Enhanced Recovery of Iron Values from Low-Grade Ores and Tailings through Reverse Cationic Flotation

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Abstract

India is well-known for its rich deposits of high-quality hematite ores, making it a vital player in the global market. As the availability of high-grade iron ores diminishes, the need to process low-grade ores, fines and slimes through beneficiation is becoming increasingly important to meet market requirements. The creation of fines and slimes leads to a mineral loss of about 20 to 25% of the overall mineral value during processing. This research investigates the beneficiation of iron ore tailings using reverse cationic flotation, with Sokem reagent acting as a collector and starch serving as a depressant. A series of comparative assessments involving magnetic separation and gravity separation were performed. An initial mineralogical examination showed that hematite and goethite were the main iron-bearing minerals, accompanied by quartz and kaolinite as significant gangue materials.

The selective flocculation technique proved effective, enhancing the iron grade from 41.05% to 57.03% Fe, with a recovery rate of 47.35%. After desliming, the outcomes improved further, yielding 58.25% Fe and a recovery of 29.00%. These results underline the potential for successful beneficiation of iron ore tailings, offering valuable insights for enhancing the recovery of high-grade iron from low-grade ores and reducing mineral losses during processing.

Keywords: Iron Ore, Low-Grade Ores, Flotation, Tailings Recovery.

Introduction

The accumulation of iron ore tailings as waste poses significant economic burdens for waste management and raises environmental concerns, along with associated sefety risks[5,14]. In response, the iron ore industry employs reverse cationic flotation as a primary process to yield a hematite concentrate[1,4]. This technique involves floating quartz and kaolinite, the principal gangue minerals, with cationic collectors. Unfortunately, during magnetic separation, a considerable proportion of the iron-bearing values is lost to tailings due to their perceived weak magnetic properties. In some cases, beneficiation processes result in the generation of excessive amounts of slime. Nevertheless, this fine fraction, commonly referred to as the tailing of the process, can be deemed as low-grade iron ores owing to their iron content. Given the increasing global demand for iron ore, despite the acknowledgment of iron ore tailings as secondary resources for industries such as ceramics and cement admixture, there is a pressing need to recover and reuse iron from these tailings. Various beneficiation methods, including gravity concentration techniques such as tabling, jigging, teetered bed separators (TBS), spiral or enhanced gravity separators, magnetic separation on dry/wet basis and flotation, are commonly employed for low-grade iron ores[13]. The feasibility of recovery and grade values is contingent upon the iron, silica and alumina content, as well as the liberation statements of these minerals.

Early mining activities predominantly targeted high-grade deposits, initially obviating the need for sophisticated beneficiation. However, as these deposits were depleted due to heightened consumption, advanced techniques became imperative to enhance ore recovery and to ensure the rational utilization of reserves. The environmental and economic advantages of recovering iron minerals from tailings have been highlighted. Processes involving wet high-intensity magnetic separation (WHIMS) and cationic reverse flotation to concentrate iron ore tailings have been developed.

The relationship between particle size and flotation efficiency, emphasizing the influence of collision efficiency and adhesion efficiency on mineral hydrophobicity and particle size, has been explored. The traditional view that very fine particles do not float, has been challenged, advocating for grinding below 10 μm for optimal liberation[6]. Their proposed design principles emphasized for achieving efficient liberation, appropriate grinding methods, understanding the role of classification and floating minerals in narrow size distributions.

The current study centers on reverse cationic flotation for concentrating iron ore slimes, with the goal of producing an ultrafine concentrate suitable for blending with traditional pellet feed fines. Despite a notable contaminant content, the iron grade in fractions below 18 μm reaches 50%, exhibiting excellent liberation. Blending the ultrafine concentrate with pellet feed fines is anticipated to enhance specific surface area, to reduce energy consumption during regrinding and to confer environmental and economic benefits by extending the life of tailings ponds.

Material and Methods

The representative samples were obtained from iron ore beneficiation plant. The tailing samples were generated after treating in multiple beneficiation process like spiral concentrator and HGMS. Size analysis was determined using the Helos particle size analyser. Mineralogical studies were carried out to identify the major mineral phases present in the iron ore tailings. X-ray diffraction (XRD) and Scanning electron microscopy (SEM) were employed for detailed mineralogical characterization. The reverse cationic flotation process was employed to beneficiate the iron ore tailings[9,11]. The flotation experiments were conducted in a laboratory flotation cell and the Sokem reagent was used as the collector, while starch served as the depressant.

The tailings were subjected to both dry and wet magnetic separation using a magnetic separator. Gravity separation method, spiral concentration was employed to concentrate the iron ore tailings. Experimental design and statistical analyses were used to optimize recovery and grade. Quality control measures ensured reliability. Overall, this comprehensive approach provides insights into the potential for sustainable iron recovery from these tailings.

Results and Discussion

Characterisation studies: The sample contains 41.05% Fe, 19.05% SiO_2, 13.34% Al_2O_3 and 8.1% loss on ignition (LOI). Figure 1 shows the particle size distribution, revealing that particles below 10 microns constitute 78.63% by weight. This observation suggests the presence of a significant proportion of ultrafine particles in the tailings.

Mineralogical studies: Microscopic studies were conducted on the tailings sample, revealing hematite as the predominant mineral, accompanied by subordinate amounts of goethite. Quartz and kaolinite emerged as major gangue minerals. Hematite particles exhibited a bright color while red particles were indicative of goethite. Kaolinite and quartz minerals were identified as black and dark brownish particles respectively. Micrographs highlighted the finely disseminated nature of mineral particles, with many existing in a liberated form.

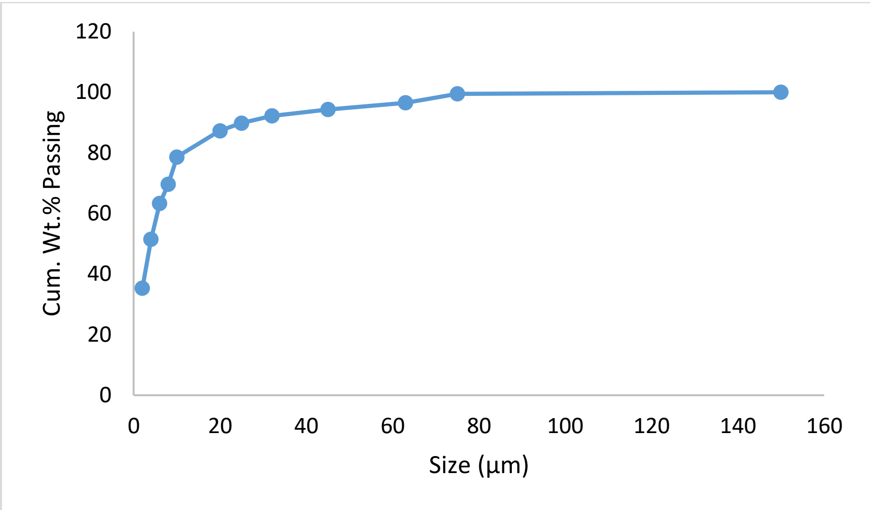

Figure 1: Particle size distribution of the Tailing sample

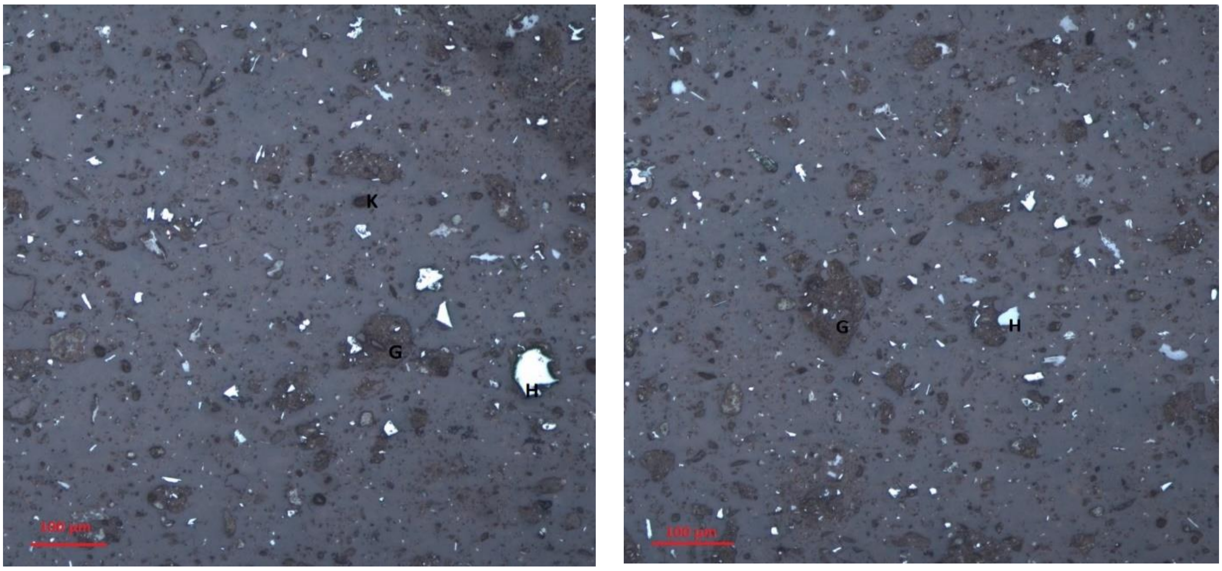

Figure 2: Optical micrographs of Tailing samples sample

X-ray diffraction (XRD) analysis (Figure 3) presented a typical diffraction pattern of the slimes. The results indicated the presence of major iron-bearing minerals, predominantly hematite (50.02%), followed by goethite (10.9%). Additionally, gangue minerals such as kaolinite (17.2%), quartz (12.98%) and gibbsite (8.9%) were identified in descending order of abundance in the slimes sample.

Gravity separation: Gravity separation studies were conducted using a spiral concentrator to assess its effectiveness in separating ultra-fine particles in the tailings sample[7]. The findings revealed a modest improvement in iron content, increasing from 41.05% to 54.36%, with a corresponding yield of 21.85%. However, the results suggest that gravity separation exhibited limited effectiveness in treating tailings with a high proportion of ultra-fine particles. Despite the increase in iron content in the concentrate, the relatively low yield indicates the challenges associated with achieving effective gravity separation for tailings containing a substantial proportion of ultra-fine particles.

Magnetic separation: The slime fraction processed by wet high-intensity magnetic separation is to explore the potential for upgrading. A series of tests were conducted by varying the magnetic intensity, while maintaining a constant pulp density of solids at 15% by weight. The magnetic field intensities selected for the present study were 4000, 6000, 8000 and 10000 gauss respectively. The objective was to investigate the impact of magnetic field intensity on iron value improvement and yield. Table 2 provides a detailed breakdown of the magnetic separation results for different field intensities.

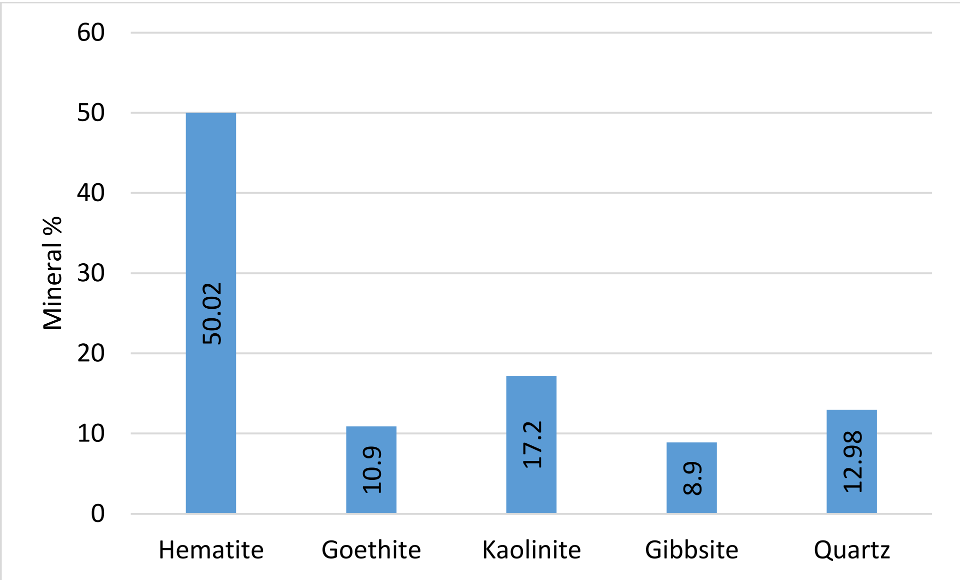

Figure 3: XRD phase analysis of the iron ore tailing

Table 1
Gravity separation of tailing sample

Product	Wt.%	Fe	SiO_2	Al_2O_3
Feed	100	41.05	19.05	13.34
Concentrate	21.85	54.36	8.21	8.32
Tailing	78.15	37.33	22.09	14.82

Table 2
Magnetic separation studies of tailing sample

Magnetic Field	Product	Wt.%	Fe	SiO_2	Al_2O_3	LOI
4000	Mag	10.38	61.91	3.50	2.37	4.57
	Non-Mag	89.62	40.47	18.01	12.38	9.52
6000	Mag	16.27	61.31	4.03	3.01	4.05
	Non-Mag	83.73	40.78	18.04	12.54	8.89
8000	Mag	16.07	61.89	4.03	3.06	3.08
	Non-Mag	83.93	40.33	18.50	12.74	8.85
10000	Mag	17.38	61.11	3.94	3.15	4.09
	Non-Mag	82.62	40.56	18.81	12.97	8.00

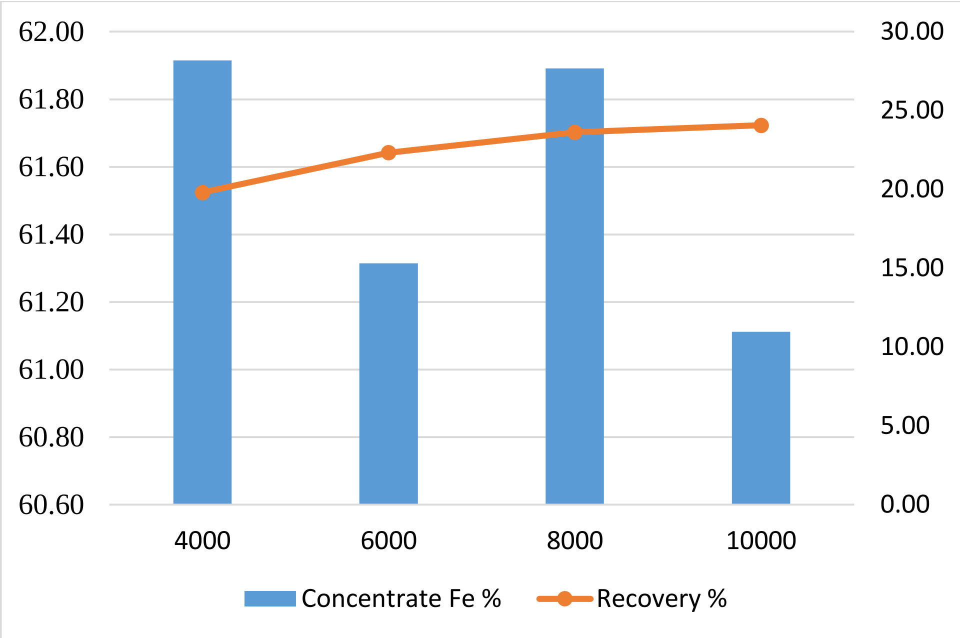

Figure 4: Effect of magnetic field intensity on yield and concentrate grade

Table 3
Denver flotation results of tailing sample

Dosage, Kg/t	Product	Wt.%	Fe	SiO_2	Al_2O_3
	Feed	100	41.05	19.05	13.34
0.5	Sink	43.95	48.325	13.45	10.39
	Float	56.05	35.35	23.44	15.65
1	Sink	41.23	50.87	11.56	6.8
	Float	58.77	34.16	24.30	17.93
1.2	**Sink**	**34.08**	**57.03**	**4.66**	**4.53**
	Float	65.91	32.79	26.50	17.90
1.5	Sink	31.34	54.22	6.33	5.99
	Float	68.66	35.05	24.85	16.72

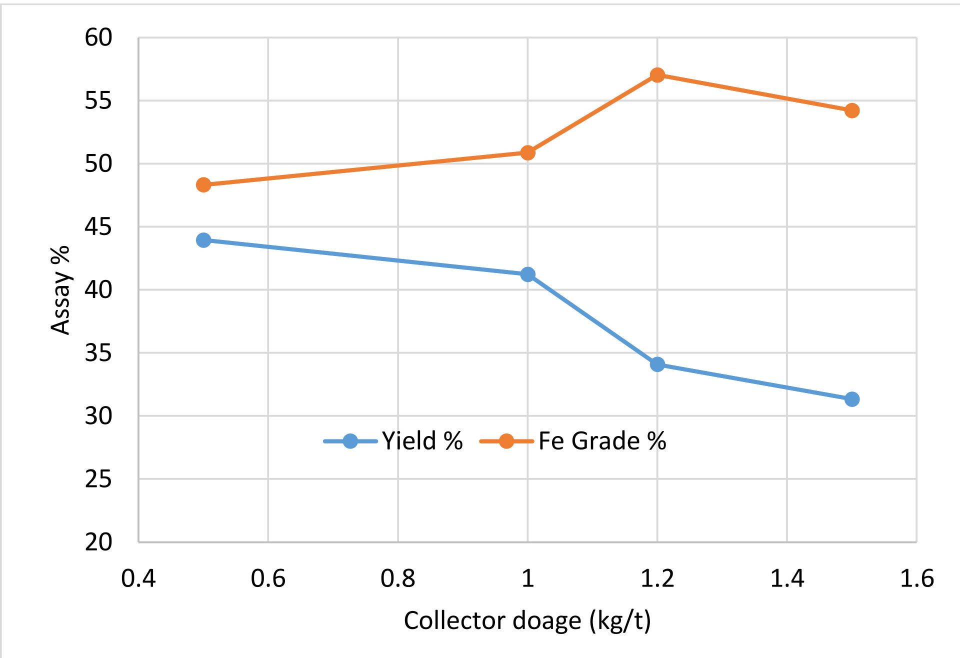

Figure 5: Effect of collector dosage on yield and concentrate grade.

Flotation without desliming: The flotation tests carried out tailing sample and results are shown in table 3. The results show a moderate improvement of Fe grade with significant yield. The flotation performance may be controlled via the dosages of amine (collector) and starch (depressant)[15]. The results show that a concentrate achieved 57.03 % Fe grade and 34.08 % yield.

Flotation with desliming: The ultrafine particles present in the tailing sample were removed by desliming cyclone. The cut point for separation was maintained at the 8 micron. The results of desliming are shown in table 4. The desliming underflow was subjected to the flotation experiments. The desliming prior to flotation was shown effective on grade improvement and selective separation of quartz and kaolinite from iron ore minerals in the flotation process[2,3,12]. The results shows that concentrate grade increases 58.25% Fe and yield as 20.44 %.

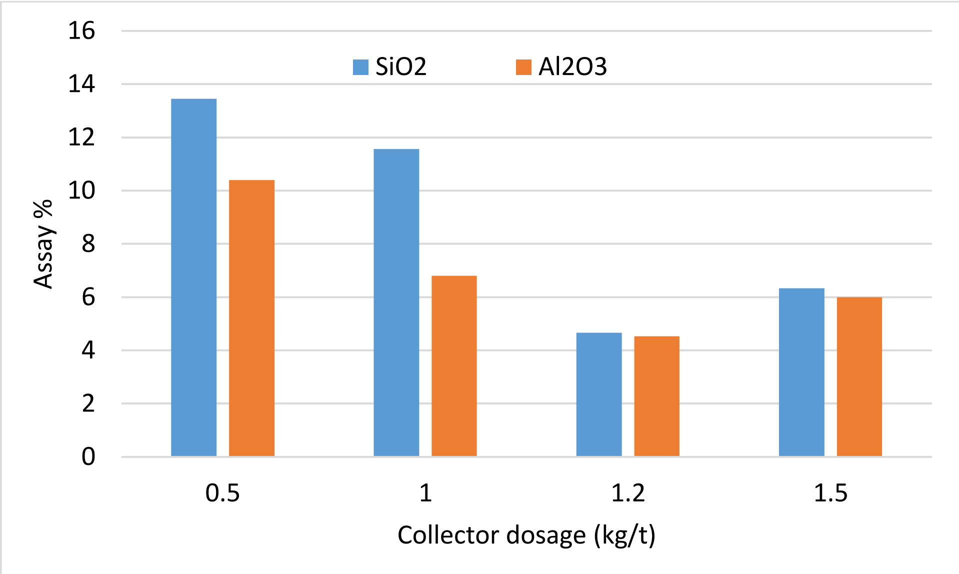

Figure 6: Effect of collector dosage on SiO2 and Al2O3 separation from concentrate

Table 4
Desliming of Tailing samples

Product	Wt.%	Fe	SiO_2	Al_2O_3
Feed	100	41.05	19.05	13.34
U/F	41.25	44.43	19.20	7.60
O/F	58.75	38.68	18.95	17.37

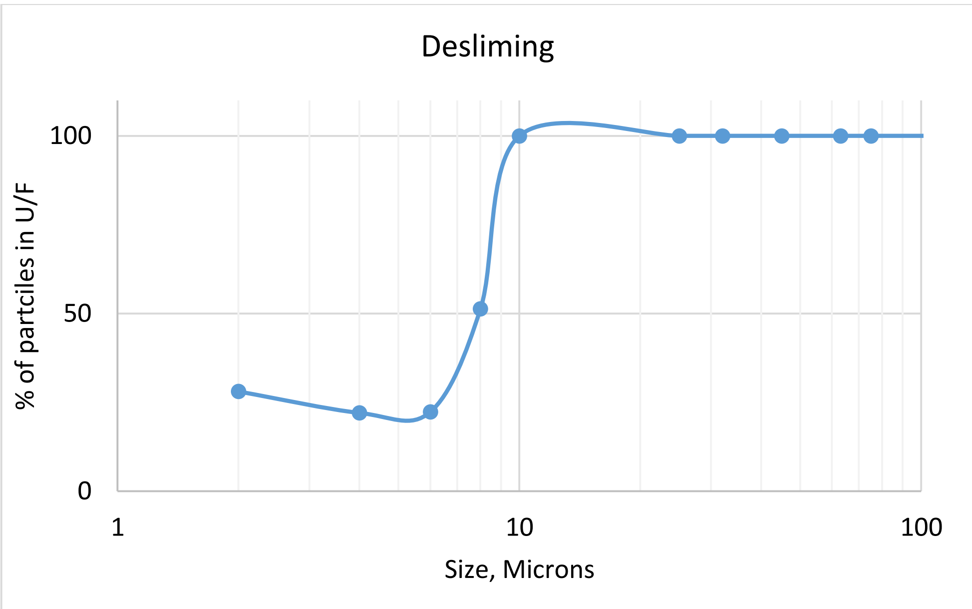

Figure 7: Desliming cyclone cut point (d50)

Table 5
Flotation results of Tailing samples (without desliming)

Dosage, Kg/t	Product	Wt.%	Fe	SiO_2	Al_2O_3
	Feed	41.25	44.43	19.20	7.60
0.5	Concentrate	19.89	53.57	7.15	6.50
	Tailing	21.36	35.92	30.42	8.63
1	Concentrate	**20.44**	**58.25**	**3.63**	**3.65**
	Tailing	20.81	30.35	35.06	11.63

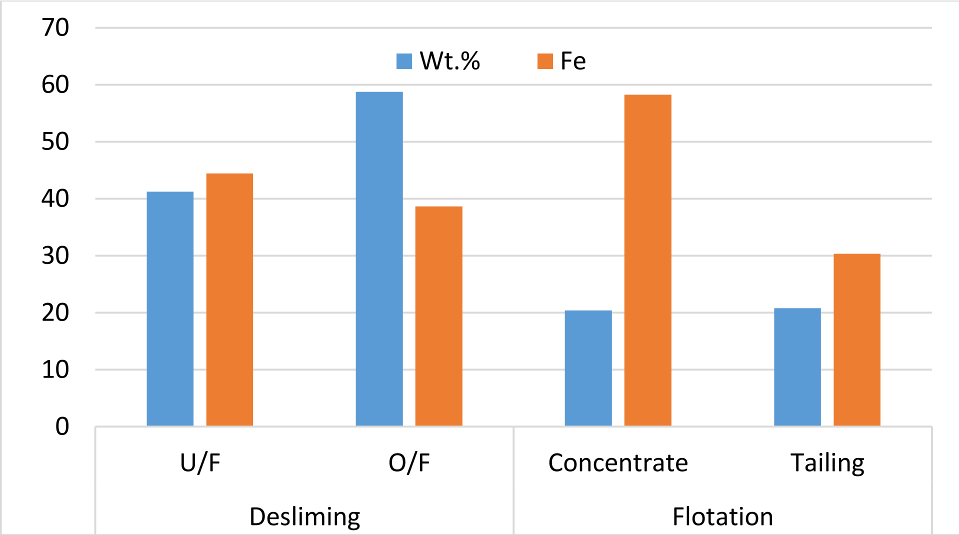

Figure 8: Results of desliming and flotation.

Table 6
Summary of all process test results.

Process	Wt. %	Fe	SiO2	Al2O3	Recovery %
Feed	100	41.05	19.05	13.34	
Gravity separation	21.85	54.36	8.21	8.32	28.93
Magnetic separation	17.38	61.11	3.94	3.15	25.87
Flotation with desliming	20.44	58.25	3.63	3.65	29.00
Flotation without desliming	34.08	57.03	4.66	4.53	47.35

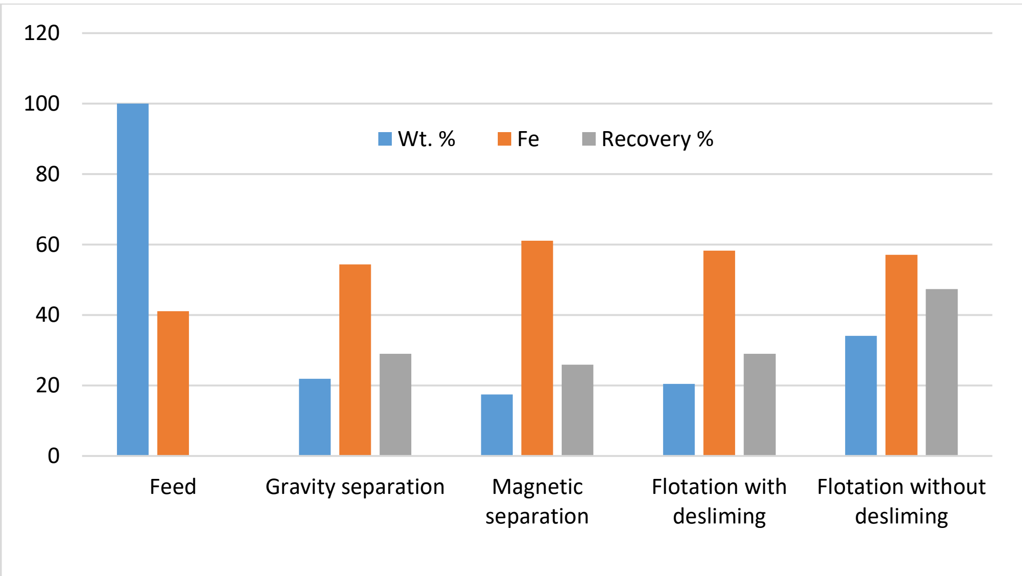

Figure 9: Comparison results of all experiments

Comparison of results: The results indicate that flotation without desliming yields the highest iron content and recovery, making it a promising process for the beneficiation of the given feed material. However, the selection of the optimal beneficiation method should consider both the iron content and recovery efficiency, taking into account specific project requirements and economic considerations.

Conclusion

- The tailing sample contains 41.05 Fe, 19.05% SiO_2 and 13.35 Al_2O_3.
- The flotation after desliming shows effectiveness for achieving a higher grade. But desliming results higher loss of iron values in the tailing.
- Flotation without desliming also shows an effective separation on the grade and yield of the concentrate. Without desliming, flotation process shows very sensitivity towards separation efficiency.
- The magnetic separation shows an effective separation in grade improvement with low recovery of yield.

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