Pilot-scale testing for the preparation of Pellet Feed of the Santa Fé Taconite Ore using a low intensity magnetic drum separator

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1. Introduction and contextualization

In previous work a drill core sample of the Santa Fé Taconite ore was used for physical characterization and a crushing/grinding plant was designed to produce 100% < 150 micron feed to the low intensity magnetic concentration plant. Laboratory tests were carried out to produce a concentrate with 92.9% iron oxides (Magnetite, Hematite and Goethite) recovering 97% of the Magnetite and 81% of the Hematite in one pass in the magnetic drum separator running with 350 Gauss. The yield for this separation was about 30%.

The pellet feed preparation is the next step in the plant design, including scaling up a mill to reduce the coarse magnetite concentrate to a Blaine surface area of 2000 cm^2/g with at least 80% < 45 microns. The milled product is to be fed to a finishing low intensity magnetic drum separation circuit to obtain a pellet feed concentrate with about 1% silica.

2. Methodology

A new drill core sample with about 50 kg was provided for the study. The sample was initially crushed to 100% < 9.5 mm. Note that this is a larger size than the previous crushing design of 6.5 mm. The objective is to relax the demand for four stage crushers, and possibly to eliminate the fourth crushing stage. However, the coarser feed to the ball mill requires a larger make up ball size, so this was increased from 50 mm to 75 mm.

Previous work has shown that the magnetite and the associated hematite are mostly liberated at a P80 of 150 microns. Therefore, the crushed ore is to be ground to a P80 of 150 microns. Also, data is generated to scale up the equivalent primary grinding stage of the industrial plant. This is done by measuring power draw and running the mill at different grinding times with the measurement of product size distributions at each grinding time.

The product of the primary ball milling (two 25 kg batches of crushed ore milled to P80 = 150 µm) is to be concentrated in a low intensity wet magnetic drum separator.

The pilot plant has a WDL8 which is a Wet Drum separator built by Inbras-Eriez for pilot scale tests of low intensity wet magnetic separation. A schematic representation of the WD-L8 working as a concurrent magnetic separator is shown in Figure 1.

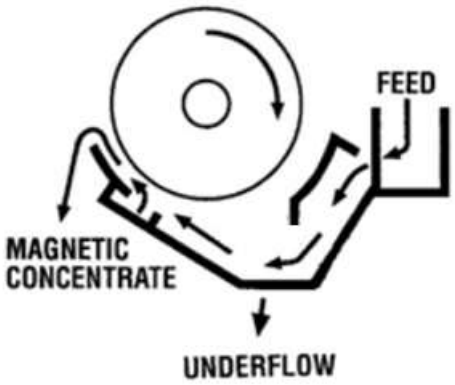

Figure 1: Schematic representation of a concurrent magnetic separation in the WD-L8

The separation in Figure 1 is said to be concurrent because the high-magnetic susceptibility particles are grabbed by the magnetic section of the rotating drum and transported towards the concentrate in the same direction as the pulp from the feed to the underflow and overflow streams.

The bottom part of the drum has an induced magnetic field that can be adjusted from zero to 1350 Gauss. Higher magnetic intensities allow for recovery of larger/heavier particles as well as particles with lower magnetic susceptibilities. Lower intensities are used for smaller/lighter particles or particles with lower magnetic susceptibilities.

In this case, for which the primary objective is the recovery of magnetite from milled ore particles, lower magnetic field strengths should be effective in recovering practically all of the magnetite.

The conditions of the tests include feed size distribution, feed % solids, magnetic field intensity and operation mode (counter-current / concurrent). Other variables such as feed rate and drum rotation speed are selected during the tests as these values can be easily changed.

The feed % solids is set at 34% by weight, as this is the design solids content in the classifier overflow of the industrial ball mill grinding in closed circuit with a hydrocyclone.

The material is continuously fed to the separator using a vibrating feeder and the addition of water is controlled through the valve in the flowmeter. As the material fills the volume of the separator a solids bed is formed under the drum. As this area is filled, the pulp is allowed to flow to the tailings, non-magnetics stream valve, located at the bottom of the separation chamber. The magnetic particles are collected on the surface of the drum and are washed to the concentrate (magnetics) stream using additional wash water, as they reach the region of the drum that is not magnetized. Most of the drum is not magnetized and in fact only the bottom part of the drum, which is inserted in the bed of particles in the separation chamber, is magnetized, as illustrated in Figure 2.

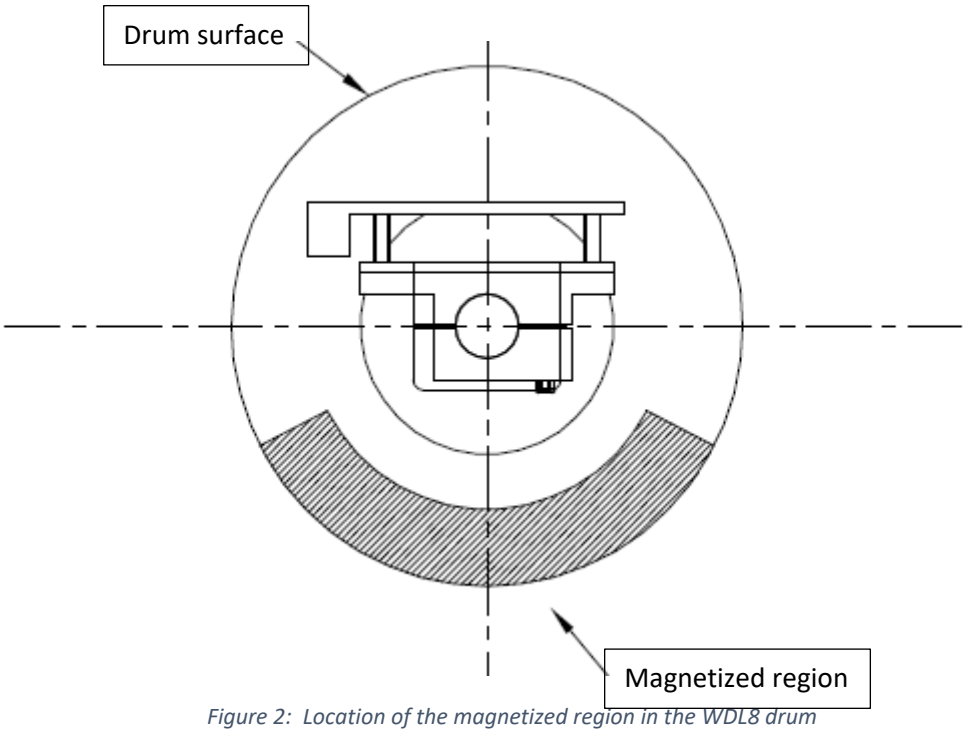

Figure 2: Location of the magnetized region in the WDL8 drum

The intensity of the magnetic field is adjusted through a potentiometer or rheostat with a ampere meter gauge located on the control panel. The higher the current the higher the magnetic field strength. Some useful values of the magnetic field intensity, in Gauss, resulting from the applied current are shown in Table 1.

Table 1: Current versus magnetic field strength for WDL8

CURRENT, AMPERES	MAGNETIC FIELD STRENGTH, GAUSS
0	0
0.7	400
1	560
1.5	800
1.9	1000
2.6	1350

The actual separator setup is shown in Figure 3. Prior to the test a dry sample of the feed is collected. The feed and water are added to the agitated feed bin. The drum rotation is started (concurrent for this test) and the magnetic field strength adjusted to the desired value (350 Gauss). The feed valve is opened and regulated to about 2 liters of pulp per minute. The separation chamber starts to fill. When full the tailings valve is opened allowing about 2 liters per minute to be released. AT this point the wash water is turned on and magnetic concentrate starts being collected. If the level of pulp in the separation chamber lowers the tailings flowrate is reduced by adjusting the tailings valve. The test is carried out until the slurry in the feed bin is exhausted. Slurry weights are measured, and the holdup material is recovered with a known amount of water. All samples are filtered and dried and the solids weights determined.

The three products (holdup, magnetics and non-magnetics) and the feed are sampled in a rotating sampler. The samples are sent for XRD and XRF analysis.

Figure 3: The WDL8 at the pilot-plant. 1- Feed bin, 2 – Separation chamber, (3) Drum, (4) Tailings valve/hose, (5) control panel.

The magnetic concentrate of the first separation stage is the feed to the secondary grinding stage, which is carried out is a batch ball mill, 250 mm x 250 mm, loaded with a finer ball size distribution. Here a make up ball diameter is 25 mm, and the ball charge was adjusted so that an integer number of batches of the same mass could be milled for the pellet Feed preparation.

The objective of the secondary grinding stage is to achieve pellet feed specification, with a Blaine of at least 2000 cm^2/g and minimum P80 of 45 µm. Data is also generated for scaling up the industrial secondary stage ball mill. The mill was stopped at different grinding times and the Blaine and size distribution measured by both, sieving and Malvern™. The batch mills used in the grinding tests and sample preparation are shown in Figure 4.

Blaine surface area is the standard surface area for pellet feed specification. The Blaine method for measurement of the specific surface area of powders is based on the measurement of air permeability of a packed bed of the powder. The device constitutes of a manometer tube to apply suction to a permeability cell that contains a fixed volume of powder. This is shown in Figure 5. The device must be calibrated with a standard of known density and surface area. The standard is usually a known cement sample.

Figure 4: The 0.5x0.5 m batch ball mill with the 75 mm equilibrium ball charge (left) used in the primary grinding tests and the 250x250 mm batch ball mill with the 25 mm equilibrium ball charge (right) used in the magnetic concentrate pellet feed grinding tests.

Figure 5: The Blaine air permeater for surface area measurements

The secondary grinding stage was carried out with the magnetic concentrate of the first separation stage, at increasing grinding times until the Blaine surface area reached the specified 2000 cm^2/g. With the corresponding grinding time and the measured power draw it is possible

to scale up the industrial secondary grinding mill for the magnetic concentrate of the first separation stage.

The pellet feed ready material was then submitted to a second separation stage in the low intensity magnetic drum separator WDL8. Two different magnetic field intensities were tested aiming at a pellet feed with around 1% silica concentration. The flowsheet in Figure 6 contains the sequence for the tests described here.

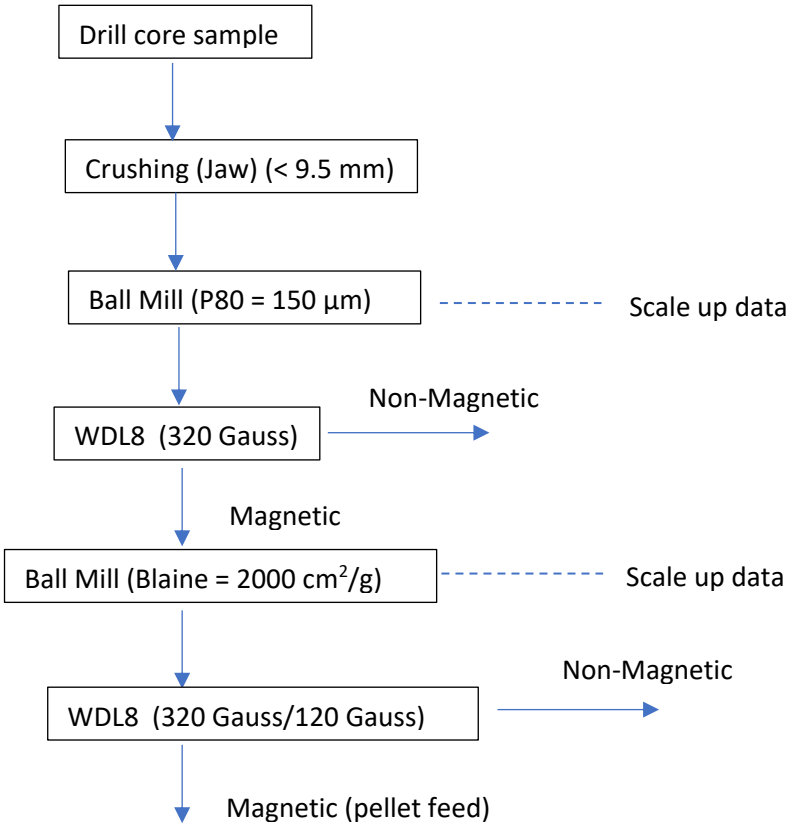

Figure 6: Flowsheet of the several procedures executed in this project

3. Results

3.1 Primary grinding

The primary grinding tests consisted of batch grinding tests in a 0.5 m x 0.5 m mill using an equilibrium ball charge with make-up ball diameter of 75 mm, which is appropriate for this ore crushed at 100% < 9.5 mm. The ball charge used is shown in Table 2.

Table 2: Equilibrium ball charge for primary grinding

Ball sizes	Number of balls	Weight of one ball,	Weight of charge,	Distribution
mm	#	kg	kg	%
75	37	1.7163	63.5	49%
50.8	92	0.5333	49.1	38%
38.1	57	0.2250	12.8	10%
25.4	54	0.0667	3.6	3%
19.05	44	0.0281	1.2	1%
			130.24	100%

The weight of the ball charge was calculated so that a batch of exactly 25 kg of powder corresponded to a charge filling *U* of 100%. Thus, the milling of the entire sample was carried out in two batches. Grinding conditions are shown in Table 3.

Table 3: Primary grinding batch tests conditions

Internal mil diameter	500 mm
Internal mil length	500 mm
Volume fraction of balls, *J*	27%, 130.9 kg
Powder filling, *U*	100%
Holdup, *H*	25 kg
% Critical speed *Cs*	70%, 60.7 RPM
% Solids	100%
Make up ball diameter, d_T	75 mm
Ball density	7800 kg/m^3

Table 4: Measured size distributions for the primary grinding tests at several grinding times.

	Cumulative % passing size after indicated grinding time				
Screen size, mm	**Feed, %**	**300 s**	**1500 s**	**2400 s**	**3600 s**
9.500	100.00	100.00	100.00	100.00	100.00
6.350	75.17	88.43	99.68	100.00	100.00
4.750	57.68	79.20	99.37	99.80	100.00
3.350	44.39	71.65	99.07	99.78	100.00
2.360	35.66	65.49	98.64	99.76	100.00
1.700	30.29	59.68	98.30	99.74	100.00
1.180	25.77	53.79	97.47	99.69	100.00
0.850	23.00	49.13	95.76	99.63	100.00
0.600	20.08	43.76	91.76	99.10	100.00
0.420	17.49	38.66	85.58	97.35	99.91
0.300	14.68	32.33	75.50	90.33	98.55
0.210	11.66	25.80	63.75	79.38	92.28
0.150	8.83	19.65	51.63	66.59	80.18
0.106	6.32	14.20	39.86	53.56	68.05
0.075	4.73	10.66	32.04	44.46	57.20
0.053	3.32	7.65	24.36	35.20	46.33
0.038	2.26	5.32	18.30	26.95	38.10

The resulting size distributions are shown in Table 4 for the Feed sample (crushed at 100% < 9.5 mm) and the products of dry grinding after 300, 1500, 2400 and 3600 seconds. Figure 7 shows that the size distributions are self-similar and no large size accumulation so that the selected ball charge is appropriate for this feed size distribution. Note that the product at the end of the tests has P80 = 150 microns, as desired. During the grinding tests the power draw was measured so that the energy specific grinding rate can be calculated for these grinding conditions (Table 3). The average power draw was 946.45 W. The power draw measurement is illustrated in Figure 8.

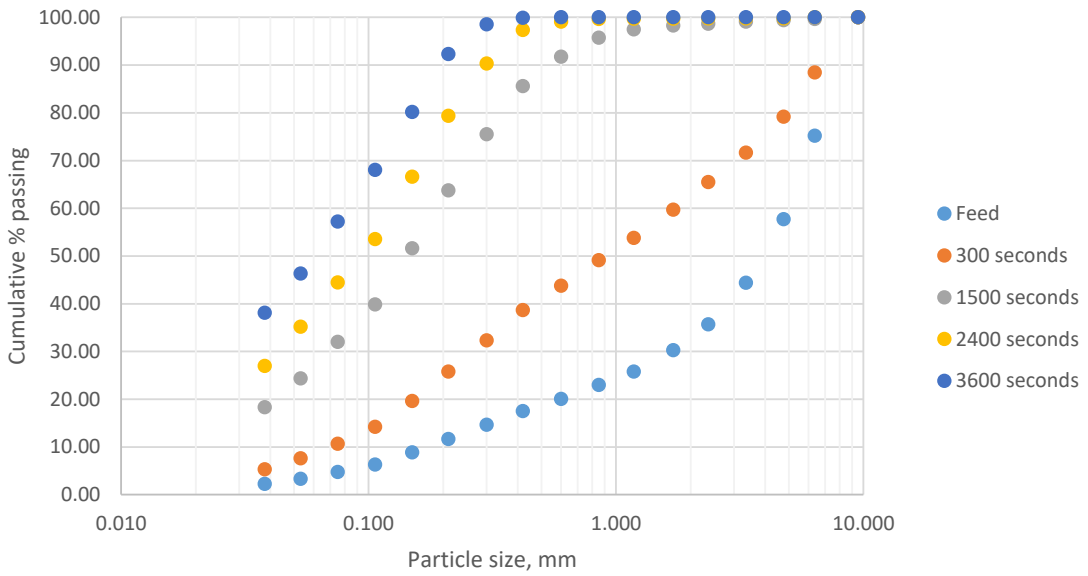

Figure 7: Primary grinding size distributions at different grinding times. Product at 3600 seconds has 80% passing in 150 microns

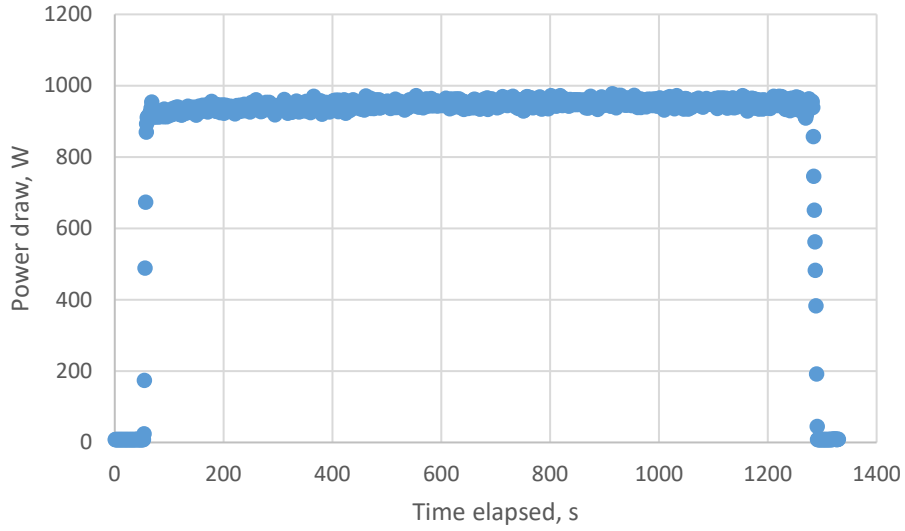

Figure 8: Primary grinding tests, power draw for the test conditions in Table 3.

3.2 First stage magnetic separation

With the sample milled with P80 = 150 microns, and due to the high degree of liberation at this size range as demonstrated in a previous report, it is definitely advantageous to pre-concentrate the iron bearing minerals before grinding it to pellet feed specification. This is, as before, accomplished in the WDL8 using 317 Gauss magnetic field strength (current = 0.6 A).

Because in the previous work the holdup in the separator had a mineralogical composition similar to the feed particles, in this experiment the holdup was reprocessed at the end in order to produce as much material as possible for the next stages of the pellet feed preparation. The separation conditions were kept with 38% solids in the feed. All streams were analyzed by XRD to quantify the mineralogical composition and by XRF which is essentially chemical analysis.

The XRD results are shown in Table 5. It is important that the mineralogy is determined so that the behavior of each phase during the separation stage can be determined. Examination of the results in Table 5 show that the concentrate, magnetic sample is rich in Magnetite and in Hematite, indicating a tendency for the hematite to be recovered in the magnetics of the low intensity separation, either because it is associated to the magnetite or because it is actually maghemite and thus present high magnetic susceptibility. Some hematite reports to the tailings and very little magnetite reports to the tailings, indicating that the recovery of these two minerals in the concentrate stream is high. The tailings stream contains almost all silicates, which is as expected, and a significant amount of goethite which is an iron oxide with low magnetic susceptibility as well as some hematite. The small amount of goethite in the concentrate stream may be due to composite particles that contain both goethite and magnetite and or maghemite. In retrospective, this sample behaved somewhat differently than the previous sample, when most of the hematite reported to the concentrate (magnetic) stream.

Table 5: XRD and Rietveld quantitative analysis of the feed and products of the separation in the WDL8

Phase Name	Feed Wt%	Concentrate (Magnetic) Wt%	Tailings (Non-magnetic) Wt%
Goethite	6.8	3.9	7.9
Hematite	19.1	24.2	17.1
Magnetite	19.5	63.2	2.3
Quartz	38.2	5.7	51.1
Actinolite	10.2	1.3	13.7
Grunerite	6.1	1.7	7.9
	100.0	100.0	100.0

Again, loosing goethite in the tailings may favor lower grades of Al and P in the concentrate, which is desired.

The consolidated results, including masses and recoveries for the separation, are shown in Tables 6 and 7.

Table 6: Masses and yields for the steady state separation, along with phase grades. The silicates have been bundled into Non-Magnetics. Grades are weight grades. P80 = 150 microns, @317 Gauss, 33% solids

Stream	Yields		Phase Grades			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	47.55	100.0%	19.1	19.5	6.8	54.6
Tails (non-magnetic)	34.12	71.8%	17.1	2.3	7.9	72.7
Conc. (magnetic)	13.43	28.3%	24.2	63.2	3.9	8.7

Table 7: Masses and yields for the steady state separation, along with phase recoveries. The silicates have been bundled into Non-Magnetics. P80 = 150 microns, @317 Gauss, 33% solids

Stream	Yields		Phase Recoveries			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	47.55	100.0%	100	100	100	100
Tails (non-magnetic)	34.12	71.8%	64.2%	8.6%	83.9%	95.5%
Conc. (magnetic)	13.42	28.3%	35.8%	91.4%	16.1%	4.5%

Differently than the previous work, this time most of the hematite reports to non-magnetics which is not desired. Apparently, this sample contains a lesser association between hematite and magnetite. Other phases behave as expected.

Most importantly, most of magnetite reports to the magnetics stream, with over 90 % recovery of this mineral. It is probable that adding a scavenger separation stage the recovery of magnetite could be significantly improved. Because the objective here is to produce a sample of commercial pellet feed, improving recoveries at all separation stages, and ultimately, optimizing the circuit, will be the subject of future work.

3.3 Secondary grinding (pellet feed specification)

The magnetic concentrate of the first separation stage was milled in a 254x254 mm batch ball mill using an equilibrium ball charge with a makeup ball diameter of 25.4 mm. The ball charge is shown in Table 8.

Table 8: Equilibrium ball charge for secondary grinding

Ball sizes	Number of balls	Weight of one ball,	Weight of charge,	Distribution
mm	#	kg	kg	%
25.4	144	0.0667	9.60	40.0%
19.05	374	0.0281	10.52	43.8%
12.5	420	0.0079	3.34	13.9%
6.35	517	0.0010	0.54	2.2%
			24.0	100%

Table 9: Secondary grinding batch tests conditions

Internal mil diameter	254 mm
Internal mil length	254 mm
Volume fraction of balls, *J*	40%, 24 kg
Powder filling, *U*	100%
Holdup, *H*	6.7 kg
% Critical speed *Cs*	70%, 61.8 RPM
% Solids in wet tests	70%
Make up ball diameter, d_T	25 mm
Ball density	7800 kg/m^3

The ball charge was again adjusted so that preparing the pellet feed could be done in two equal batches. The mill was run for a short time and the charge sampled for assessing the Blaine surface area. This was repeated until 200 cm^2/g was achieved. For the second batch the same total grinding time was used.

The measured size distributions corresponding to each grinding time are shown in Table 10.

Table 10: Measured size distributions for the secondary grinding tests at several grinding times, wet and dry. Blaine surface area results at each grind time.

Sieve size, mm	Feed	Dry grinding		Wet grinding, 70% solids		
		600 sec	4200 sec	+3600 sec	9600 sec	14100 sec
0.600	100.00	100.00	100.00	100.00	100.00	100.00
0.420	99.48	100.00	100.00	100.00	100.00	100.00
0.300	97.11	99.32	100.00	99.98	100.00	100.00
0.212	88.90	94.63	99.88	99.96	100.00	100.00
0.150	75.66	83.45	97.99	99.91	99.98	100.00
0.106	58.90	66.81	86.91	99.82	99.96	100.00
0.075	49.07	55.47	75.83	98.86	99.87	99.95
0.053	38.73	44.93	63.19	93.52	98.48	99.46
0.045	34.00	39.36	57.12	87.33	96.03	98.08
0.038	27.51	32.11	47.80	80.10	91.81	95.45
Blaine cm^2/g	**370.9**	**433.9**	**473.59**	**1386.23**	**1807.05**	**2041.64**

Note that after 14100 seconds of wet grinding pellet feed specification is obtained with approximately 2000 cm^2/g Blaine and 98% passing 45 microns. The evolution of the measured size distributions is shown in Figure 9. Power measurements were carried out for scaling up the pellet feed grinding stage. For the wet conditions in Table 9, power draw results are shown in Figure 10. Average power draw was 295.7 W for this mill/ball charge.

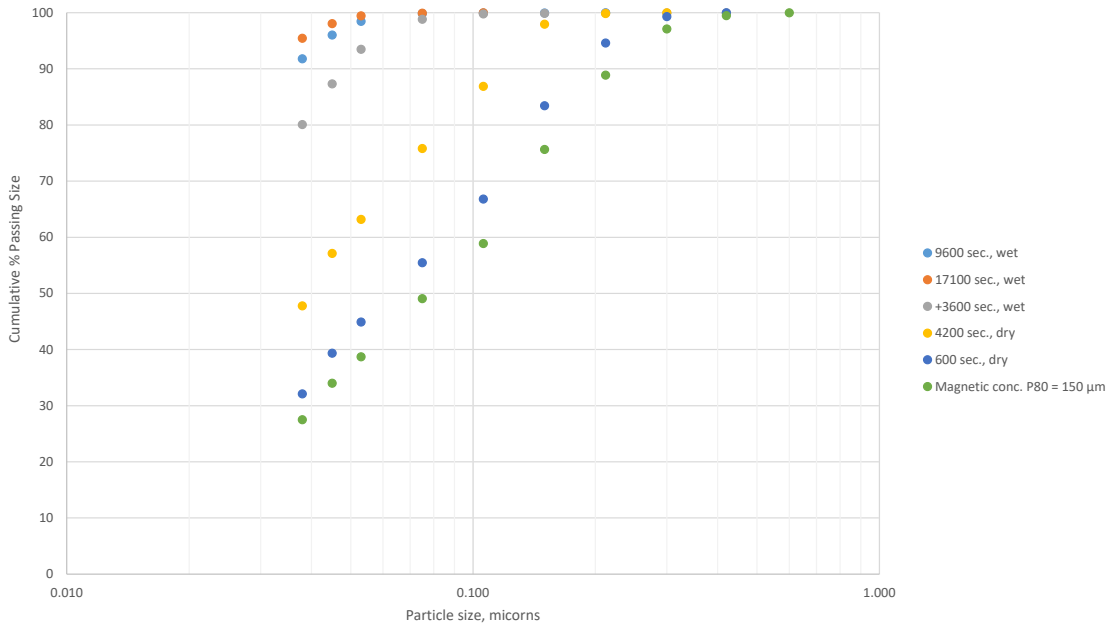

Figure 9: Size distributions after dry grinding and after additional wet grinding.

It is important to point out that this grinding operation will be very much energy intensive and the design of the actual mill for pellet feed preparation must contemplate every possible alternative for the highest possible energy efficiency. Thus, the reason pre-concentrating in the primary stage is of fundamental importance. HPGR may be used for finishing, such as elevating Blaine from 1800 to 2000 cm^2/g for example. The use of tower mills for secondary grinding may

result in additional energy savings. Also, the ball charge size distribution should be optimized so as to increase the grinding rate, usually by means of smaller balls, but with careful consideration of steel consumption which is reduced with larger balls.

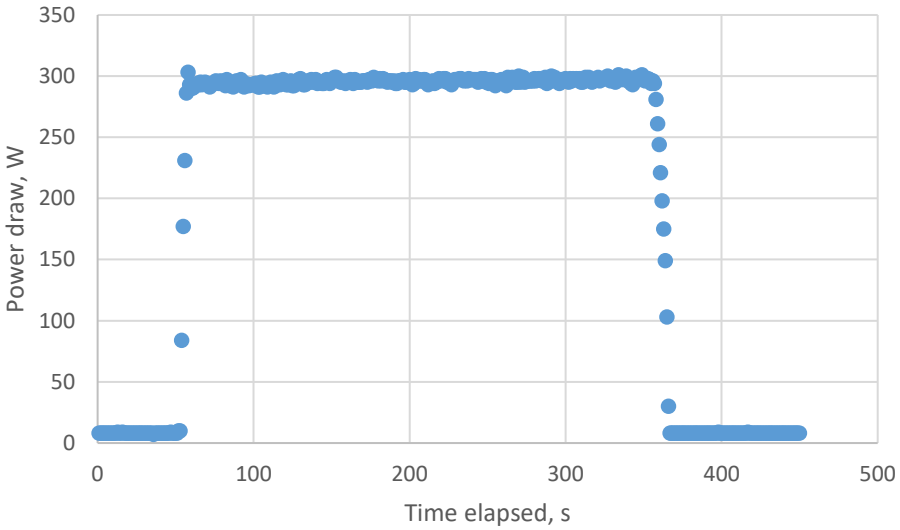

Figure 10: Secondary grinding tests, power draw for the test conditions in Table 9.

3.4 Second stage magnetic separation, 211 Gauss

With the magnetic concentrate of the first separation stage milled at pellet feed specification, 2000 cm^2/g, a secondary concentration using very low field strength was first attempted aiming at obtaining a high-quality concentrate. At this stage recovery is not the main objective as this can be achieved in closed circuit and by means of scavenging the tailings streams. This, as before, was carried out in the WDL8 using 211 Gauss magnetic field strength (current = 0.4 A).

Instead of using the mineralogical composition of the concentrate (magnetics) from Table 5, the feed mineralogical composition was calculated from the mineralogical composition of the two products (magnetic concentrate and non-magnetic tailings) and the yields measured in this separation. All recoveries and grades are calculated in this way. The main reason for this is that there is always a hold up in the WDL8 which is not processed, and this holdup is not fully characterized because it is known that it's composition is very close to the composition of the feed stream (but not exactly equal). The mineralogical composition of the streams is shown in Table 11.

Table 11: XRD and Rietveld quantitative analysis of the feed and products of the 211 Gauss separation of pellet feed in the WDL8

Phase Name	Feed Wt%	Concentrate (Magnetic) Wt%	Tailings (Non-magnetic) Wt%
Goethite	3.4	3.6	3.3
Hematite	23.3	20.6	26.0
Magnetite	65.5	74.2	56.6
Quartz	5.0	0.5	9.6
Actinolite	1.4	0.6	2.3
Grunerite	1.3	0.4	2.3
	100.0	100.0	100.0

The result indicates that the magnetic field strength may not have been sufficient. The consolidated results, including masses and recoveries for the separation, are shown in Tables 12 and 13.

Table 12: Masses and yields for the steady state separation, along with phase grades. The silicates have been bundled into Non-Magnetics. Grades are weight grades. 2000 cm^2/g, @317 Gauss, 33% solids

Stream	Yields		Phase Grades			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	13.24	100.0%	23.3	65.5	3.4	7.8
Tails (non-magnetic)	6.53	49.3%	26.0	56.6	3.3	14.2
Conc. (magnetic)	6.71	50.7%	20.6	74.2	3.6	1.5

Table 13: Masses and yields for the steady state separation, along with phase recoveries. The silicates have been bundled into Non-Magnetics. 2000 cm^2/g, @317 Gauss, 33% solids

Stream	Yields		Phase Recoveries			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	13.24	100.0%	100.0%	100.0%	100.0%	100.0%
Tails (non-magnetic)	6.53	49.3%	55.0%	42.6%	46.8%	90.1%
Conc. (magnetic)	6.71	50.7%	45.0%	57.4%	53.2%	9.9%

This low intensity separation resulted in about 50% recovery of iron oxides to the magnetic concentrate and only 10% recovery of silicates to the tailings (non-magnetic). This results in a very low grade of silicates in the magnetic concentrate of 1.5%. The low recovery is not a problem because recovery issues can be mitigated using scavenger stages and recirculation.

The certified chemical assay, by XRF, of this pellet feed concentrate and the corresponding tailings is given in Table 14, below.

Table 14: XRF results for the magnetic concentrate and non-magnetic tailings of the low intensity pellet feed magnetic separation.

Analyte	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	MgO	Na_2O	K_2O	Cr_2O_3	LOI
Unit	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Sample												
Magnetic	70.6	0.88	<0.10	0.02	0.08	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	gf
Non-Magnetic	60.6	12.4	<0.1	0.025	0.13	<0.1	0.45	0.5	<0.1	<0.1	<0.1	gf

gf = gain on ignition

Important to note the very low grade of SiO_2 in the pellet feed product (magnetic) as well as the very low grades of Al_2O_3 and P.

3.5 Second stage magnetic separation, 317 Gauss

A second exploratory separation was carried out but this time with higher magnetic intensity of 317 Gauss which is the same intensity (field strength) used for the first stage. Results are given below, following the same methods as discussed in the previous separation.

Table 15: XRD and Rietveld quantitative analysis of the feed and products of the 317 Gauss separation of pellet feed in the WDL8

Phase Name	Feed Wt%	Concentrate (Magnetic) Wt%	Tailings (Non-magnetic) Wt%
Goethite	3.5	2.9	7.6
Hematite	25.1	24.3	30.2
Magnetite	63.1	71.5	9.6
Quartz	5.8	0.9	37.3
Actinolite	1.3	0.4	7.2
Grunerite	1.1	0.0	8.2
	100.0	100.0	100.0

The result indicates that the magnetic field strength is high enough to recover most of the magnetite. The consolidated results, including masses and recoveries for the separation, are shown in Tables 16 and 17.

Table 16: Masses and yields for the steady state separation, along with phase grades. The silicates have been bundled into Non-Magnetics. Grades are weight grades. 2000 cm^2/g, @317 Gauss, 33% solids

Stream	Yields		Phase Grades			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	12.92	100.0%	25.1	63.1	3.5	8.3
Tails (non-magnetic)	1.77	13.7%	30.2	9.6	7.6	52.7
Conc. (magnetic)	11.15	86.3%	24.3	71.5	2.9	1.3

Table 17: Masses and yields for the steady state separation, along with phase recoveries. The silicates have been bundled into Non-Magnetics. 2000 cm^2/g, @317 Gauss, 33% solids

Stream	Yields		Phase Recoveries			
	kg	%	HEM, %	MAG, %	GOET, %	NON_MAGS, %
Feed	12.92	100.0%	100.0%	100.0%	100.0%	100.0%
Tails (non-magnetic)	1.77	13.7%	16.5%	2.1%	29.5%	86.9%
Conc. (magnetic)	11.15	86.3%	83.5%	97.9%	70.5%	13.1%

This higher intensity separation results in much higher recovery and yield, as expected but now the magnetic concentrate contains 13% silicates. Concentrate quality could be easily improved by adding a cleaner stage. However, it seems more reasonable to just use lower magnetic field strength, like shown in the previous section, and improve recoveries by adding scavenging units.

The certified chemical assay, by XRF, of this pellet feed concentrate and the corresponding tailings is given in Table 18, below.

Table 18: XRF results for the magnetic concentrate and non-magnetic tailings of the low intensity pellet feed magnetic separation.

Analyte	Fe	SiO_2	Al_2O_3	P	Mn	TiO_2	CaO	MgO	Na_2O	K_2O	Cr_2O_3	LOI
Unit	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)	(%)
Sample												
Magnetic	69.9	1.23	<0.1	0.019	0.09	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	gf
Non-Magnetic	35.3	43.4	0.18	0.043	0.24	<0.1	1.49	1.76	0.14	<0.1	<0.1	1.2

gf = gain on ignition

here, the grade of SiO_2 in the pellet feed magnetic concentrate is higher, 1.23 %. Again the contaminants (P and Al_2O_3) are very low.

Conclusions and recommendations

The main conclusion is that is possible to produce a high-quality pellet feed from the Gameleira ore. The processing route includes crushing to 100% < 9.5 mm, a primary grinding stage to P80 = 150 microns, a first separation stage of low intensity magnetic separation (320 Gauss) to obtain a preconcentrate rich in iron oxides. This is very important because pellet feed grinding is very energy intensive and this separation discards about 70% of the feed to the plant, reducing considerably the energy requirements for pellet feed preparation.

The secondary grinding stage to produce pellet feed surface area of 2000 cm^2/g can be achieved using either tower mills or perhaps HPGR. For the subsequent report a VertiMill™ grinding circuit will be designed for pellet feed preparation because these mills can be at least 30% more efficient than tumbling ball mills.

After pellet grinding, a second stage magnetic separation is required to reach pellet feed commercial quality specifications. It is recommended that low intensity magnetic separation drums is used for this stage, with a very low magnetic intensity. The circuit should include scavenger units at higher magnetic intensity so that recoveries as high as 99% can be achieved.

Future work will include scale-up of the crushing and grinding circuits to the new specifications. Also, and looking further ahead when larger samples are available, a magnetic separation pilot plant should be run to prepare relatively high amounts of pellet feed that can be tested in a pot grade.

The calculation of recovery and Yields for a separation with one feed and two product streams:

Definitions

R^T = Recovery to tailings (non-magnetics)

R^C = Recovery to concentrate (magnetics)

C = Mass or flowrate of concentrate stream

T = Mass or flowrate of tailings stream

F = Mass or flowrate of feed stream

c = grade of phase in concentrate stream

t = grade of phase in tailing stream

f = grade of phase in feed stream

The recovery of phase to the concentrate stream is, by definition:

$$R^C = \frac{Cc}{Ff} \tag{1}$$

and the recovery of phase to the tailing stream is:

$$R^T = \frac{Tt}{Ff} \tag{2}$$

As there are only two product streams, the sum of these recoveries must equal 100%, that is:

$$R^C + R^T = 1 \tag{3}$$

Also, the sum of flowrates or masses of Concentrate and Tailings must be equal to the feed:

$$C + T = F \tag{4}$$

Substituting eqs. (1) and (2) into eq.(3)

$$\frac{Cc}{Ff} + \frac{Tt}{Ff} = 1 \tag{5}$$

Rearranging:

$$Cc + Tt = Ff \tag{6}$$

Eq. (4) can be written as:

$$C = F - T \tag{7}$$

Substituting this definition of *C* into eq. (6) we get:

$$(F - T)c + Tt = Ff \tag{8}$$

Rearranging eq. (8)

$$Fc - Tc + Tt = Ff$$

$$Tc - Tt = Fc - Ff$$

$$T(c - t) = F(c - f)$$

$$\frac{T}{F} = \frac{(c-f)}{(c-t)} \tag{9}$$

Substituting eq. (9) into eq. (2) which is the definition of recovery of phase to the tailings stream, we get:

$$R^T = \frac{t}{f}\frac{(c-f)}{(c-t)} \tag{10}$$

Eq. (10) allows for calculating the recovery of phase to the tailings streams using only the measured grades in the streams involved, not requiring measured flowrates or masses. It follows that:

$$R^C = \frac{c}{f}\frac{(f-t)}{(c-t)} \tag{11}$$

Note that once RT or RC are known from eqs. (10) or (11) the other value is the reciprocate calculated using eq. (3).