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Effect of Hydrocyclone Process Parameters on Desliming of Low-Grade Indian Iron Ores with Respect to their Optimum Utilization

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Abstract

Objectives: To ascertain how desliming affects concentration efficiency of low-grade Indian iron ore and how hydrocyclone process parameters affect desliming effectiveness of low-grade iron ores for their optimum utilization. **Methods:** Low grade Indian iron ores viz high aluminous type slime (sample A) and siliceous type BHQ (sample B) assaying 56.3% Fe, 7.64% SiO_2, 5.14% Al_2O_3, 5.34% LOI and 40.5% Fe, 40.6% SiO_2, 0.7% Al_2O_3, 0.5% LOI are used for this study. The samples undergo beneficiation study by employing the techniques like desliming followed by gravity and magnetic separation for the recovery of iron values. **Findings:** Two ores appear to behave differently depending on the process parameters. Desliming followed by gravity separation of the ores increases the separation efficiency of the concentration process for both sample A and sample B. Improved iron recovery and grade observed in case of desliming-cum-gravity separation than that of direct gravity separation. The particle size and mineral are dominating the separation response in case of iron ore slime sample A, while in BHQ sample B the dominating factor is particle size only. The grade of deslimed product (hydrocyclone underflow) increased in case of sample A. The grade of deslimed product did not increase in sample B but the particle sizes are more segregated. sample A can be processed to produce an iron ore concentrate with a 65% Fe content and weight(%) recovery of 42 by adopting desliming followed by gravity separation techniques. An iron ore concentrates of 64% Fe with 25 weight (%) recovery can also be obtained from sample B by adopting the same. **Novelty & Application:** Present investigation establishes the response of different low grade ores in terms of separation with and without desliming. Desliming before concentration will be an easier decision resulting in efficient separation.

Keywords: Iron Ore Slime; BHQ Iron Ore: Desliming; Hydrocyclone; Concentration Efficiency

1 Introduction

India is the fourth largest producer of Iron ore in the world and occupies sixth position in the world iron ore reserves. The steel production in India is expecting an exponential growth and expected to reach 230-240 million ton in next 5 years[(1)]. According to estimation, 1.6 million tons of high-grade iron ore is required to produce 1 million ton of steel. Therefore, the current reserves of iron ore in India may last only for next 10 years. India has huge iron ore resources of 30 billion tons[(2)]. The resources of iron ores like BHQ (Banded Hematite Quartzite), BHJ (Banded Hematite Jasper), BMQ (Banded Magnetite Quartzite) are generally low grade in nature and contains significant amount of gangue minerals. Apart from these low grade resources, India has huge quantities of fines and slimes generated from past mined ore. In the mining process, the iron ore need to be sized before its end use in iron ore industry. The mined iron ore contains surfacial gangue minerals like clay need to be removed prior to its end use. Therefore the sized iron ore is washed in scrubbers to remove the surficial/coated clay. During sizing and washing of iron ore substantial amount of fines and slimes are generated, which also contains significant amount of liberated iron values but end up in tailing ponds. According to an estimation around 10 million tons of slime is generated each year during the iron ore production[(3)]. The low grade iron ore resources like BHQ/ BHJ, BMQ and Iron ore slimes can be utilized for beneficiating the ores for recovery of iron values. Mineral processing is a technology where ores are concentrated by removing the gangue minerals by application of series of processes. Beneficiation of both low-grade iron ores and iron ore dump slimes for producing high-grade iron concentrate may help to overcome the growing demand of iron ore.

In general Iron ores of India consists of major iron bearing minerals like hematite, goethite and martitized magnetite. The major gangue minerals include aluminous clay, gibbsite and quartz which makes it difficult for iron ore to be directly used in iron and steel making[(4)]. For separation of iron bearing minerals, the minerals must be liberated from gangue minerals. In order to achieve liberation, the ore has to be crushed and ground to specific sizes. In some of the cases the liberation of gangue minerals like quartz and clay from iron bearing minerals are in extremely fine sizes (70-100 μm). The characteristics of Indian iron ore are broadly classified according to the iron bearing and gangue bearing minerals present in the ore. Some of them are high aluminous ore, high siliceous ore and magnetite ore respectively. Gravity separation is widely used in mineral beneficiation practices for its low-cost, ease of operation, easy to control, and eco-friendly nature[(5–7)]. Its performance can be characterized by the split of the particles from a feed stream to a concentrate or heavy particles stream[(8,9)]. It also remains the main concentrating method for iron ore due to the specific gravity difference between iron bearing minerals (5-5.5 g/cc) and gangue minerals (2.5-2.8 g/cc). Gravity separators are extremely sensitive to the presence of slimes (mostly alumina and silica in the size fraction less than 20 μm) which increase the viscosity of the slurry and hence reduce the sharpness of separation[(8,10,11)]. The beneficiation strategy of iron ore depends upon the mineralogy and characteristics of iron bearing mineral and the gangue mineral associated with it. Nevertheless, throughout the mineral processing stages, particularly during gravity separation processes, particle size segregation poses a substantial problem. To achieve the highest level of separation efficiency, proper particle size segregation is crucial. To address this issue, hydrocyclones are employed as mineral processing equipment for classification and desliming based on particle size and specific gravity. In past, several researchers studied the potential of Indian low grade iron ore utilization by beneficiation[(12–15)]. However very few of them addressed the effect of process parameters on desliming and its implications on separation efficiency.

The researchers like Pani et al[(12)] studied the beneficiation characteristics of Indian iron ore slime. They established the interactive effect of process parameters on desliming response of hydrocyclone. However they have not studied the desliming effect of other low grade ores like BHQ and BMQ. They also did not report the influence of desliming in the gravity separation process like tabling in terms of concentration efficiency. Muthaimanoj and Mukhapadhyay[(16)] carried out the low grade iron ore beneficiation through hydrocyclone. They did not study the effect of process parameters on hydrocyclone process and the effect of desliming on gravity separation process. Nanda et el[(13)] studied the beneficiation response of BHQ iron ore, however they fail to explain the process parameters related to hydrocyclone influencing the desliming process. The hydrocyclone process parameters for iron ore slime beneficiation were recently researched by the researchers Padhi et al.[(17)], although they only concentrated on hydrocyclone design and flow parameters but they were unable to answer the effect of desliming for the concentration of ores like BHQ and the concentration efficiency. The features of Iron ore slimes and their influence on the flotation process were examined by Lima et al[(18)] & it was observed that the presence of ultrafine particles (less than 10 μm) significantly hampers the flotation process response. However neither did they remove the ultrafine particles through desliming nor studied the desliming response. A combination of magnetization roasting and magnetic separation was proposed by Yuan et al[(19)] but roasting process is extremely expensive and also proves detrimental to environment. They also did not study the effect of desliming on magnetic separation process.

The objective of the current investigation is to explore the effect of hydrocyclone process parameters on desliming of Indian low grade iron ores. Additionally, the impact of desliming on the gravity separation process for producing iron ore concentrate appropriate for commercial use from different low grade iron ores (Slime and BHQ).

2 Methodology

Two different low grade Indian iron ore samples of different nature viz iron ore slime (sample A) and BHQ (sample B) were used for the study. The characterization study of the samples was done by chemical as well as mineralogical techniques. After characterization study the beneficiation potential for iron values of two samples were studied. The concentration efficiency for the two samples were studied for process like desliming followed by gravity separation. The different process parameters of desliming by hydrocyclone were also studied.

2.1 Materials

Representative high aluminous type low grade dump iron ore slimes (sample A) and siliceous iron ore of Banded Hematite Quartz (BHQ) type (sample B) weighing around 100 kilogram each from eastern part of India were used for the study. The images of sample A and sample B are given in Figure 1 (a) & (b) respectively.

2.2 Methods

The Run of Mine (ROM) sample A of size around -0.2 mm (200 μm) was thoroughly mixed and homogenized, and representative sample was drawn for chemical analysis, characterization and other processing studies. Similarly ROM of sample B of around 100 mm size was drawn by crushing, riffling/coning and quartering to -0.2 mm size. The crushed sample of -0.2 mm size (sample B) was thoroughly mixed and homogenized, and representative sample was drawn for chemical analysis, characterization and other processing studies. Representative portions of ROM samples and beneficiation products were drawn and ground to a size below 74μm for X-ray Fluorescence (XRF) and X-ray diffraction (XRD) analysis.

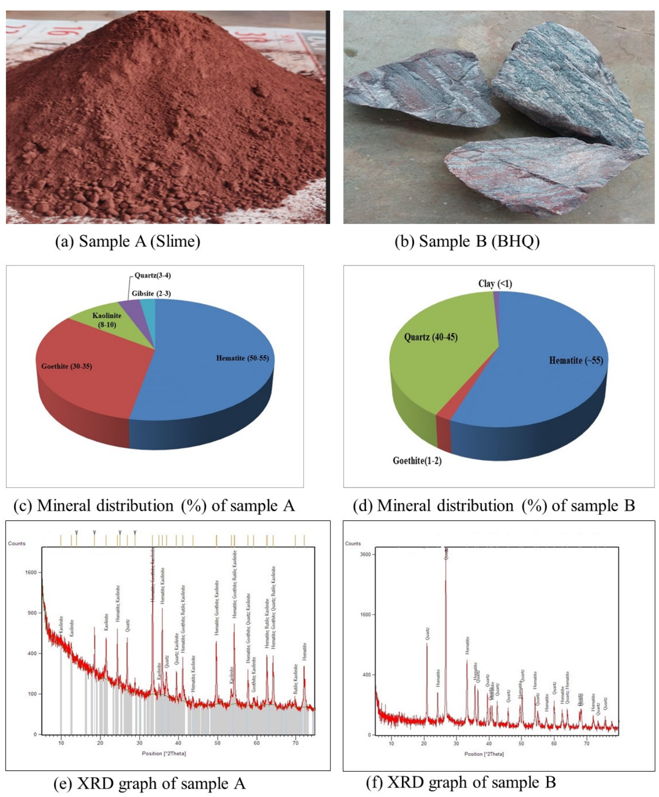


Fig 1. Sample A (Slime) and sample B (BHQ) (Megascopic Image, Mineral distribution (%) & XRD graphs)

2.3 Chemical and mineralogical analysis

The chemical composition of both study samples and their beneficiated products were done by using the XRF instrumental techniques. The Loss on Ignition (LOI) was carried out by conventional pyro metallurgical weight difference technique.

The mineralogical characterization study of the sample was done by optical microscopy and XRD techniques. As received representative ROM samples of 200 μm size were studied for mineral (%) by optical microscopy on Leica DM-750P microscope. The distribution (%) of minerals were determined by using grain counting method. Similarly the XRD studies were carried out by PanAnalytical X-pert PRO instrument. The X-ray scanning on both the sample A & sample B were carried out from 5° 2θ to 80° 2θ with constant scanning speed approximately 10° 2θ / minute. The characteristic X-ray data for the mineral phases present in the sample A & sample B were obtained in the form of peaks with relative intensities, angle of the peaks in 2θ with their respective d values (inter-atomic spacing) in Angstrom units which are given in Figure 1 (e) & (f) respectively. The X-ray data obtained on the sample was interpreted by using diagnostic patterns of standard minerals given in JCPDS (Joint Committee on Powder Diffraction Standards)[(20)].

2.4 Beneficiation study

The study sample was subjected to different beneficiation studies like size reduction, screening, classification, gravity separation and magnetic separation respectively. The sample A was subjected to particle size analysis by wet sieve analysis followed by cyclosizing in Warman cyclosizer. A representative batch of sample was subjected to wet size analysis through different BSS (British standard sieves) standard sieves from 150 μm to 63 μm size. The representative portion of -63 μm size product was subjected to Warman cyclosizer. The sieve fractions and cyclosizer products were weighed and analyzed for its chemical constituents. From the chemical analysis data, distribution of iron bearing minerals along with gangues at different size fractions was determined. Similarly sample B was crushed and ground to 150 μm to achieve the adequate liberation. The crushed and ground sample was subjected to particle size analysis under similar conditions as was for the sample A. After size analysis, both the samples were subjected to gravity separation with desliming and without desliming in a Diester Concentrating Table.

The desliming study was carried out in a 2 inch Mozley Hydrocyclone by varying different parameters like apex opening and slurry pressure respectively. The other process parameters like pulp density of the slurry fed to hydrocyclone and the diameter of vortex finder were constant. The conditions I and II are given in Table 1 . The process response in terms of grade of iron and weight(%) recovery of iron were studied against various combination of process parameters of hydrocyclone. The desliming process parameters were optimized according to process response. The products of hydrocyclone were hydrocyclone underflow (U/F) which was deslimed product and hydrocyclone overflow (O/F). The hydrocyclone underflow was further subjected to gravity separation study for recovery of iron values. The study was carried out on a Diester Concentrating Table according to the parameters given in Table 1 . The process parameters are kept constant for both sample A and sample B. The products of gravity separation were labelled as table concentrate, table middling and table tail.

Table 1. Conditions for Hydrocyclone Parameters for Sample-A and Sample-B

Condition	Constant Parameter	Variable Parameter	Process Response
Condition I	Vortex Finder = 14mm Pressure = 20 psi Pulp Density =15% Solid	Apex Opening 3 mm to 7mm	Fe(%) in Underflow Wt (%) in Underflow Wt(%) in Overflow Particle size in micron for overflow at 60% Passing
Condition II	Vortex Finder = 14mm Apex Opening=5mm Pulp Density =15% Solid	Pressure 8 psi to 20 psi	

To recover the iron value from table middling and hydrocyclone overflow for both sample A and sample B, the representative portion of these products mixed together were subjected to magnetic separation on a Wet High Intensity Magnetic Separator. The products obtained were labelled as magnetics and non- magnetics. The magnetic intensity was kept constant at 1.5 Tesla. After each beneficiation process, the product samples were dried, homogenized and analysed chemically. The results of all the above tests are discussed in subsequent sections.

3 Results and Discussion

3.1 Chemical and mineralogical characteristic of original sample

The bulk ROM of sample A assayed 56.3% Fe, 7.64% SiO_2, 5.14% Al_2O_3, 5.34% LOIand sample B assayed 40.5% Fe, 40.6% SiO_2, 0.7% Al_2O_3, 0.5% LOI (Table 2). From the megascopic observation, it was found that the sample B is banded with alternating layers of hematite and quartz, and the band thickness of iron varies from 200 μm to 500 μm in size. The average band thickness of iron layer in the study sample B is around 200 μm. Therefore for beneficiation, the sample B was crushed to -150 μm size to liberate the iron bearing layer but in case of sample A it was directly subjected to beneficiation.

Table 2. Chemical Assay of Sample A and Sample B

Sample	Assay (%)			
	Fe	SiO_2	Al_2O_3	LOI
Sample A (Iron Ore Slime)	56.30	7.64	5.14	5.34
Sample B (BHQ Iron Ore)	40.50	40.6	0.7	0.5

The iron ore study samples, sample A and sample B was subjected to mineralogical characterization by microscopic and XRD study. From the characterization studies, it was revealed that sample A consists of major amounts of hematite and goethite/limonite with subordinate amounts of clay minerals. The other minerals like gibbsite and quartz were also found in minor to trace amount whereas the sample B consists mainly of quartz and hematite with very minor amounts of goethite and clay. The distribution (%) of minerals for sample A and sample B are also given in Figure 1 (c) & (d).

According to the microscopic examination, 70 to 80% iron bearing minerals (hematite and goethite) liberate from silicate gangue at 150 μm size, and the remaining 20 to 30% iron bearing minerals were intermixed/interlocked with gangues in sample A. It was found that in the case of sample B, around 60% of the iron bearing minerals are liberated at 150 μm size, while the remaining 40% are interlocked/intermixed with quartz.

The X-Ray Diffraction (XRD) study reveals that the sample A (Figure 1 (e)) mainly consists of mineral phases like hematite, goethite and kaolinite whereas in the sample B it is dominated by hematite and quartz (Figure 1 (f)). The presence of goethite and clay (kaolinite) in sample B is identified by microscopic studies. However, these phases (goethite and kaolinite) were not identified in the XRD study because of their occurrence in lower concentration level and poor crystallinity nature.

3.2 Beneficiation study

3.2.1 Particle size analysis

The representative portion of ROM sample A undergoes particle size analysis. Similarly for sample B, it was ground to all -150 μm and subjected to particle size analysis. The results of particle size analysis are given in Figure 2.

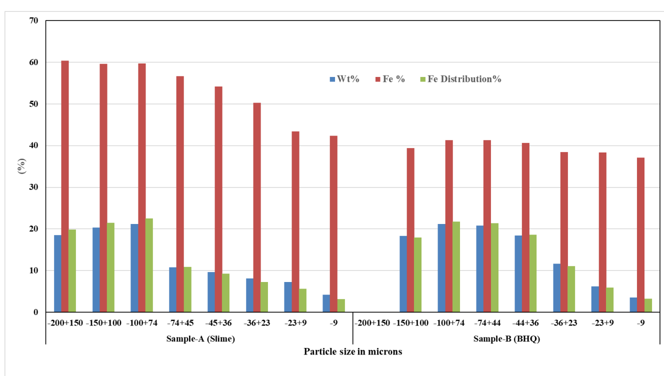
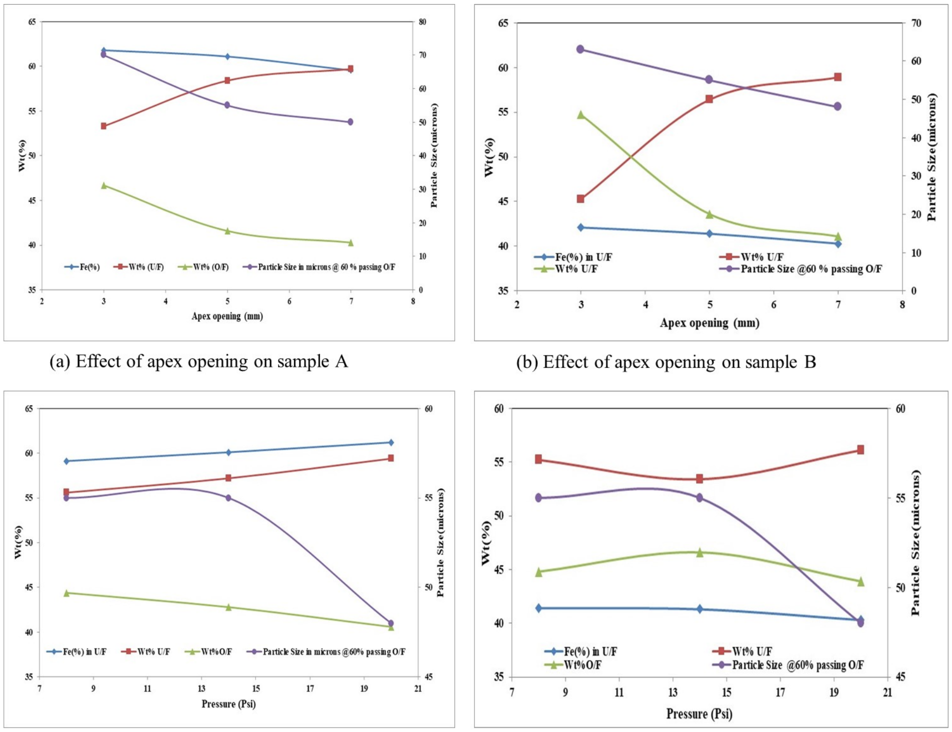


Fig 2. Particle Size analysis of ROM Sample A (Slime) and Sample B (-150 μm) (BHQ)

From the size analysis data, it was evident that 80% of sample A as well as sample B passes through 150 μm. For sample A, it was observed that the grade of iron decreases with decrease in particle sizes. The majority of iron was distributed in coarser size fractions (-200+150 μm) than that of ultra-fine fractions (-44μm). This is due to the enrichment of iron bearing minerals at coarser sizes. For sample B, the grade of iron is almost same in all of the size fractions. There is very little or no enrichment of iron in the coarser and finer fractions. This is due to the difference in hardness of quartz and iron minerals.

3.2.2 Desliming study of sample A and sample B in hydrocyclone

The sample A and sample B both were subjected to desliming on a 2 inch Mozeley Hydrocyclone. The conditions of hyodrocyclone process parameters are given in Table 1. According to condition I, apex opening was varied from 3mm to 7mm whereas feed pressure and vortex finder was constant at 20 psi and 14mm respectively. After optimization of apex opening, experiment with condition II was carried out i.e. feed pressure was varied from 8 psi to 20 psi whereas apex opening and vortex finder was constant at 5mm and 14mm respectively. The response of sample A and sample B in terms of grade of Fe(%), weight(%) recovery and Particle size (μm) are presented in Figure 3. The results of hydrocyclone test for sample A and sample B with Optimized parameters are presented in Table 1.



(a) Effect of apex opening on sample A

(b) Effect of apex opening on sample B

(c) Effect of pressure on sample A

(d) Effect of pressure on sample B

Fig 3. Desliming response of Sample A and Sample B with variable Apex opening and Pressure

3.2.2.1 Effect of apex opening. The effect of apex opening was studied for the responses and the results are also given in Figure 3. It was observed that when the apex opening increases, the grade of Fe(%) in the hydrocyclone underflow decreases, the weight(%) recovery in hydrocyclone underflow increases. This is because most (iron and silica) particles report to the underflow, which increases weight(%) recovery but grade of Fe(%) decreases. The above trend is similar for both sample A and sample B. This is in line with the previously addressed research papers[21]. The particle size (60% passing) decreases in overflow with increase in apex opening in both sample A and sample B. For sample A, this is caused due to the presence of gangue mineral clay and cryptocrystalline goethite at ultrafine sizes. The increased apex opening also cause fines reporting to the underflow, resulting in comparatively much fines reporting to the overflow. The grade of Fe(%) is similar in hydrocyclone overflow and underflow in sample B. This is due to the particle breakage characteristics caused by the hardness of the sample B. The sample contains quartz as gangue minerals and hematite as iron bearing mineral. The hematite grains breaks faster than that of quartz grains due to difference in hardness of hematite and quartz. Here particle size plays an important role than that of gravity due to the particle breakage characteristic of hematite and quartz. According to concentration ratio, the larger particle of quartz possesses same settling velocity as that of smaller sized hematite[8]. More number of larger quartz reporting to the underflow along with smaller sized hematite mineral resulting very minimal or no change in grade of Fe(%) in the overflow and underflow. These results confirms with the outcomes of the study carried out by Nanda et. al[13].

3.2.2.2 Effect of Pressure. The effect of pressure on process parameters for different responses in the desliming of sample A and sample B are also given in Figure 3. It is evident that, for sample A more number of iron bearing particles with higher specific gravity report to the underflow, therefore the grade of Fe(%) and weight(%) yield increases simultaneously with increase in pressure. These results confirms with the outcomes of the study carried out by Padhi et. al[22] for iron ore slime. However the same effect was not studied for BHQ ore. For sample B grade of Fe(%), the hydrocyclone underflow nearly remains constant with increase in pressure, but weight(%) yield first increases and then slightly declines with pressure. These results slightly deviate from the previously published research articles[17,22]. For overflow particle size (60 percent passing), it increases modestly in the begining before falling off suddenly. This is due to the particle breakage characteristic of the minerals (hematite and quartz) present in BHQ iron ore.

The process parameters were optimized at 14mm vortex finder, 5mm apex opening and 20 psi pressure and the results are given in Table 3. From Table 3, it can be observed that hydrocyclone underflow and overflow obtained from desliming of sample A assayed 61.21% Fe, 49.51% Fe with 59.4 weight(%) recovery and 39.5 weight(%) yield respectively. Similarly for sample B the hydrocyclone underflow and overflow obtained assayed 40.32% Fe, 40.53% Fe with 56.1 weight(%) recovery and 43.9 weight(%) yield. It was observed that there is no difference in grade of Fe(%) for hydrocyclone overflow and underflow in case of sample B. While for sample A there is huge difference in grade of Fe(%) in overflow and underflow. In case of sample A, gravity as well as classification occurs while in sample B only classification plays an important role. The calculation for cut size of hydrocyclone test for sample A and sample B was done according to the procedure developed by Lynch et. al[23] and the results are given in Figure 4.

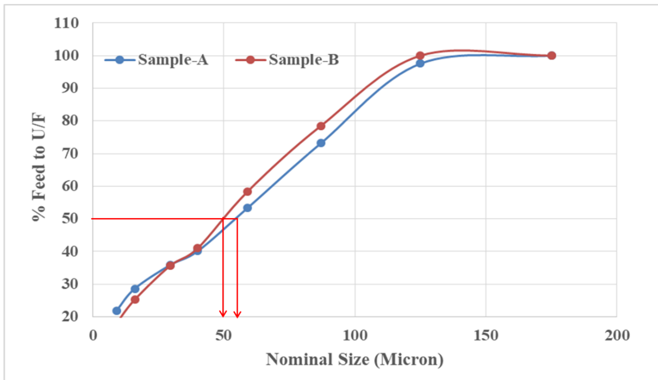


Fig 4. Result of cut point analysis of optimized hydrocyclone test

Table 3. Results of Hydrocyclone Study and Gravity separation study for Sample A and Sample B with Optimized parameters

Parameters (Hydrocyclone)	**Sample**	**Results**					
		Products	**Wt%**	**Fe%**	**SiO_2 %**	**Al_2O_3 %**	**LOI%**
Vortex Finder= 14mm Apex Opening=5mm Pressure=20 Psi Pulp density=15% Solids	Sample A	Hy Underflow	59.4	61.21	4.88	2.38	4.26
		Hy Overflow	49.5	49.51	10.85	9.66	7.11
		Head (Cal)	**100**	**56.53**	**7.30**	**5.31**	**5.42**
	Sample B	Hy Underflow	56.1	40.32	41.15	0.21	0.33
		Hy Overflow	43.9	40.53	41.33	0.38	0.35
		Head (Cal)	**100**	**56.51**	**41.23**	**0.28**	**0.34**
Parameters (Gravity Separation)	**Sample**	**Results**					
		Products	**Wt%**	**Fe%**	**SiO_2 %**	**Al_2O_3 %**	**LOI%**
Feed Rate:5kg/hr Water Rate:5ltr/min Deck Amplitude:3mm Wash Water rate: 3ltr/min	Sample A	Table Concentrate	42.6	65.12	2.11	1.1	3.50
		Table Middling	15.3	52.30	9.91	5.21	8.81
		Table Tail	1.5	42.22	17.10	11.50	9.20
		Head (Calc)	**59.4**	**61.24**	**4.50**	**2.42**	**5.01**
	Sample B	Table Concentrate	25.6	64.34	5.11	0.45	0.40
		Table Middling	10.3	37.32	44.31	0.40	0.51
		Table Tail	20.2	11.22	82.33	0.49	0.50
		Head (Calc)	**56.1**	**40.25**	**40.11**	**0.46**	**0.45**

From the hydrocyclone cut point study it reveals that the cut point of sample A is 54 μm whereas the cut point of sample B is 50 μm respectively. Thus, it concludes that the sample B has a sharp cut point (D_{50}) than that of sample A. This is due to the crystalline nature of iron bearing minerals and gangue minerals present in sample B. Also sample A has particles with cryptocrystalline nature for iron bearing goethites and silicates bearing clay minerals.

3.2.3 Gravity separation study with and without desliming for both sample A and sample B

The hydrocyclone underflow obtained from desliming of sample A and sample B was subjected to gravity separation study on a Diester Concentrating Table. The sample A and sample B were ground to -150 μm and the ground samples also subjected to gravity separation by tabling separately. The results of tabling were analyzed in terms of weight(%) yield and grade of Fe(%) for products table concentrate, table middling and table tail respectively. The concentration efficiency for the process was calculated according to the equation given in books authored by Wills and Napier-Munn[8]. The equation for evaluation of concentration efficiency is as follows,

$$CE\,(\%) = \frac{W*(C-f)*C_{max}}{f*(C_{max}-f)}$$

where CE(%) is the concentration efficiency, C is the grade of iron in the concentrate, f is the grade of iron in feed, C_{max} is the maximum (theoretical) Fe(%) in concentrate and W is the weight(%) yield of concentrate obtained. C_{max} (maximum theoretical yield) values of 68% and & 70% are taken for sample A (contains hematite and goethite as major iron bearing minerals) and sample B (contains only hematite as major iron bearing mineral) separately. The results were compared and analyzed according to the optimized parameters. The results obtained from gravity separation study with desliming and without desliming are given in Figure 5.

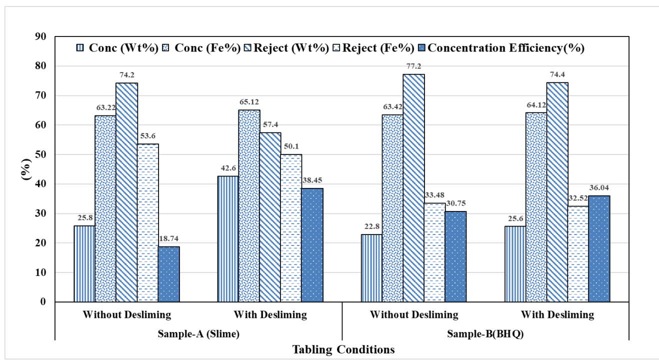


Fig 5. Results of Gravity Separation Study with desliming and without desliming for Sample A and Sample B

From Figure 5 it can be observed the gravity separation study with desliming gives better results than that of without desliming in case of both sample A and sample B. A concentrate grade of 65.12% Fe with 42.6 weight(%) yield can be obtained from sample A with desliming. Similarly results for same sample without desliming assayed 63.22% Fe with weight(%) yield of 25.8. The concentration efficiency of Gravity separation process conducted on a Diester Concentrating Table also increases from 18.74% to 38.45% for sample A with desliming. The sample B shows similar response for concentration efficiency and grade of Fe(%). A concentrate of 64.12% Fe with 25.6 weight(%) yield can be obtained from desliming followed by tabling of sample B (BHQ). The concentration efficiency of gravity separation process for sample B increases from 30.75 to 36.04 with desliming. The researchers Padhi et al.[17], did not study the effect of desliming on gravity concentration of iron ores. This study concludes that desliming considerably improves concentration efficiency.

After observation of all the results, the gravity separation study was carried out with desliming for sample A and sample B under similar condition as that of above. The Gravity separation study results for sample A and sample B is given in Table 3.

It can be observed from Table 3 that the table concentrate of sample A, assayed 65.12% Fe, 2.11% SiO_2,1.1% Al_2O_3 and 3.50% LOI with weight(%) yield of 42.6%. Similarly the table concentrate of sample B assayed 64.34% Fe, 5.11% SiO_2,0.45% Al_2O_3, and 0.40% LOI with weight(%) yield of 25.6%. The table tails of sample A, assayed 42.22% Fe, 17.10% SiO_2,11.50% Al_2O_3, and 9.20% LOI with weight(%) yield of 1.5% (Table-3). The table tails of sample B assayed 11.22% Fe, 82.33% SiO_2,0.49% Al_2O_3, and 0.50% LOI with weight(%) yield of 20.2%. Both the tails of sample A and sample B were considered as reject/dump since the iron content was found to be below threshold value (45% for aluminous type of iron ore and 35% for siliceous type of iron ore) specified by Indian Bureau of Mines[24].

3.2.4 Magnetic separation Study

It was also observed from Table 3 that there are significant losses of iron values in the table middling and hydrocyclone overflow in both sample A and B. To recover these iron value, the representative portion of these products mixed together were subjected to magnetic separation on a Wet High Intensity Magnetic Separator at 1.5 Tesla.

From the results of Magnetic separation study, it was concluded that the magnetic products of sample A assayed 60.44% Fe, 4.47% SiO_2,2.51% Al_2O_3 and 5.45% LOI with weight(%) yield of 18.5%. Similarly, the magnetic concentrate of sample B assayed 55.43% Fe, 19.34% SiO_2,0.43% Al_2O_3, and 0.37% LOI with weight(%) yield of 21.9%. The non-magnetics of sample A, assayed 44.40% Fe, 13.84% SiO_2,11.26% Al_2O_3, and 8.33% LOI with weight(%) yield of 37.4%. The non-magnetics of sample B assayed 29.72% Fe, 56.13% SiO_2,0.35% Al_2O_3, and 0.34% LOI with weight(%) yield of 32.3. These magnetic products should find its utilization as ore feedstock by blending with high grade ore.

3.2.5 Summarized results of beneficiation

Table 4 lists the findings for all tests conducted to determinebeneficiation potential of sample A and sample B. It was observed that sample A can be converted into an iron ore concentrate with an assay of 65.12% Fe, 2.11% SiO_2, and 1.10% Al_2O_3 with weight(%) yield of 42.6. From sample A, a subgrade comprising of magnetic product assayed 60.44% Fe, 4.47% SiO_2, 2.57% Al_2O_3 withweight(%) yield of 18.5 can also be recovered. The reject comprising of non-magnetics of sample A assayed 44.32% Fe, 13.97% SiO_2, 11.27% Al_2O_3 withweight(%) yield of 38.9 and can be discarded due to its low iron content.

Table 4. Summarized results

Sample	Results					
	Products	**Wt%**	**Fe%**	**SiO_2 %**	**Al_2O_3 %**	**LOI%**
Sample A	Concentrate	42.6	65.12	2.11	1.10	3.50
	Subgrade	18.5	60.44	4.47	2.51	5.45
	Reject	38.9	44.32	13.97	11.27	8.36
	Head (Calc)	**100**	**56.16**	**7.16**	**5.32**	**5.75**
Sample B	Concentrate	25.6	64.34	5.11	0.45	0.40
	Subgrade	21.9	55.43	19.34	0.43	0.37
	Reject	52.5	22.60	66.21	0.40	0.40
	Head (Calc)	**100**	**40.48**	**40.30**	**0.42**	**0.39**

In case of sample B, the concentrate comprising of table concentrate assayed 64.34% Fe, 5.11% SiO_2,0.45% Al_2O_3, and 0.40% LOI with weight(%) yield of 25.6% can be utilized in iron ore industries. The subgrade comprising of magnetic products assayed 55.43% Fe, 19.34% SiO_2,0.43% Al_2O_3, and 0.37% LOI with weight(%) yield of 21.9% are obtained. The reject comprising of table tail and nonmagnetic assayed 22.60% Fe, 66.21% SiO_2,0.40% Al_2O_3, and 0.40% LOI with weight(%) yield of 52.5% can be dumped due to its low iron content. The developed process flowsheet for both the sample A and sample B with complete material balance is given in Figure 6.

4 Conclusion

The desliming is an important process in iron ore beneficiation at fine sizes. Desliming of iron ores improves the concentration efficiency of downstream gravity separation process by segregating the particle sizes. According to the findings in the study above, sample A and sample B displayed different behaviors based on different experimental conditions and parameters employed in the current study. The concentration method for both ore samples was found to be more effective when desliming was followed by gravity separation. A notable difference between direct gravity separation and desliming-cum-gravity separation was observed with the improvement in iron recovery and grade. The gravity and particle size plays a dominant role in the desliming of sample A by employing hydrocyclone. In case of sample B the particle size only plays an important role in the desliming operation by employing hydrocyclone. The concentrate assaying 65.12% Fe, 2.11% SiO_2, 1.10% Al_2O_3 can be recovered from sample A. Similarly, concentrate assaying 64.34% Fe, 5.11% SiO_2, 0.45 % Al_2O_3 can also be recovered from low grade sample B. The particle size segregation behavior in case of BHQ ore need to be addressed in future research. The innovative aspect of this study is the thorough evaluation of grade, recovery, and concentration efficiency in relation to the effects of hydrocyclone (desliming) process parameters. These findings have important practical ramifications since they offer helpful advice to the Indian iron ore sector on how to best beneficiate low-grade iron ores. The industry may boost iron recovery rates, increase efficiency, and improve the quality of the iron ore concentrates produced by implementing the desliming and gravity separation procedures described in the current study. These discoveries hold great promise for the iron ore sector, opening the door to more effective and environment friendly iron ore extraction and use.

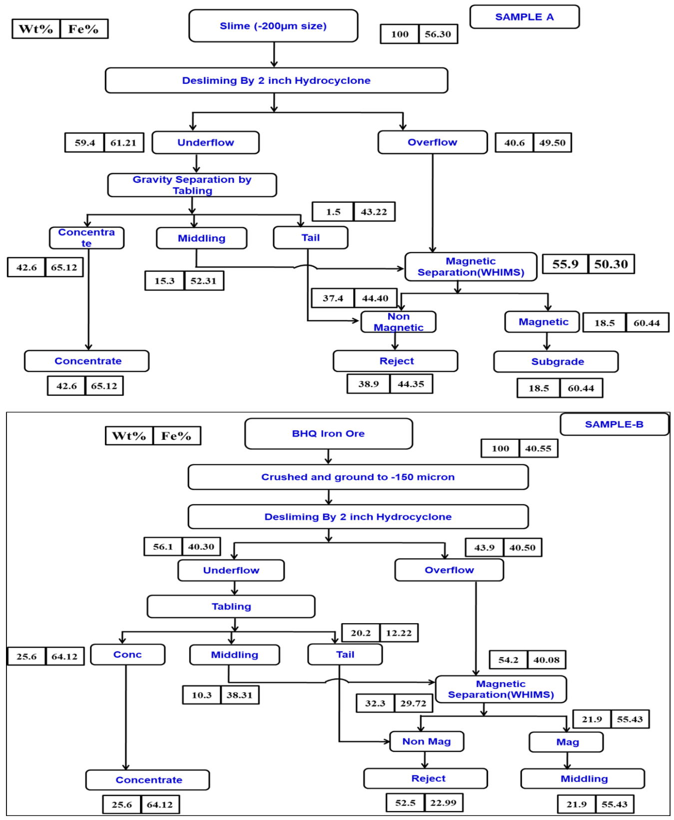


Fig 6. Developed process flow sheets for Beneficiation of iron ore slime (Sample A) & BHQ (Sample B)

Recommendation

It can be noted that for sample B (BHQ) there is no significant improvement of iron grades in cyclone underflow after desliming. However, the concentration efficiency of the gravity separation process increases significantly. This is due to the particle size segregation characteristics of BHQ ore. The particle size segregation behavior in case of BHQ ore need to be addressed in future research.

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