Fine Particle Processing Of Iron Ore Slimes From Wash Plant

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Abstract

Closing down iron ore mines due to environmental constraints spurred the iron ore washing plants to recover the values from their slimy tail pond. The paper enumerates the developments in ecofriendly processing of iron ore slimes by state of art vertical pulsating wet high intensity high gradient magnetic separation. The wash plant tails assayed 46.45%Fe, 18.03%SiO_2, 5.25% Al_2O_3, and 6.10%LOI. The process comprises of high pressure cycloning of dispersed pulp to remove slimes less than 10 microns. The cyclone under flow is subjected to vertical pulsating high intensity high gradient magnetic separation at 8200gauss [open air intensity] 35% Solids pulp density followed by cleaning at 7000 gauss in [open air intensity] 15% solids. The concentrate is thickened and filtered in lab Larox pressure filter. The above process produced a concentrate assaying 64.00% Fe, 2.41% SiO_2, 2.51% Al_2O_3, 1.90%LOI,-150 mesh size and 8.6% moisture with 30% Fe recovery at wt% yield of 20.0 meeting the requirements of on line pelletization plant. Locked cycle test by desliming at 5 microns and the recycling the cleaner tails back produced the concentrate assaying 62.89%Fe with 35% Fe distribution at wt% yield of 26.1. The concentrate marginally failed to meet the chemical specifications stipulated and cycloning to remove -5 microns content was not practically feasible in industrial operations and hence dispensed with. Detailed on site pilot plant tests are recommended as the process appears economically and ecologically feasible and can be retrofitted as tail piece in the existing washing plants.

[Key words: WHIMS, Iron ore slimes, processing]

1 Introduction

Indian Iron ore occurs mostly as oxides in nature. A substantial amount of this reserve is high grade hematite. India's total reserve is estimated to around 17880 million tones assaying on an average +58% Fe. The deposits are fairly well distributed in the states of Jharkhand, Chattisgarh, Orissa, Karnataka, Maharashtra, Goa and Andhra Pradesh. The remaining are mostly magnetite ores with low iron content and concentrated in deep forest areas of the country where mining is prohibited. The production of iron ore in India has been in steady growth from a very low level of 0.41 million tons in 1917 to 208 million tons in 2010. [1] Although India is blessed with large reserves of iron ore, lack of consistency with respect to the ratio of Al_2O_3 to SiO_2 make these ores unsuitable for direct use in the blast furnace [3,4] and need beneficiation or washing prior to industrial use. During the preparation of ore as a feed to blast furnace a significant amount of slimes (-0.150 mm) are being generated [5]. The presence of alumina bearing clay and excessive generation of fines during mining, washing operations, material handling and very soft nature of ore are the main problems in the Iron ore industries. In an ideal condition the alumina to silica ratio of the iron ore feed to blast furnace should be less than one. Therefore, most of the iron ore mines producing hematite in India are provided with washing plants to produce lumps and fines to blast furnace operations. The process of conventional plant comprises of treating the ROM assaying ~60% Fe mostly hematite ore. The ROM is crushed to -70 mm in jaw crusher, followed by closed circuit secondary crushing to -30 mm, The -30 mm fraction is scrubbed in log washer and sands are wet screened over 10mm screen to get lumps of -30+10mm . The fines and log washer over flow is fed to screw classifier to get sinter feed sandy material of -10+0.2 mm. The spiral classifier over flow is further subjected to 2 stage of hydro cyclone classification to recover -0.2+0.075 mm high grade fine sand. The slimy cyclone over flow -0.075mm fraction is currently thrown to tailing pond which assays about 45% Fe with 20 Wt% yield. The tails are classified as clayey tails based on alumina content [>5%] and siliceous tails based on silica content [>15%] and alumina [<3%]. Around 32 million tones of hematite ore is washing every year, producing 24 million tons of lumps and fines for blast furnace operations. The balance of 8 million tons of mined ore is lost as tailing (slimes) containing around 52-63% Fe. The loss of iron ore thus amounting to 8 million tons per year is not a good proposition in a developing country like India. Besides, the slime disposal into tailing pond poses enormous environmental hazards and ecological problems. With an increase in iron ore production to 155 million tons per annum, the slime generation is expected to be above 10-12 million tons. Further, with the rapid increase in the projected iron and steel making capacity in India, utilization of these slimes as sources of iron values is imperative.

At present these slimes containing higher amount of gangue cannot be used directly in the sinter feed without beneficiation. Thus, safe disposal and utilization of such vast mineral wealth are posing big challenges to mineral engineering in the country. Finding a viable solution to recover iron values from slimes is a great problem facing mineral technology. Further closing down iron ore mines due to environmental constraints spurred the iron ore washing plants to recover the values from their slimy tail pond. Efforts have been made to recover iron values from slimes as enumerated by the works of IBM [2], Rao [3], Chakravarthy et. al.,[4] Banerjee et. al.,[5] . Most of the processes centrted on inverse flotation and wet high intensity magnetic separation. Sherrrel and Novans [6], and Tong et.al.,[7] described the developments in WHIMS for processing iron ore slimes. The centrifugal gravity concentration is rendered difficult industrially due to high pulp volumes involved and inverse flotation process has environmental constraints due to use of chemical reagents. Hence the processing of slimes by magnetic separation seems to be the best alternative. The local pellet industries desire a concentrate assaying Fe >62.5%, SiO_2 + Al_2O_3 < 6%, LOI<3%, 100% passing 100mesh size and moisture <12%.

2 Material and Methods

The iron ore wash plant slimes were collected from iron ore washing plants of Sandur – Hospet region of Karnataka. Mozley hydro cyclone [25,50 and 75mm dia] test rig was used for desliming. The particle size analysis was done by test sieves and beaker decantation method. Lab model WHIMS was used for carrying out lab tests while at the site VPWHIMS of LONGI make was used to confirm the findings.

3 Results and Discussion

3.1 Principles of VPWHIMS: The primary forces that significantly affect magnetic separation are magnetic force, gravity and hydrodynamic forces. The magnetic force F_m is given below

F_m = K x X_m x H x [dH/dx] x V

Where,

F_m = Magnetic force,
K = Constant,
X_m = Intentsity of Magnetisiation related to magnetic susceptibility,
H = Magnetic intensity

dH/dx = Magnetic gradient
V = Volume of particle

As the particle becomes small, volume V is very small, hence, the intensity and gradient has to be increased to very high values for paramagnetic materials as X_m values are also very low. The basic principle of wet high intensity magnetic separation [WHIMS] and high gradient magnetic separation [HGMS] consists of generation of background intensity of 10,000 gauss [H] and insertion of very fine magnetic matrix with more surface area increasing the intensity to 20,000 gauss with a gradient serving as capture zone of paramagnetic minerals. The nonmagnetic minerals pass through. The matrix is rotated and captured magnetic particles are flushed when current to separator is off.

In the conventional horizontal WHIMS, the magnetic flux is transverse to the flow of pulp and fluids as shown in Fig 1.The mechanical nonmagnetic gangue entrapment with magnetic and matrix clogging due to concentric side tube type enlargement around matrix is shown in Fig 2.

This problem of matrix clogging was partially overcome by Eriez with vertical ring wet magnetic separator, where the carousel rotates vertically and magnetics are flushed in counter current direction of feeding to minimize matrix clogging . Sala used reverse vacuum based flushing of magnetics to minimize matrix clogging. The problem of mechanical gangue entrapment and as well as matrix clogging was solved by redesigning the matrix and flux flow directions by SLON. The pulp and fluid flow is parallel to high intensity- very high gradient matrix mostly thin rods. The gangue entrapment and matrix clogging is minimized bearding of matrix as shown in Fig 3. Further vertical pulp pulsation similar to jigging is carried out to minimize gangue entrapment. Also magnetic matrix rotates vertically similar to Eriez ferrous wheel. The combination of parallel pulp and high gradient matrix, vertical pulsation during feeding and vertical rotation of matrix to discharge magnetics counter current to loading direction flow revolutionized magnetic separation of paramagnetic slimes.

Longi magnetics subsequently concentrated on reducing the cost of operation by saving the energy for energizing the coils. Hitherto the conventional WHIMS or VPWHGMS had used low voltage and high current for energizing the coils. The coils are tubes with low wire space factor of 40%, low cross sectional area and long water pass length as shown in Fig 4. Longi used high voltage, low current for energizing coils. The coils are small dia solid wires with high wire space factor of 60%, low cross sectional area and short water pass length as shown in Fig 5. Under identical conditions of field, coil shape and material, energizing power is inversely proportional to coil space factor. The ratio of power to Longi WHGMS and other WHIMS/WHGMS is inversely proportional to ratios of coil space factors of WHIMS and Longi WHGMS which is 60%. The detail of power saving due to wire space factor is shown in Table 1.

3.2 Sample characteristics: The as received reclaimed sample from pond consisted of moist reddish brown powder with specific gravity of 1.6. The sample assayed 46.45% Fe, 18.03% SiO_2, 5.25% Al_2O_3, and 6.10% LOI. The sample contained mostly hematite, goethite with subordinate to minor amounts of ferruginous clay and quartz. The as received sample was subjected to wet sieve and sub sieve analysis and the products were assayed for Fe. The results are given in Table 2. Table 2 clearly indicates that the sample contained mostly slimes of 10 microns size.

4.1 Effect of open air field intensity: The open air intensity was varied at 6000,7200,8200,9000 and10000 gauss. The results are given in Table 4. The results on feed sample yielded a magnetic fraction assaying 61.12% Fe with 47.7% Fe distribution at 37.2 wt % yield at 8200 gauss. The % Fe recovery increases with increase in field intensity.

4.2 Effect of desliming: Tests were conducted by desliming the feed by 75 mm hydro cyclone to reject 10 micron slimes from fresh feed followed by WHIMS. The results are given in Table 5. The result indicated that a cyclone under flow assaying 51.32% Fe with 57.7% Fe distribution at 52.7 wt% yield can be produced. The results are similar to that obtained in characterization size- sub sieve analysis study. The deslimed feed was subjected to WHIMS at 8200 gauss. The results indicated that the concentrate grade increased from 61% Fe close to stipulated grade assaying 62.89%Fe but the Fe recovery dropped from 47% to 36%. This may be due to high slime content in the feed. Incidentally the sub sieve analysis indicated that the sample contained 75% material finer than 10 microns accounting for 30% Fe distribution and contained ferruginous clay and hydrated iron oxide slimes mostly

4.3 Final Test under optimum conditions: The process comprises of high pressure cycloning of dispersed pulp to remove slimes less than 10 microns. The cyclone under flow is subjected to vertical pulsating high intensity high gradient magnetic separation at 8200gauss [open air intensity] 35% Solids pulp density followed by cleaning at 7000 gauss in [open air intensity] 15% solids. The results are given Table 6. The concentrate is thickened and filtered in lab Larox pressure filter. The above process produced a concentrate assaying 64.00% Fe, 2.41% SiO_2, 2.51% Al_2O_3, 1.90%LOI,-150 mesh size and 8.6% moisture with 30% Fe recovery at wt% yield of 20.0 meeting the requirements of on line pelletization plant. Locked cycle test by desliming at 5 microns and the recycling the cleaner tails back produced the concentrate assaying 62.89%Fe with 35% Fe distribution at wt% yield of 26.1. The concentrate marginally failed to meet the chemical specifications stipulated and cycloning to remove -5 microns content was not practically feasible in industrial operations and hence dispensed with. Detailed on site pilot plant tests are recommended as the process appears economically and ecologically feasible and can be retrofitted as tail piece in the existing washing plants.

5 Conclusions

The wash plant tails assayed 46.45%Fe, 18.03%SiO_2, 5.25% Al_2O_3 and 6.10% LOI. The process comprises of high pressure cycloning of dispersed pulp to remove slimes less than 10 microns. The cyclone under flow is subjected to vertical pulsating high intensity high gradient magnetic separation at 8000gauss [open air intensity] 35% Solids pulp density followed by cleaning at 7000 gauss in [open air intensity] 15% solids. The concentrate is thickened and filtered in lab Larox pressure filter. The above process produced a concentrate assaying 64.00% Fe, 2.41% SiO_2, and 2.51% Al_2O_3, 1.90% LOI,-150 mesh sizes and 8.6% moisture with 30% Fe recovery at wt% yield of 20.0 meeting the requirements of on line pelletization plant. The desliming, Longi VPWHIMS of deslimed -0.1 + 0.01 mm fraction could yield marketable concentrates assaying > 62% Fe with 25-30 wt% yield, , reducing the load on tail pond by 25% and reducing the tails losses < 40% Fe. The energy efficient, economical Longi WHIMS seems to be viable alternative for sustainable processing iron ore slimes. Detailed investigation for the selection of process equipment in term of its capacity, operation and cost of maintenance in handling voluminous amount of slime being generated at commercial plants needs to be conducted

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Table 1 ; Energy Savings Of Longi VPWHIMS *w.r.t* Conventional WHIMS

No	Particulars	LongiWHIMS	Conventional WHIMS
1	Wire type	Solid	Hollow tube
2	Wire space factor Z	70%	40%
3	Cooling water pass	3 m	150m
4	Cooling water pass section area mm^2	$2600mm^2$	$230mm^2$
5	Current	Low	High
6	Voltage	High	Low
7	Power equivalent $P=[(NI)^2 . Sg . L]/[S .Z]$	0.6	1

Where P = power .N = no of turns of coil, I= current, Sg= sp gr, L= coil length, S = total coil cross section area, and Z = wire space factor.

Table 2 : Wet Sieve And Sub- Sieve Analysis Of As Received Sample

Sl No	Size in mm	Wr% retained	Fe Assay%	Fe% Distn
1	-0.1+0.045	2.8	4.235	3.3
2	-0.045+0.025	8.5	60.79	11.1
3	-0.025+0.01	12.5	58.80	15.9
4	-0.01	76.2	42.50	69.7
5	Head Calc	100.0	46.45	100.0
6	-0.1+0.01	23.8	58.97	30.0

Table 3 Longi Magnetic Separator Data

Sl No	Particulars	Specs
1	Make -Size/Model	Longi, China,1m dia ring, LGS1000
2	Capacity	$150M^3/h$ pulp.6 tph -0.5mm material
3	Rotation – Pulsation	Vertical
4	Field	Variable with variable frequency drive
5	Matrix rod/mesh	1mm dia rod
6	Ring speed	3 rpm
7	Frequency	Variable 30-50 cpm
8	% solids	20-40% variable

Table 4: Effect open field strength on feed

Gauss	Products	Wt%	%Fe assay	%Fe Distn
6000	Mag	35.7	60.62	44.0
	Non mag	64.3	40.29	56.0
	Head Calc	100	49.24	100.0
7200	Mag	32.3	59.86	39.7
	Non mag	67.7	40.85	60.3
	Head Calc	100.0	48.47	100.0
8200	Mag	37.2	60.12	47.7
	Non mag	62.8	39.09	52.3
	Head Calc	100.0	46.91	100.0
9000	Mag	45.8	60.34	54.9
	Non mag	54.2	41.85	45.1
	Head Calc	100.0	50.32	100.0
10000	Mag	47.1	59.21	56.4
	Non mag	52.9	40.67	43.4
	Head Calc	100.0	49.41	100.0

Table 5: Effect of desliming

Particulars	Products	Wt%	%Fe assay	%Fe Distn
Undeslimed feed	Mag	37.2	60.12	47.7
	Non mag	62.8	39.09	52.3
	Head Calc	100.0	46.91	100.0
Delslimed in 75mm cyclone	UF Mag	24.6	62.12	32.6
	UF non mag	28.1	41.78	25.1
	CO/F	47.3	42.00	42.3
	Head Calc	100.0	46.91	100.0
	UF Calc	57.7	51.32	57.7

Table 6: Final test

1 75mm Hydrocyclone, 50 psi pressure, 15% S, 5 mm VF, 3mm Apex
2 Rougher WHIMS 35% S, 8200 gauss and Cleaner WHIMS 15% S, 7200 gauss

Products	Wt%	%Fe assay	%Fe Distn
UF Cl Mag	22.0	64.00	30.0
UF Cl Non mag	2.6	50.50	2.8
UF R non mag	33.1	43.29	30.5
CO/F	42.3	40.89	36.9
Head Calc	100.0	46.91	100.0

Fig.1 Schematic diagram of loading in conventional WHIMS and vertical pulsating WHIMS [After Sherrel and Novans, 2010]

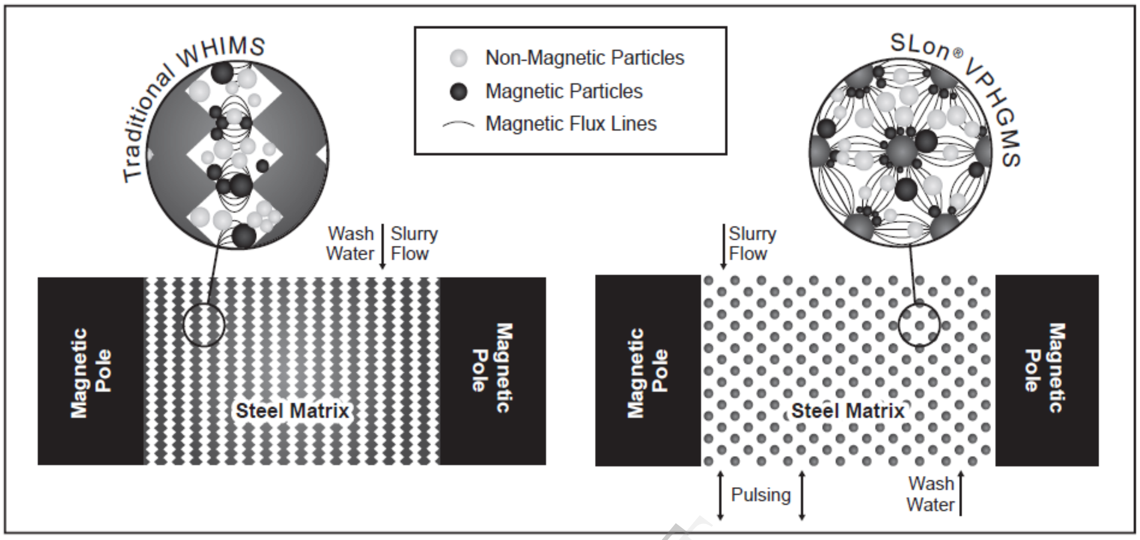
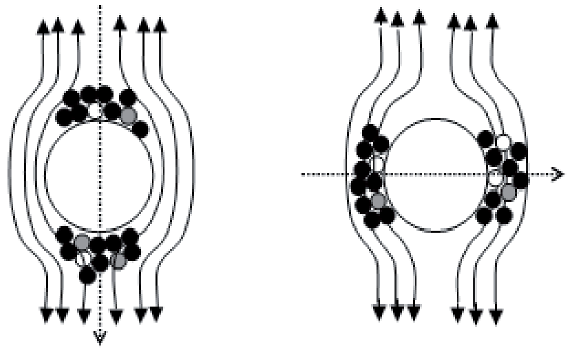


Fig.2 Loading and discharge in a horizantal matrix and blockage of matrix due to side tyre buildup [After Tong *et.al.* 2010]



Slurry reciprocating motion direction Lines of force
— Magnetic particles — Intergrowths — Gangue minerals

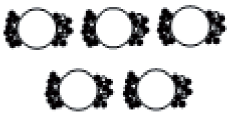
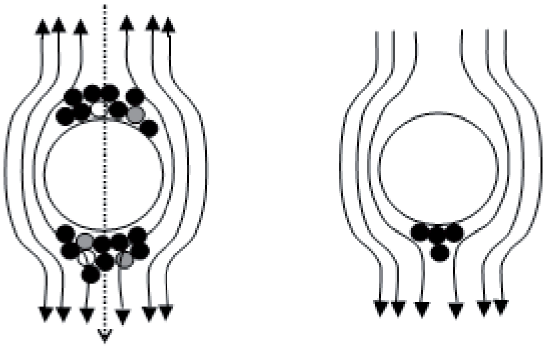


Fig.3: Loading and discharge in a vertical matrix parallel to feed pulp /fluid leading to beard formation averting matrix blockage and gangue entrapment
[After Tong *et.al.* 2010]



Slurry reciprocating motion direction Lines of force
Washing water motion direction Magnetic particles — Intergrowths — Gangue minerals

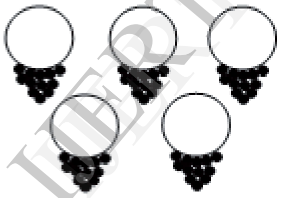


Fig 4: Coil structure of conventional WHIMS indicating tube with low wire space factor.

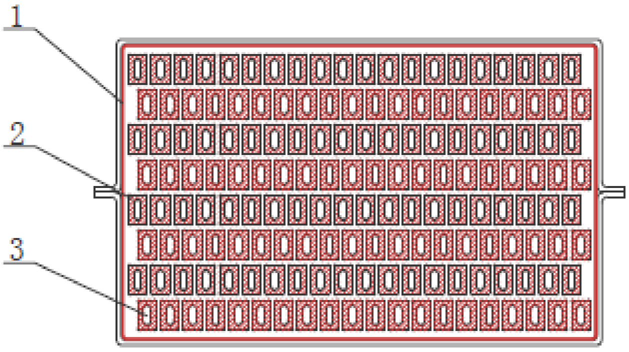
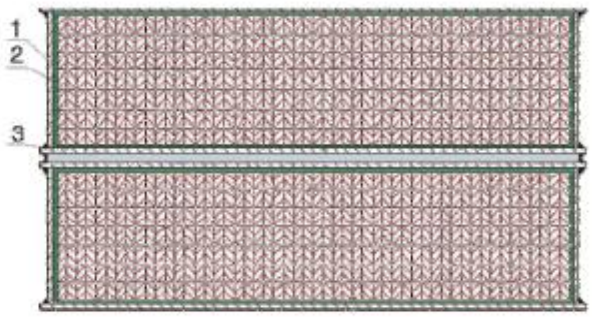


Fig 5 Coil structure of LONGI WHIMS indicating solid wire and high wire space factor



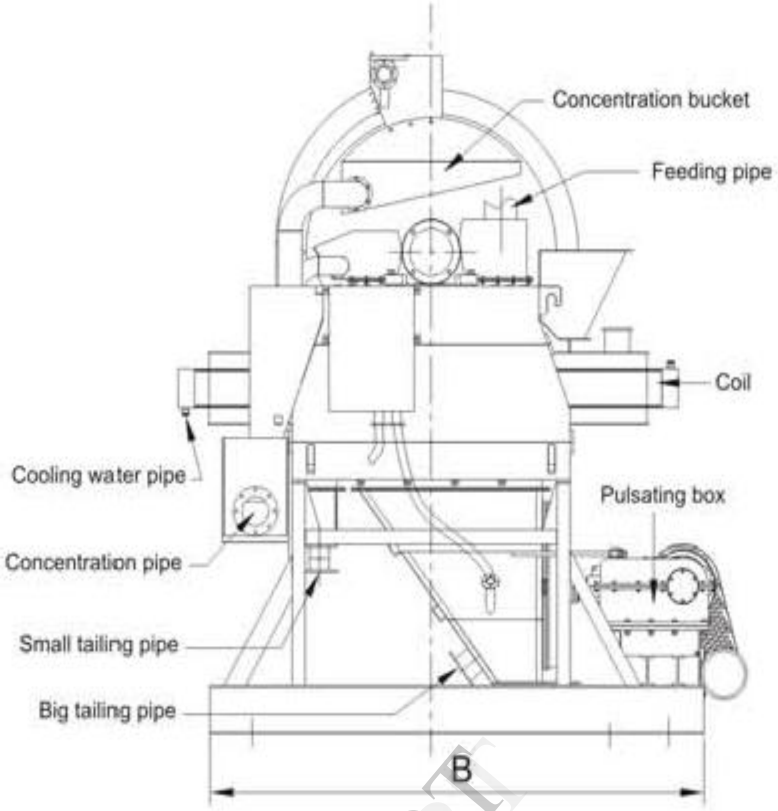


Fig 6: Vertical pulsating high gradient wet high intensity magnetic separator