentrate that would assay above 67% iron, as hydraulic upgrading failed to produce concentrates assaying any higher than 65.1% soluble iron, although premium-grade concentrates were produced in the laboratory without the use of flotation. In one laboratory test (Test 4) magnetic cleaning of a cyclone overflow at 62.7% soluble iron was successful in the removal of most of the fine middling particles contaminating the overflow, and hydraulic upgrading yielded a concentrate assaying 67.3% soluble iron. Failure to achieve similar results in the pilot plant may be attributed to the build-up of middling particles in the circuit in the course of a continuous operation.

Flotation could have been applied directly to the rougher concentrate of Test 5, grading 62.8% soluble iron, to produce a premium-grade concentrate. In Test 7, flotation of a similar product at 62.6% soluble iron, resulted in the selective separation of fine middling particles, and yielded a concentrate assaying 66.5% soluble iron. The total loss of magnetic iron in the cleaning of the rougher concentrate by magnetic and hydraulic means amounted to 8.8%. This loss was due largely to the loss of free magnetite, and it is believed that flotation would have substantially reduced this loss. It is also possible that the overall recovery might have been improved by the elimination of cobbing of the cyclone underflow. However, lack of material prevented further testing.

CONCLUSIONS

The limited testwork done in the pilot plant did serve to point out the basic differences between the two approaches to the treatment of this ore. Of the two concentration flowschemes investigated, "closed-circuit roughing" and "open-circuit roughing", the latter appears to have more advantages. Cycloning of a ball mill discharge resulted in an overflow with fewer middlings, and consequently roughing resulted in a higher grade of rougher concentrate. Flotation could have been applied directly to this rougher concentrate.

With the concentration flowscheme shown in Figure 1, a concentrate assaying 67.66% soluble iron was produced with a recovery of 77.1% of the magnetic iron in the feed. The ratio of concentration was 4.35:1. The feed consisted of products from an Aerofall mill circuit which included dry magnetic cobbing. Taking into account the rejection of material in the Aerofall mill circuit, the recovery of iron from the run-of-mine ore will be slightly lower, and the ratio of concentration will be slightly higher.

To obtain a premium grade concentrate, it was necessary to grind the ore to 98% minus 500 mesh, and to float silica from the final magnetic concentrate.

DETAILS OF LABORATORY INVESTIGATION

Preliminary Davis Tube Tests

Davis Tube tests were done on ore samples A, B, and C at different grinds and the results are given in Table 3. The results show that the per cent weight rejected increased in direct proportion with the grind. The grades of the tailings from ore samples A and B were uniform, assaying between 5.72 and 6.72% soluble iron. Microscopic examination of these tailings showed fine inclusions of magnetite in gangue. Tailings from ore sample C were high in soluble iron due to the presence of hematite.

From a metallurgical point of view, the results did not indicate any optimum grind for coarse separation. This had to be determined independently by grinding tests in an Aerofall mill circuit.

Laboratory Beneficiation of Ore Samples A, B, and C

Laboratory beneficiation of ore samples A, B, and C resulted in concentrates assaying 67% soluble iron. The same four-stage test procedure was used in each case.

In stage one, a 2000-g sample of ore was ground to minus 100 mesh and fed to a single-drum Sala magnetic separator. The Sala had a permanent magnet with a field strength of 500 gauss. In stage two, the magnetic concentrate from stage one was reground to minus 200 mesh and passed through the Sala again. In stage three, the magnetic concentrate from stage two was reground to minus 325 mesh and passed through a three-drum Jeffrey magnetic separator. The first and second drums of the Jeffrey had a field strength of 550 gauss, and the third drum had a field strength of 450 gauss. The non-magnetic products from the first and second drums were discarded as tailing. The non-magnetic and magnetic products from the third drum were combined to form a single concentrate. In stage four, this concentrate was reground to minus 500 mesh and passed through the Jeffrey under the same operating conditions. The non-magnetic products from the first and second drums were again discarded as tailing. However, the non-magnetic and magnetic products from the third drum were kept separate. The results are given in Table 4.

TABLE 3

Metallurgical Results of Davis Tube Tests at Different Grinds

Grind, Mesh	Product	Sample A			Sample B			Sample C		
		Wt %	Sol Fe %	Distn %	Wt %	Sol Fe %	Distn %	Wt %	Sol Fe %	Distn %
-20	Conc	75.2	25.96	92.5						
	Tail	24.8	6.36	7.5						
	Feed *	100.0	21.10	100.0						
-48	Conc	62.0	30.33	88.8						
	Tail	38.0	6.21	11.2						
	Feed *	100.0	21.16	100.0						
-65	Conc	55.2	32.43	86.9						
	Tail	44.8	6.01	13.1						
	Feed *	100.0	20.59	100.0						
-100	Conc	50.4	35.74	84.4						
	Tail	49.6	6.72	15.6						
	Feed *	100.0	21.34	100.0						
-150	Conc	41.8	42.56	82.2	51.6	48.84	88.9	49.6	44.9	72.1
	Tail	58.2	6.62	17.8	48.4	6.50	11.1	50.4	17.1	27.9
	Feed *	100.0	21.64	100.0	100.0	28.35	100.0	100.0	30.9	100.0
-200	Conc	33.6	52.02	81.5	44.8	56.56	87.8	39.6	53.9	65.3
	Tail	66.4	5.96	18.5	55.2	6.38	12.2	60.4	18.8	34.7
	Feed *	100.0	21.44	100.0	100.0	28.85	100.0	100.0	32.7	100.0
-270	Conc	30.0	57.50	81.2	41.2	61.60	88.2	35.2	57.6	64.0
	Tail	70.0	5.72	18.8	58.8	5.76	11.8	64.8	17.6	36.0
	Feed *	100.0	21.25	100.0	100.0	28.77	100.0	100.0	31.7	100.0

* Calculated

TABLE 4

Metallurgical Results of Laboratory Beneficiation of Ore Samples A, B, and C

Grind, Mesh	Product	Sample A			Sample B			Sample C		
		Wt %	Sol Fe %	Distn %	Wt %	Sol Fe %	Distn %	Wt %	Sol Fe %	Distn %
-100	1st Mag Tail	53.4	6.33	15.9	36.7	6.21	7.9	45.2	17.74	25.7
	1st Mag Conc*	46.6	38.5	84.1	63.3	41.9	92.1	54.8	42.4	74.3
-200	2nd Mag Tail	16.0	6.96	5.2	19.5	5.29	3.6	15.8	17.33	8.7
	2nd Mag Conc*	30.6	54.9	78.9	43.8	58.2	88.5	39.0	52.6	65.6
-325	3rd Mag Tail	4.6	17.56	3.8	5.3	18.21	3.4	9.2	24.46	7.2
	3rd Mag Conc*	26.0	61.5	75.1	38.5	63.7	85.1	29.8	61.2	58.4
-500	4th Mag Tail	2.8	23.7	3.1	2.9	24.1	2.4	4.9	33.75	5.3
	4th Mag Midd	1.6	54.6	4.1	1.3	59.4	2.7	2.3	63.35	4.7
	4th Mag Conc	21.6	67.0	67.9	34.3	67.2	80.0	22.6	67.00	48.4
	Total Feed*	100.0	21.3	100.0	100.0	28.8	100.0	100.0	31.3	100.0

* calculated

Recoveries of soluble iron in the final concentrates were 67.9% for ore sample A, 80.0% for ore sample B, and 48.4% for ore sample C. Recoveries of magnetic iron in the final concentrates, calculated on the basis of magnetic iron assays given in Table 1, were 85% for ore sample A, 90.8% for ore sample B, and 74.7% for ore sample C. Each of the ore samples was amenable to the production of premium grade concentrate at a grind of minus 500 mesh.

Laboratory Beneficiation of Aerofall Mill Products

Laboratory tests were conducted on the coarse and fine products separately.

Coarse Concentrate

Test 1

A 2000-g sample of coarse concentrate was ground to minus 100 mesh and screened on a 500-mesh sieve. The minus 500-mesh fraction was passed through a Sala magnetic separator. The concentrate was collected and passed through the Sala again, then upgraded to 67.9% soluble iron in a Wade hydroseparator. The plus 500-mesh fraction was cobbed to remove flake-like material that resisted fine grinding, and reground. The reground cobber concentrate was cleaned twice on the Sala and upgraded to 69% soluble iron in the Wade hydroseparator. The results are given in Table 5. They indicate that a premium grade concentrate may be produced using a single stage of grinding in closed circuit with a classifier making a separation at 500 mesh. The overall recovery of soluble iron from the cobber concentrate was 74.9%. The overall recovery of magnetic iron, calculated on the basis of the magnetic iron assay given in Table 2, was 88.6%.

TABLE 5

Metallurgical Results of Test 1

Product	Wt %	Sol Fe %	Distn %
-500 mesh fraction*	83.1	34.14	87.8
Magnetic Rougher Conc*	36.6	66.31	75.1
Magnetic Rougher Tail	46.5	8.82	12.7
Hydroseparator Overflow	2.5	44.44	3.4
Hydroseparator Underflow	34.1	67.91	71.7
+500 mesh fraction*	16.9	23.32	12.2
Cobber Conc*	7.9	30.63	7.5
Cobber Tail	9.0	16.91	4.7
Magnetic Cleaner Conc*	2.5	66.80	5.2
Magnetic Cleaner Tail	5.4	13.93	2.3
Hydroseparator Overflow	1.0	63.60	2.0
Hydroseparator Underflow	1.5	68.99	3.2
Coarse Conc - Feed*	100.0	32.31	100.0

*calculated

Test 2

A 2000-g sample of coarse concentrate was ground to minus 100 mesh and passed through a Sala magnetic separator. The concentrate was collected and passed through the Sala again. The non-magnetic products from each pass were combined and discarded as tailing. The final magnetic product was collected and screened. Screen analysis of the product showed that the minus 500-mesh fraction assayed 64.4% soluble iron, while the plus 500-mesh fraction assayed 29.8% soluble iron. The minus 500-mesh fraction was upgraded to 67.2% soluble iron in a Wade hydroseparator. The plus 500-mesh fraction was reground and cleaned twice on the Sala. The results are given in Table 6. They indicate that a satisfactory final concentrate may be produced using a single stage of grinding and magnetic separation in closed circuit with a classifier making a separation at 500 mesh. The overall recovery of soluble iron from the coarse concentrate was 78.7%. The overall recovery of magnetic iron from the coarse concentrate, calculated on the basis of the magnetic iron assay given in Table 2, was 92.9%.

TABLE 6

Metallurgical Results of Test 2

Product	Wt %	Sol Fe %	Distn %
Magnetic Rougher Conc*	46.7	58.48	84.7
Magnetic Rougher Tail	53.3	9.29	15.3
-500 mesh fraction*	38.7	64.39	77.3
Hydroseparator Overflow	3.3	34.82	3.6
Hydroseparator Underflow	35.4	67.16	73.7
+500 mesh fraction*	8.0	29.85	7.4
Magnetic Cleaner Tail	5.6	14.11	2.4
Magnetic Cleaner Conc	2.4	66.67	5.0
Coarse Conc - Feed*	100.0	32.26	100.0

*calculated

Fine Products

Test 3

A 2000-g sample of the fine products was made up by combining material from the cyclone and filter products in a ratio of 4.5:1. The ratio was derived from the distribution of the products given in Table 2. The sample was cleaned twice on a Sala magnetic separator. This resulted in the rejection of 64% of the weight, with a loss in the recovery of magnetic iron of only 1.9%.

A screen analysis was done on the fines magnetic concentrate and the results are given in Table 7. Attempts were made to upgrade the minus 500-mesh fraction using a Wade hydroseparator, but grades higher than 65% soluble iron could not be achieved. Therefore, the fines magnetic concentrate was reground to minus 100 mesh and cleaned twice on the Sala. The non-magnetic products from each cleaning were combined and discarded as tailing.

The cleaner magnetic product was collected and screened. Screen analysis of this product showed that the minus 500-mesh fraction assayed 66.7% soluble iron, while the plus 500-mesh fraction assayed 34.6% soluble iron. The minus 500-mesh fraction was upgraded to 67.8% soluble iron in a Wade hydroseparator. The results are given in Table 8. The recovery of soluble iron from the fine products was 61.9%, and the recovery of magnetic iron, calculated on the basis of the magnetic iron assay given in Table 2, was 83.7%.

TABLE 7

Screen Analysis of the Fines Concentrate

Mesh, Tyler	Wt %	Sol Fe %	Distn %
+100	12.6	21.61	6.0
-100+270	19.6	23.43	10.1
-270+325	4.4	28.38	2.7
-325+400	2.5	35.63	2.0
-400+500	11.5	40.37	10.2
-500	49.4	63.70	69.0
Cobber Conc*	100.0	45.56	100.0

*calculated

TABLE 8

Metallurgical Results of Test 3

Product	Wt %	Soluble Fe, %		Magnetic Fe, %	
		Assay	Distn	Assay	Distn
Fines Magnetic Conc*	35.8	46.4	73.6		
Fines Magnetic Tail	64.2	9.29	26.4	0.5	1.9
Magnetic Cleaner Conc*	24.9	62.4	68.8		
Magnetic Cleaner Tail	10.9	9.95	4.8	-	-
+500 mesh	3.3	34.55	5.0	-	-
-500 mesh*	21.6	66.7	63.8		
Hydroseparator Overflow	1.0	42.60	1.9	-	-
Hydroseparator Underflow	20.6	67.83	61.9	67.83	83.7
Fine Products - Feed*	100.0	22.6	100.0	16.7**	100.0

* calculated
** from Table 2

Derivation of Flowschemes

Two flowschemes were derived from laboratory testing for beneficiating this ore. One would involve "open-circuit roughing" and the other "closed-circuit roughing". The terms "open-circuit roughing" and "closed-circuit roughing" are best defined by inspection of the flowschemes illustrated in Fig. 1 and Fig. 2. Each flowscheme includes only one stage of fine grinding.

By combining the results of tests on the coarse and fine products it is possible to estimate the overall recoveries for each method of treatment. Table 9 gives the results of such calculations. The weight distributions of the feed products were calculated from the weight distributions of the products given in Table 2 , after the coarse tailing had been discarded. The weight distributions of the concentrates were obtained by multiplying the weight per cent of concentrate obtained from each product by the relative weight distribution of each product in the total feed. The overall recovery of magnetic iron in "open-circuit roughing" was 86.7%, and in "closed-circuit roughing" was 88.4%.

Test 4

From a practical point of view, it is necessary to employ cyclones to make a size separation at 500 mesh. Tests were made in the laboratory using a Dorr P-50 cyclone to classify a rougher concentrate similar to that produced in Test 2.

Approximately one-quarter of the rougher concentrate reported to the cyclone overflow. This cyclone overflow was 95% minus 500 mesh, and assayed 62.7% soluble iron. One pass through the Sala magnetic separator resulted in the removal of most of the fine middling particles contaminating the overflow, and hydraulic upgrading in the Wade hydroseparator resulted in a concentrate assaying 67.3% soluble iron.

The cyclone underflow assayed 57.2% soluble iron. It was reground and upgraded to 66.6% soluble iron, using one stage of magnetic cleaning and one stage of hydraulic upgrading. The results are given in Table 10. Overall recovery of soluble iron from the coarse concentrate was 79.7%. Overall recovery of magnetic iron from the coarse concentrate, calculated on the basis of the magnetic iron assay given in Table 2, was 94.2%.

TABLE 9

Calculated Results of Tests on Aerofall Mill Products

Products	Closed-Circuit Magnetic Roughing					Open-Circuit Magnetic Roughing				
	Wt %	Soluble Fe,%		Magnetic Fe,%		Wt %	Soluble Fe,%		Magnetic Fe,%	
		Assay	Distn	Assay	Distn		Assay	Distn	Assay	Distn
Coarse Concentrate Product	38.2	32.3	47.2	27.3	50.3	38.2	32.3	47.2	27.3	50.3
Cyclone and Filter Products	61.8	22.3	52.8	16.7	49.7	61.8	22.3	52.8	16.7	49.7
Total Feed*	100.0	26.1	100.0	20.7	100.0	100.0	26.1	100.0	20.7	100.0
Conc from Coarse Product (-500 m)	13.5	67.16	34.8	67.16	43.7	13.1	67.91	34.1	67.91	42.9
" " " " (+500 m)	0.9	66.67	2.3	66.67	2.9	0.6	68.99	1.6	68.99	2.0
Conc from Cyclone and Filter Products	12.8	67.83	33.2	67.83	41.8	12.8	67.83	33.2	67.83	41.8
Total Conc*	27.2	67.46	70.3	67.46	88.4	26.5	67.89	68.9	67.89	86.7

* calculated

TABLE 10

Metallurgical Results of Test 4

Product	Wt %	Sol Fe %	Distn %
Magnetic Rougher Conc*	46.5	58.7	84.5
Magnetic Rougher Tail	53.5	9.3	15.5
Cyclone Overflow*	11.7	62.7	22.7
Magnetic Cleaner Tail	0.9	17.4	0.5
Hydroseparator Overflow	0.3	33.3	0.3
Hydroseparator Underflow	10.5	67.3	21.9
Cyclone Underflow*	34.8	57.2	61.8
Magnetic Cleaner Tail	4.6	15.2	2.2
Hydroseparator Overflow	2.2	26.1	1.8
Hydroseparator Underflow	28.0	66.6	57.8
Coarse Conc - Feed*	100.0	32.23	100.0

* calculated

DETAILS OF PILOT PLANT INVESTIGATION

Tests 5, 6, and 7 were done in the pilot plant on products from a composite sample of ore ground by an Aerofall mill. Figures 1, 2, and 3 illustrate the flowschemes used in each test. There were four basic operations in each flowscheme. These were preconcentration, blending, roughing, and cleaning.

Preconcentration

This operation was applied to the fine products from the Aerofall mill. The cyclone and filter products were combined and passed through a 3-drum Dings wet magnetic separator. The feed rate was 1000 lb/hr at a pulp density of 25% solids. The current to each drum was 9 amp, and the field strength was 620 gauss. The fines magnetic concentrate was collected and filtered to facilitate blending with the coarse concentrate.

Blending

Blending was done in a 12-in. x 6-ft Akins screw classifier. The coarse concentrate from the Aerofall mill and the preconcentrated fines magnetic concentrate were blended in a ratio of 1.7:1, and then fed to the ball mill. The ratio between coarse concentrate and fines magnetic concentrate was derived from the weight distributions of the products given in Tables 2 and 8. Fine grinding was done in a 4-ft x 4-ft Dominion ball mill charged with 3/4-in. steel balls.

Roughing

A 3-drum Stearns magnetic separator was used for roughing in all three tests. In Test 5, cycloning of the ball-mill discharge produced an overflow that was 97.8% minus 500 mesh. Roughing was done on this cyclone overflow. The current to each drum of the magnetic rougher was 6 amp. The cyclone underflow was cobbed and deslimed before being returned to the ball mill. The field strength of the magnetic cobber was 450 gauss. A detailed account of the performance of the magnetic roughers under the various operating conditions is given later in Table 16.

In Test 6, roughing was done in closed circuit on the ball mill discharge. The current to each drum of the magnetic rougher was maintained at 6 amp. Cycloning was done on the rougher concentrate, and produced an overflow that was 99% minus 500 mesh.

In Test 7, roughing was also done in closed circuit on the ball mill discharge, but the current to each drum was maintained at 9 amp. Cycloning was followed by desliming of the cyclone overflow.

Cleaning

Cleaning involved three unit processes: magnetic separation, hydraulic upgrading, and flotation. The main contaminants in the feed to cleaning were fine middling particles of quartz-magnetite, or gangue with magnetite inclusions.

Magnetic cleaning was done using a 3-drum Dings magnetic separator. In Tests 5 and 6, the current to each drum was 5.5 amp, and the field strength was 250 gauss. In Test 7, the current to each drum was 6.5 amp, and the field strength was 350 gauss.

Magnetic cleaning was followed by hydraulic upgrading in a 2-ft-diameter hydroseparator. Hydraulic upgrading of the fine magnetic cleaner concentrate proved to be difficult as overflows contained free magnetite as well as fine middling particles.

Flotation was added to the flowschemes when it became apparent that a satisfactory final product was not being produced by magnetic and hydraulic means alone. In Test 5 flotation was done using a three-stage procedure: roughing, scavenging of the rougher froth, and re-scavenging of the scavenger froth. The quantities of reagents added were 0.08 lb of MG-83 per ton of feed to flotation, and 0.13 lb of MIBC. The flotation time was estimated to be 6 minutes. In Test 6, flotation also involved a three-stage procedure. In Test 7, flotation was done using a two-stage procedure: roughing, and scavenging of the rougher froth. Analysis of the flotation tailings indicated that flotation was successful in selectively removing the fine middling particles contaminating the feed. Table 11 gives the chemical analyses of the flotation concentrates.

TABLE 11

Chemical Analyses of Flotation Concentrates

Sample	Sol Fe	Metallic Fe	SiO_2	P	S
Flotn Conc Test 1	67.66	0.16	5.42	0.04	0.01
Flotn Conc Test 2	67.66	0.08	5.34	0.04	0.01
Flotn Conc Test 3	66.50	0.18	7.11	0.03	0.01

Sampling and Analysis

Grab samples of the products from each unit process were taken after a circuit was in balance. Weight distributions of the products were calculated on the basis of soluble iron assays. Time samples were taken to check the calculated weight distributions. Iron assays of the pilot plant products were done by C. Ivanoff, of the pilot plant crew, using the "Lerch" method for iron determinations by the stannous chloride-potassium dichromate procedure.

Results

The metallurgical results of the pilot plant tests are given in Tables 12, 13, and 14. A screen analysis of the various products is given in Table 15. Data on the operation and performance of the magnetic roughers and cleaners are given in Table 16. This table outlines each magnetic operation in terms of the machine used, the feed to the machine, and the resulting metallurgy, and allows for a comparison between tests.

ACKNOWLEDGEMENTS

The author wishes to record his appreciation to J. Banks, technician, for his assistance in the laboratory testwork; and to A. Boisonnault, supervisor of the pilot plant, for his assistance and co-operation in the pilot plant testwork.

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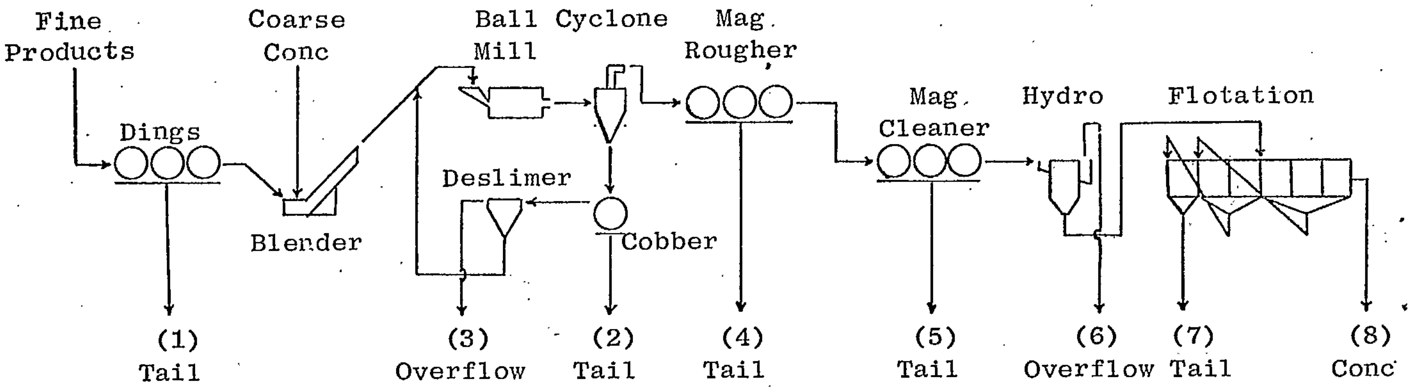

Figure 1. Flowscheme: open-circuit roughing.

TABLE 12

Metallurgical Results of Pilot Plant Test 5

Product	Item	Wt %	Soluble Fe, %		Magnetic Fe, %	
			Assay	Distn	Assay	Distn
Preconcentration						
Fine Products		57.76	22.29	48.4		
Fines Magnetic Tail	(1)	33.64	10.45	13.2	2.91	4.9
Fines Magnetic Conc		24.12	38.80	35.2		
Blending						
Fines Magnetic Conc		24.12	38.80	35.2		
Coarse Conc*		42.24	32.50	51.6		
New Ball Mill Feed		66.36	34.79	86.8		
Roughing						
New Ball Mill Feed		66.36	34.79	86.8		
Circulating Load		67.49	57.54	146.0		
Ball Mill Discharge		133.85	46.26	232.8		
Cyclone Underflow		75.25	54.39	153.9		
Cobber Tail	(2)	5.88	31.84	7.0	18.57	5.4
Cobber Conc		69.37	56.30	146.9		
Deslimer Overflow	(3)	1.88	12.10	0.9	0.30	-
Deslimer Underflow		67.49	57.54	146.0		
Cyclone Overflow		58.60	35.25	78.9		
Magnetic Rougher Tail	(4)	30.08	10.28	11.6	2.51	3.7
Magnetic Rougher Conc		28.52	62.76	67.3		
Cleaning						
Magnetic Cleaner Feed		28.52	62.76	67.3		
Magnetic Cleaner Tail	(5)	1.72	48.75	3.2	39.77	3.4
Magnetic Cleaner Conc		26.80	63.66	64.1		
Hydroseparator Overflow	(6)	2.33	49.36	4.3	46.78	5.4
Hydroseparator Underflow		24.47	65.00	59.8		
Flotation Tail	(7)	1.49	23.71	1.3	2.30	0.1
Flotation Conc	(8)	22.98	67.66	58.5	67.66	77.1
Total Feed [Items (1) to (8)]		100.00	26.60	100.0	20.18	100.0

*Preconcentrated at Aerofall Mills

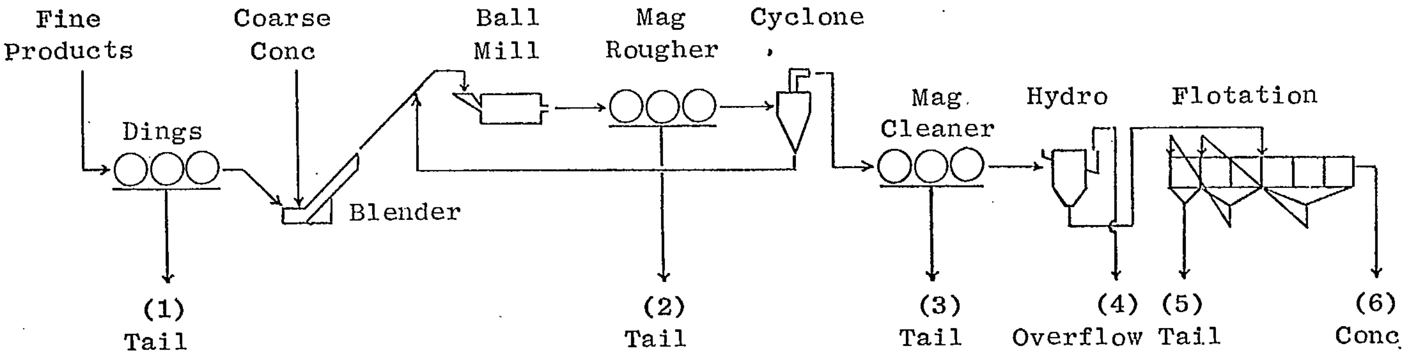

Figure 2. Flowscheme: closed-circuit roughing.

TABLE 13

Metallurgical Results of Pilot Plant Test 6

Product	Item	Wt %	Soluble Fe, %		Magnetic Fe, %	
			Assay	Distn	Assay	Distn
Preconcentration						
Fine Products		57.42	22.29	48.0		
Fines Magnetic Tail	(1)	33.44	10.45	13.1	2.91	4.7
Fines Magnetic Conc		23.98	38.80	34.9		
Blending						
Fines Magnetic Conc		23.98	38.80	34.9		
Coarse Conc*		42.58	32.50	52.0		
New Ball Mill Feed		66.56	34.77	86.9		
Roughing						
New Ball Mill Feed		66.56	34.77	86.9		
Circulating Load		63.34	57.04	135.6		
Ball Mill Discharge		129.90	45.63	222.5		
Magnetic Rougher Tail	(2)	34.89	11.41	14.9	4.20	7.1
Magnetic Rougher Conc		95.01	58.20	207.6		
Cyclone Overflow		31.67	60.52	72.0		
Cleaning						
Magnetic Cleaner Feed		31.67	60.52	72.0		
Magnetic Cleaner Tail	(3)	6.03	47.09	10.7	37.13	10.9
Magnetic Cleaner Conc		25.64	63.68	61.3		
Hydroseparator Overflow	(4)	2.34	49.57	4.4	46.58	5.3
Hydroseparator Underflow		23.30	65.08	56.9		
Flotation Tail	(5)	1.45	26.20	1.4	3.02	0.2
Flotation Conc	(6)	21.85	67.66	55.5	67.66	71.8
Total Feed [Items (1) to (6)]		100.0	26.64	100.0	20.59	100.0

*Preconcentrated at Aerofall Mills

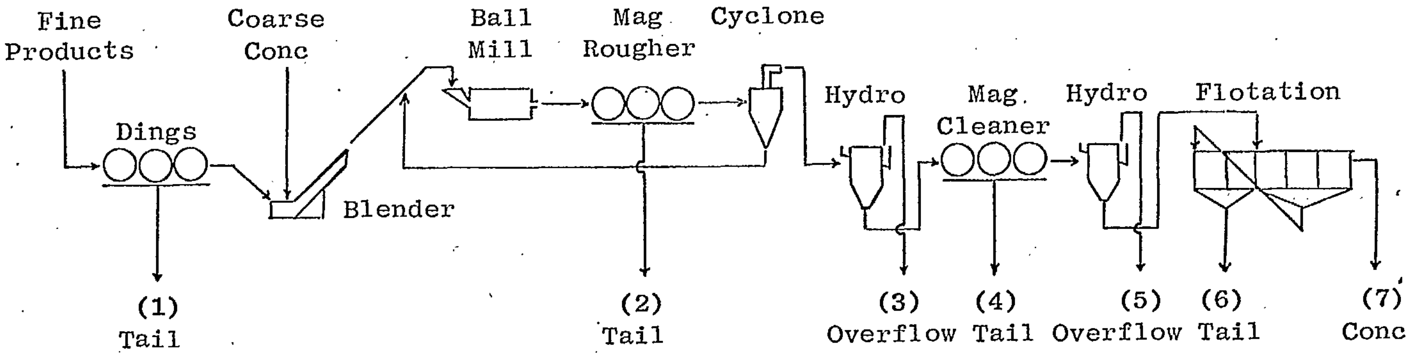

Figure 3. Flowscheme: closed-circuit roughing followed by desliming.

TABLE 14

Metallurgical Results of Pilot Plant Test 7

Product	Item	Wt %	Soluble Fe, %		Magnetic Fe, %	
			Assay	Distn	Assay	Distn
Preconcentration						
Fine Products		55.65	22.29	46.1		
Fines Magnetic Tail	(1)	32.41	10.45	12.6	2.91	4.5
Fines Magnetic Conc		23.24	38.80	33.5		
Blending						
Fines Magnetic Conc		23.24	38.80	33.5		
Coarse Conc*		44.35	32.67	53.9		
New Ball Mill Feed		67.59	34.78	87.4		
Roughing						
New Ball Mill Feed		67.59	34.78	87.4		
Circulating Load		76.31	57.37	162.8		
Ball Mill Discharge		143.90	46.76	250.2		
Magnetic Rougher Tail	(2)	31.74	9.28	10.9	0.53	0.8
Magnetic Rougher Conc		112.16	57.37	239.3		
Cyclone Overflow		35.85	57.37	76.5		
Deslimer Overflow	(3)	1.12	16.13	0.7	4.52	0.2
Deslimer Underflow		34.73	58.70	75.8		
Cleaning						
Magnetic Cleaner Feed		34.73	58.70	75.8		
Magnetic Cleaner Tail	(4)	3.70	35.00	4.8	25.06	4.4
Magnetic Cleaner Conc		31.03	61.53	71.0		
Hydroseparator Overflow	(5)	2.68	50.08	5.0	46.56	6.0
Hydroseparator Underflow		28.35	62.61	66.0		
Flotation Tail	(6)	3.28	32.83	4.0	29.27	4.6
Flotation Conc	(7)	25.07	66.50	62.0	66.50	79.5
Total Feed [Items (1) to (7)]		100.00	26.89	100.0	20.97	100.0

*Preconcentrated at Aerofall Mills

TABLE 15

Screen Analysis of Products from Pilot Plant

Products from Pilot Plant Test 5

Size Fraction	Ball Mill Discharge		Mag Ro Concentrate		Cyclone Underflow		Cyclone Overflow	
Mesh, Tyler	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe
- 65+100	3.8	39.67			3.8	54.28		
-100+150	2.2	40.01			2.4	43.99		
-150+200	1.5	33.86			2.1	36.11		
-200+270	0.5	34.20			0.8	36.85		
-270+325	3.5	32.20			7.5	36.85		
-325+400	1.5	34.54			3.0	37.93		
-400+500	8.3	35.46	2.3	53.12	20.0	40.83	2.2	8.13
-500	78.7	48.64	97.7	63.74	60.4	62.41	97.8	36.69
Total*	100.0	45.94	100.0	63.49	100.0	53.94	100.0	36.06

Products from Pilot Plant Test 6

Fraction	Ball Mill Discharge		Mag Ro Concentrate		Cyclone Underflow		Cyclone Overflow	
Mesh, Tyler	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe
- 65+100			1.1	50.91	1.7	49.21		
-100+150	0.8	32.04	1.6	40.63	2.4	41.00		
-150+200	1.2	31.21	1.8	36.67	2.7	36.85		
-200+270	0.3	32.54	0.7	41.43	1.0	44.32		
-270+325	1.0	31.79	6.1	40.16	9.2	39.84		
-325+400	2.1	31.71	1.9	37.36	2.8	37.84		
-400+500	10.0	33.16	10.4	40.67	15.2	40.50	0.9	38.34
-500	84.6	48.09	76.4	63.44	65.0	65.47	99.1	60.83
Total*	100.0	45.72	100.0	58.02	100.0	56.70	100.0	60.63

Products from Pilot Plant Test 7

Size Fraction	Ball Mill Discharge		Mag Ro Concentrate		Cyclone Underflow		Cyclone Overflow	
Mesh, Tyler	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe	Wt %	Sol Fe
- 48+ 65	0.2	50.32						
- 65+100	2.2	50.32	2.3	55.22	3.4	54.96		
-100+150	2.1	42.51	1.8	45.00	2.6	45.67		
-150+200	3.7	33.55	2.6	37.31	3.7	38.69		
-200+270	7.9	36.70	3.8	37.63	5.4	38.86		
-270+325	7.1	39.53	7.2	36.53	10.3	37.53		
-325+400	0.7	44.01	0.5	43.00	0.6	45.67		
-400+500	5.0	44.01	8.5	43.00	10.4	45.67	5.8	24.57
-500	71.1	49.48	73.3	63.52	63.6	66.23	94.2	59.45
Total*	100.0	46.74	100.0	57.54	100.0	57.60	100.0	57.43

* calculated

TABLE 16

Magnetic Separation Data

		Test 5	Test 6	Test 7
Operation		roughing	roughing	roughing
Machine	designation	Stearns	Stearns	Stearns
	stages	3	3	3
	flow	counter-current	counter-current	counter-current
	current	6 amp	6 amp	9 amp
	field strength	450 gauss	450 gauss	570 gauss
Feed	source	cyclone overflow	ball mill discharge	ball mill discharge
	size distn +100 m	-	-	2.4%
	-325 m	100%	96.7%	76.8%
	% solids	15%	23 %	23 %
	rate	430 lb/hr	960 lb/hr	1360 lb/hr
Metallurgy	% Mag Fe - Feed	30.9	42.3	43.3
	Tail	2.5	4.2	0.5
	Conc	60.8	56.3	55.4
	Efficiency %	95.8	97.3	99.7

		Test 5	Test 6	Test 7
Operation		cleaning	cleaning	cleaning
Machine	designation	Dings	Dings	Dings
	stages	3	3	3
	flow	concurrent	concurrent	concurrent
	current	5.5 amp	5.5 amp	6.5 amp
	field strength	250 gauss	250 gauss	350 gauss
Feed	source	rougher concentrate	cyclone overflow	deslimer underflow
	size distn +325 m	-	-	1.0%
	-500 m	97.7%	99.1%	94.2%
	% solids	26 %	22 %	22 %
	rate	210 lb/hr	250 lb/hr	250 lb/hr
Metallurgy	% Mag Fe - Feed	60.8	57.3	57.0
	Tail	39.8	37.1	25.1
	Conc	62.2	62.5	60.8
	Efficiency %	96.1	87.7	95.3