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Beneficiation of low-grade iron ore using individual and combined gravity and magnetic methods

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ABSTRACT

The depletion of high-grade iron ore reserves has increased interest in beneficiating fine-grained, low-grade iron ores, including those from the Tang Zagh deposit in southern Iran. This study evaluated multi-gravity separation (MGS), wet high-intensity magnetic separation (WHIMS), and a combined MGS–WHIMS flowsheet for upgrading a low-grade iron ore sample containing 45.56% total Fe. Individual tests were conducted on three particle size fractions with d_{90} values of 38, 75, and 150 µm using three-stage rougher–cleaner–recleaner circuits under fixed operating conditions. In addition, combined tests were conducted on the particle size fractions with d_{90} values of 38 and 75 µm. Metallurgical performance was compared using concentrate grade, iron recovery, and the separation efficiency (S.E.) index. Both MGS and WHIMS showed a clear grade–recovery trade-off with decreasing particle size. WHIMS produced the highest concentrate grades, reaching 62.18% Fe, but showed substantially lower recovery, particularly in the finest fraction, where recovery declined to 13.60%. In contrast, MGS provided a better balance between grade and recovery, achieving 60.56% Fe at 39.13% recovery for the d_{90} = 38 µm fraction and outperforming WHIMS in overall separation efficiency. Relative to the three-stage WHIMS tests, the combined MGS–WHIMS circuit resulted in higher recovery and separation efficiency (S.E.), while producing concentrates with 62.10% Fe at 27.72% recovery for the d_{90} = 38 µm fraction and 60.79% Fe at 34.92% recovery for the d_{90} = 75 µm fraction. However, its overall separation efficiency remained lower than that of a standalone three-stage MGS. These results indicate that a three-stage MGS is the most effective route among the tested options for beneficiating fine-grained Tang Zagh iron ore. While, the combined circuit may be considered when a higher concentrate grade is prioritized over maximum recovery.

KEYWORDS

Fine hematite particles, low-grade iron ore, multi-gravity separator (MGS), WHIMS, magnetic separation, Tang_Zagh Mine

I. INTRODUCTION

The depletion of high-grade iron ore reserves and the growing global demand for steel have intensified the need for effective beneficiation of low-grade iron ores. Among these, hematite–goethite ores present particular processing challenges due to their fine particle size distribution, low magnetic susceptibility, and complex mineralogy (Rao et al., 1985; Nunna et al., 2022; Bulayani et al., 2024). Conventional beneficiation techniques, such as shaking tables, spirals, and magnetic separation, significantly diminish in efficiency for particles smaller than 75 µm, leading to considerable iron loss in the tailings (Roy, 2009; Sakthivel et al., 2010). A substantial body of research has investigated the application of the Multi Gravity Separator (MGS) for upgrading fine and ultrafine iron ores. Roy (2009) processed goethitic laterite ore from eastern India and demonstrated that the MGS substantially outperformed conventional shaking tables for ultrafine fractions, improving Fe grade from 54.43% to 66.5% at an iron recovery of 63.34%, while simultaneously reducing Al_2O_3 content from 8.02% to 1.17%. Bhaskar et al. (2006) employed the MGS to recover iron and silver values from base metal plant tailings, achieving a Fe recovery of 52.19% at a concentrate grade of 22.08% Fe from a feed containing only 9.07% Fe, and identified drum rotational speed as the most significant parameter. Chaurasia et al. (2017a) applied response surface methodology (RSM) based on a Box–Behnken design to simultaneously optimize three key MGS parameters for hematite recovery from low-grade iron ore tailings, producing a concentrate of 65.11% Fe at an iron recovery of 71.88% from a feed of 50.74% Fe without the use of chemical reagents. In a subsequent study, Chaurasia et al. (2017b) modeled MGS performance using an artificial neural network (ANN) as a function of drum inclination angle, rotational speed,

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and oscillation amplitude, confirming an upgrade from 50.74% to 65.26% Fe at an iron recovery of 71.25% for low-grade hematite ore from the Barbil region of India. Venkateswara Rao (2017) applied a Box–Behnken statistical design to optimize MGS parameters for low-grade iron ore from the Bailadila deposit, achieving a maximum concentrate grade of 64% Fe. Collectively, these studies demonstrate the strong potential of the MGS for upgrading fine iron-bearing materials and indicate that drum rotational speed is often among the most influential operational parameters. In addition to gravity-based beneficiation methods, wet high-intensity magnetic separation (WHIMS) has been widely investigated for recovering fine, low-grade iron ore minerals. Zhang et al. (2014) proposed a novel HGMS–centrifuge combined process for recovering iron ore from low-grade hematite tailings with an Fe grade of 28.12%, producing a concentrate of 58.48% Fe at a recovery of 21.66%. Wills and Finch (2016) further demonstrated that WHIMS systems can effectively beneficiate fine hematite and goethite particles that are difficult to recover by conventional means. However, despite the individual merits of both MGS and WHIMS, direct comparisons of their performance across different particle size fractions of the same ore remain limited, and integrated MGS–WHIMS flowsheets for hematite–goethite ores have not been widely reported. The Tang Zagh iron ore deposit, located in southern Iran, is characterized by a hematite–goethite mineral assemblage with minor magnetite (Zare et al., 2023; Akbari et al., 2018). The sample investigated in the present study was obtained from a low-grade iron ore zone of this deposit, which exhibits a fine particle size distribution of iron-bearing minerals. These characteristics render conventional beneficiation methods insufficient to produce a marketable iron concentrate, necessitating the use of advanced separation technologies. Therefore, the present study aims to investigate and compare the performance of the MGS and WHIMS (Fig. 1), both individually and in combination, for the beneficiation of this low-grade iron ore sample across different particle size fractions. The effects of particle size, MGS tilt angle, magnetic field intensity, and separation process (individual versus combined) on concentrate grade and iron recovery were evaluated to identify the most effective beneficiation strategy for the fine-grained, low-grade iron ore from the Tang Zagh deposit.

II. MATERIALS AND METHODS

A. *SAMPLING AND SAMPLE PREPARATION*

To investigate the beneficiation potential of the low-grade iron ore from the Tang-Zagh mine, a representative sample of approximately 400 kg was collected from the stockpile and transferred to the Mineral Processing Laboratory at the University of Tehran under the code AZ_B. Following the crushing and sieving stages, the samples were analyzed by X-ray diffraction (XRD) for phase identification using a Philips PW1730 diffractometer, and by X-ray fluorescence (XRF) for chemical composition determination using a Philips PW1410 spectrometer. The XRD measurements were performed using Cu-Kα radiation with a wavelength of 1.54056 Å, at an operating voltage of 40 kV. The measurements were performed over a 2θ range of 4–70°, with a step size of 0.05° and a counting time of 1 s per step. Additionally, the concentrations of total iron (TFe) and ferrous oxide (FeO) were determined using the titration method. Furthermore, mineralogical characterization and the Bond ball mill work index test were conducted to determine the mineralogical features and grindability of the ore.

B. *COMMINUTION AND DETERMINATION OF OPTIMAL GRINDING TIME*

To determine the grinding time, wet grinding tests were performed in a rod mill. In each test, 1 kg of sample with an initial particle size of -2.36 mm and a solids content of 50% was ground for various durations. Based on the results, the required times to achieve d90 = 38, 75, and 150 microns were 35, 13, and 7 minutes, respectively. After determining the optimal times, the main sample was wet-ground, and three feeds with the aforementioned particle sizes were prepared for the beneficiation tests.

C. *THREE-STAGE MAGNETIC SEPARATION TESTS*

To evaluate the magnetic separation efficiency of the low-grade iron ore sample, 5 kg of each size fraction (d_{90} = 38, 75, and 150 μm) was subjected to a three-stage magnetic separation circuit (rougher, cleaner, and recleaner) at magnetic field intensities of 13,000, 10,000, and 7,000 Gauss, respectively (Fig. 3A), under a constant solids content of 50%. All tests were conducted using a Boxmag Rapid wet high-intensity magnetic separator (WHIMS) available at the Mineral Processing Laboratory of the University of Tehran. This separator operates on principles closely related to high-gradient magnetic separation (HGMS) through the use of a magnetic matrix (Wills & Finch, 2016); consequently, the Boxmag Rapid unit is referred to as an HGMS in some studies (Ibrahim et al., 2016). The separator unit has physical dimensions of approximately 1 m in length, 1 m in width, and 1 m in height, with a processing capacity of 150 kg/h. It is equipped with a centrally positioned rotor with a diameter of approximately 0.6 m, operating at a rotational speed of 1–3 rpm, and is capable of generating a maximum magnetic field intensity of 17,000 Gauss (1.7 T). The concentrate obtained from each test was collected and analyzed to assess the separation performance across the different particle size fractions.

D. THREE STAGE GRAVITY SEPARATION TESTS

The Multi Gravity Separator (MGS), developed by Richard Mozley Limited in the late 1980s, is designed to beneficiate fine and ultrafine heavy minerals (Chan et al., 1991; Rao et al., 2017). The MGS operates by combining centrifugal force, thin film water flow, and oscillatory motion. The rotating drum generates a centrifugal force several times that of gravity, which enhances the separation of particles by density. The oscillatory motion further improves separation by creating shear forces within the flowing slurry. In this process, high-density particles move toward the inner surface of the drum and are collected as concentrate by scraper blades, while lighter particles are washed away as tailings (Fitzpatrick et al., 2018). To evaluate the efficiency of gravity separation, the pilot-scale Mozley Multi-Gravity Separator (MGS) with a capacity of 200 kg/h (Model: SCMG1/C900) was employed. This unit consists of a 0.50 m diameter open drum, open at one side, with a length of 0.60 m, mounted slightly inclined to the horizontal. The drum rotates clockwise at varied speeds ranging from 102 to 285 rev/min, leading to an enhanced gravitational pull of 6–24 g on the drum surface. A sinusoidal shake is applied to the drum, with amplitudes of 10, 15, and 20 mm, superimposed on the drum motion in the axial direction. The operating principle and design configuration of the MGS are schematically illustrated in Fig. 2. The experiments were conducted at the Mineral Processing Laboratory of the University of Tehran. Based on previous investigations conducted using the MGS on low-grade iron ore and plant tailings from Tang Zagh (Akbari et al., 2018; Zare et al., 2023), together with preliminary screening tests performed in this study, the main operating conditions of the MGS were selected and fixed. In this work, two key parameters, feed particle size and tilt angle, were intentionally varied. In contrast, all other operational variables (including drum rotational speed, wash water flow rate, shake frequency, shake amplitude, feed solids content, and feed flow rate) were maintained at near-optimal values established in previous studies. Subsequently, the three-stage rougher, cleaner, and recleaner tests were performed for each of the three size fractions d_{90} = 38, 75, and 150 µm, using 15 kg of the sample. All tests were carried out under constant conditions, including a residence time of 7 minutes, a rotational speed of 280 rpm, solids content of 50%, wash water flow rate of 4 L/min, and inlet water flow rate of 2 L/min. This experimental design focused on evaluating the effects of feed particle size and tilt angle, two selected variables directly related to MGS performance in the beneficiation of fine and ultrafine low-grade iron ore. These tests were performed at three tilt angles of 2°, 4°, and 6°, respectively. To evaluate the performance of gravity separation across the three stages, the third-stage tailings (T3) corresponding to the d_{90} = 38 µm size fraction was selected as the representative sample for mineralogical studies (Fig. 3B).

E. COMBINED GRAVITY AND MAGNETIC SEPARATION TESTS (MGS-WHIMS)

Based on the results obtained from the individual separation methods, a combined separation flowsheet was designed. In this flowsheet, the samples with particle sizes of d90 = 38 µm and d90 = 75 µm were first processed through a three-stage MGS circuit under the aforementioned optimal conditions. The final MGS concentrate produced from the d90 = 38 µm sample was then subjected to magnetic separation at 7000 Gauss, while that obtained from the d90 = 75 µm sample was processed at 13000 Gauss (Fig. 4). The primary objective of this experimental program was to evaluate and compare the beneficiation performance of the individual separation methods with that of the combined separation flowsheet.

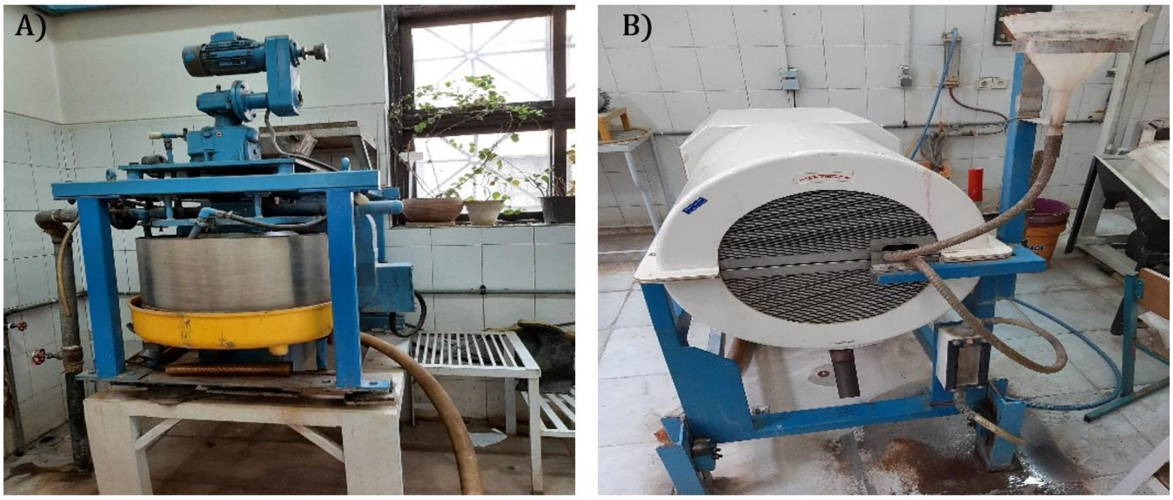

Fig. 1. (A) Photograph of WHIMS (Box Mag device); (B) Photograph of Mozley C-900 MGS

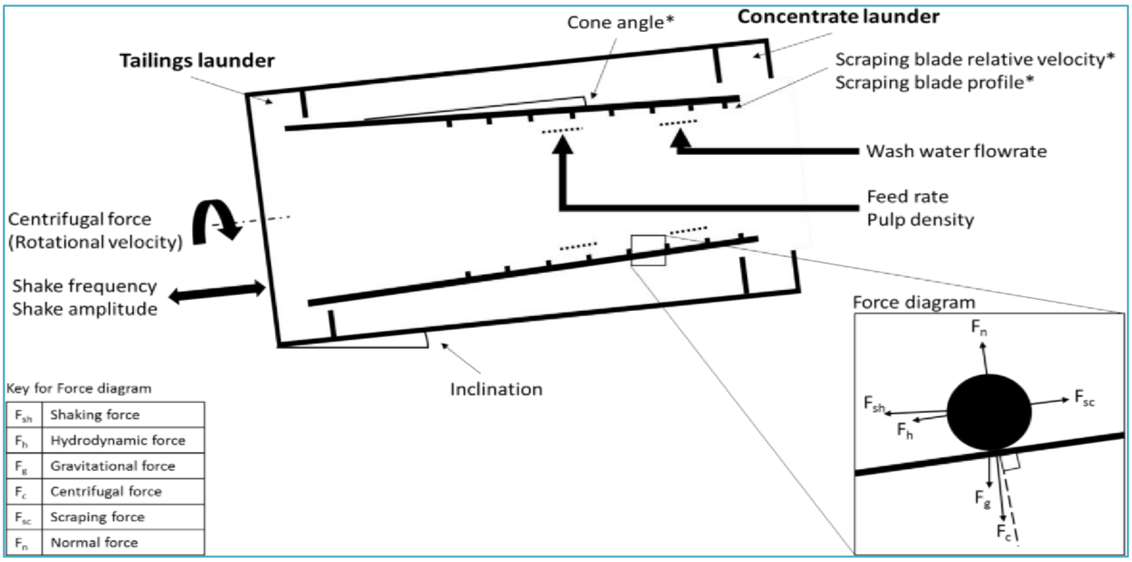

Fig .2. Schematic diagram of the Multi-Gravity Separator (MGS) (Glass, 1998)

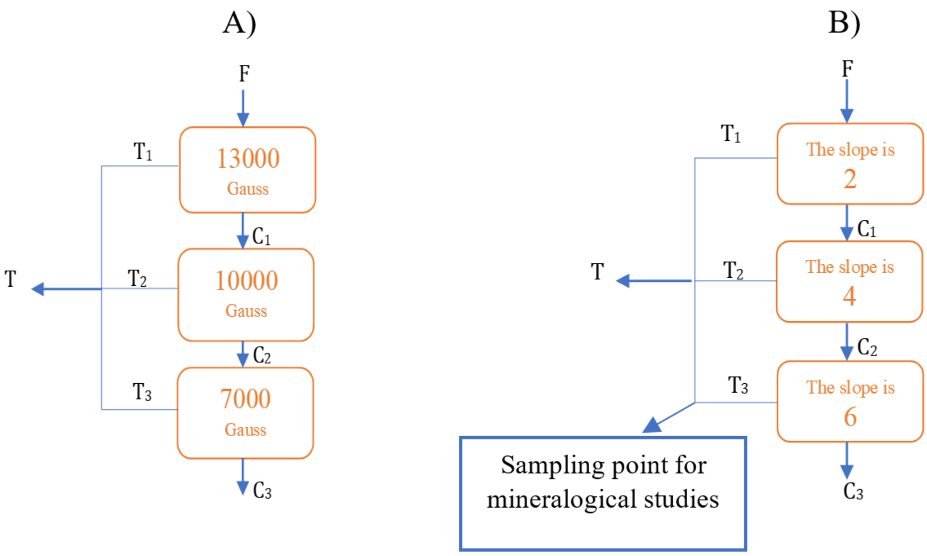

Fig 3. (A) Flowsheet of the three-stage wet high-intensity magnetic separation (WHIMS), (B) Flowsheet of the three-stage multi-gravity separation (MGS)

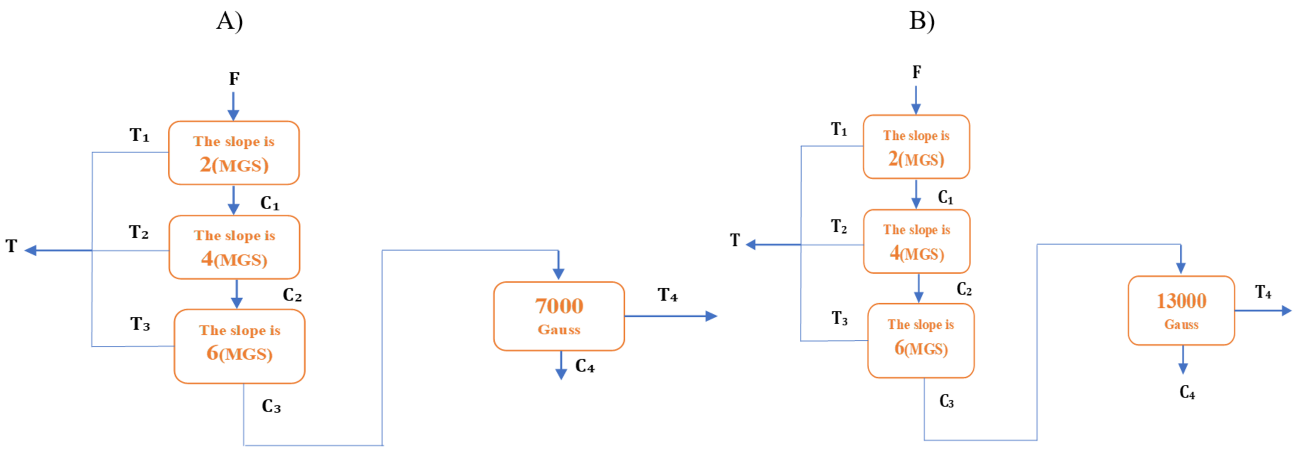

Fig. 4. Flowsheet of the combined multi-gravity separation (MGS) and wet high-intensity magnetic separation (WHIMS) tests: (A) d_{90} = 38 µm, (B) d_{90} = 75 µm

III. RESULTS

A. *CHARACTERIZATION RESULTS*

Mineralogical analyses reveal that hematite is present both as discrete grains and aggregates within the host rock, predominantly resulting from the replacement of manganite minerals. In certain areas, hematite is further replaced by iron hydroxides such as limonite and goethite, occasionally exhibiting encapsulation of hematite grains by these hydroxides. A significant portion of the gangue sample is also impregnated with iron hydroxides. The abundance of manganite and manganese-bearing minerals is very low, constituting less than 1% of the sample (Fig. 5). Non-metallic minerals are mainly quartz, occurring in both polycrystalline and monocrystalline forms. Carbonate minerals are primarily calcite, which, similar to other textural components, shows impregnation with iron hydroxides. Hematite exhibits the highest association with iron hydroxides and quartz, followed by calcite. These observations are detailed in Table 1 and Fig. 5. Additionally, a fraction of the fine iron minerals exists as fine dust within the sample, which cannot be effectively processed by conventional beneficiation methods. The XRF and XRD analyses, summarized in Table 2 and Fig. 6, confirm the presence of hematite. Titration results further showed that the total iron (TFe) and FeO contents of the sample were 45.56% and 0.56%, respectively. Moreover, the sieve analysis results, presented in Fig. 7, illustrate the distribution of metal content, iron grade, and weight recovery across different size fractions. The liberation degree of hematite in particles smaller than 38 microns is estimated to be approximately 90%. The ball mill work index for the sample was determined to be 9.74 kWh/t, suggesting a moderate grindability.

Table 1. Mineralogical study results of sample AZ_B.

Metallic minerals	Hematite, Iron hydroxide, Magnetite, Manganese-bearing minerals
Non-metallic minerals	Quartz, Carbonate minerals, Clay minerals

Table 2. XRF chemical analysis results for sample AZ_B.

Corresponding Oxide	SiO_2	Al_2O_3	BaO	CaO	Fe_2O_3	MgO	MnO	P_2O_5	SO_3	TiO_2	SrO	LOI
Content (wt. %)	23.87	1.71	0.98	0.63	65.5	0.23	0.17	0.87	1.72	0.21	0.45	3.59

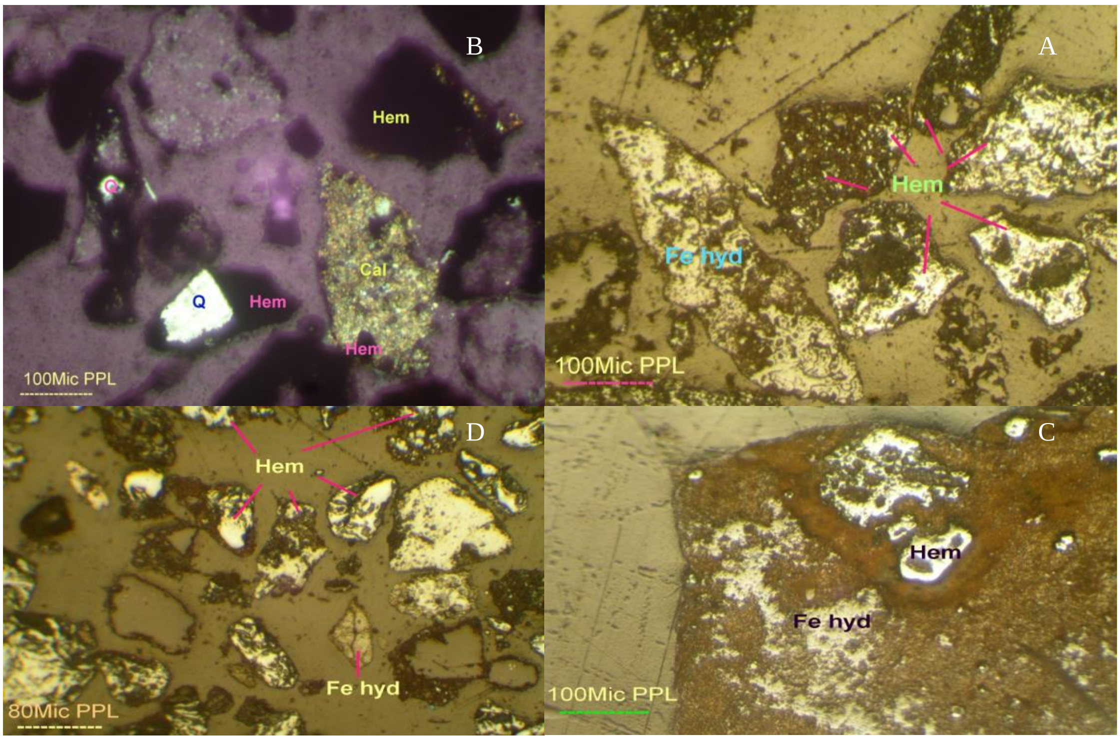

Fig. 5. (A) Hematite particles interlocked with gangue, (B) Iron minerals interlocked with quartz and calcite, (C) Hematite (Hem) interlocked with iron hydroxide (Fe hyd), (D) Hematite interlocked with gangue minerals.

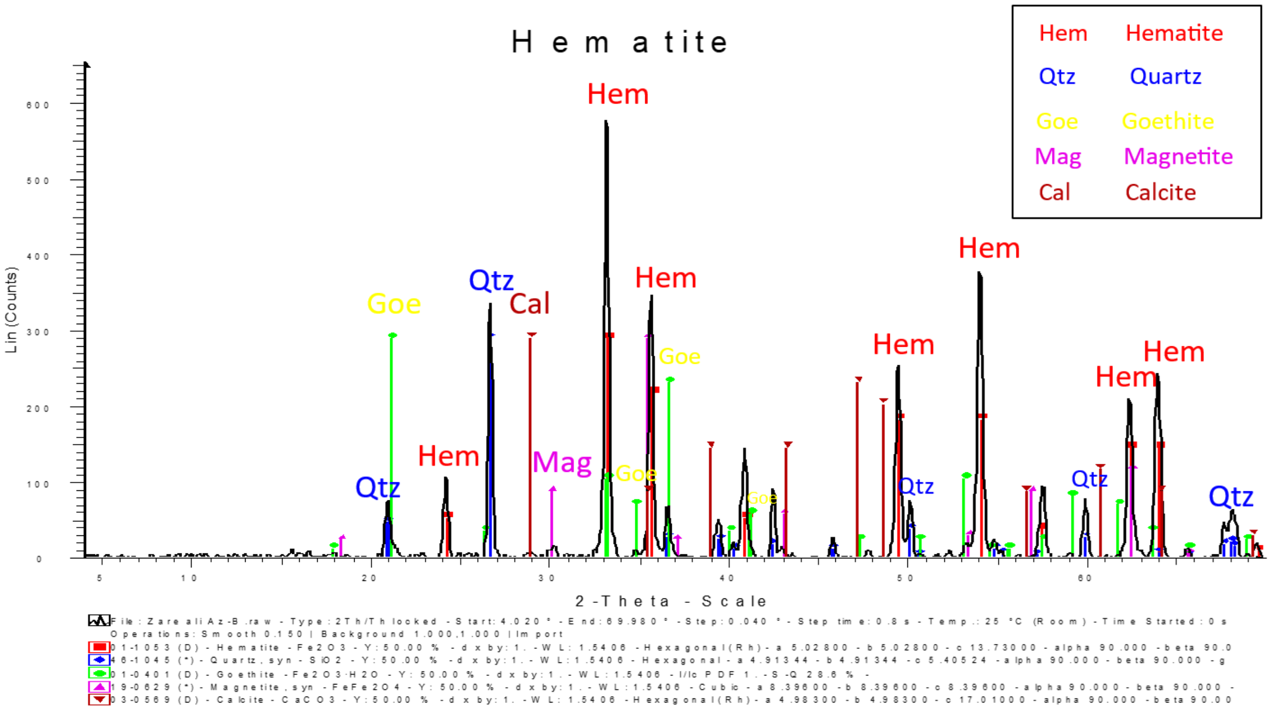

Fig. 6. XRD analysis graph of the sample AZ_B

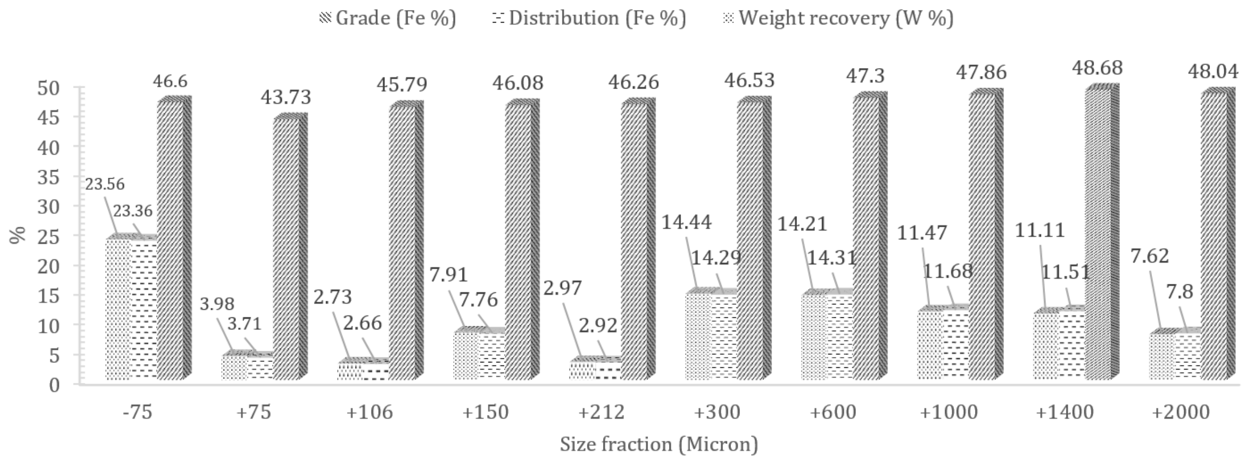

Fig. 7. Distribution of metal content and iron grade, and weight recovery of minerals in different size fractions

B. RESULTS OF THREE-STAGE MAGNETIC SEPARATION TESTS

The results showed that magnetic field intensity strongly affected the separation performance. As the magnetic field intensity increased, both iron recovery and weight recovery increased, while the concentrate grade decreased. On the other hand, lowering the magnetic field intensity improved the concentrate grade, but reduced both iron recovery and weight recovery. Consequently, to optimize the circuit performance, the maximum magnetic field intensity was applied during the rougher stage to maximize the recovery of iron-bearing minerals in the first stage. In contrast, lower intensities were strategically utilized in the cleaner and re-cleaner stages to facilitate the rejection of entrained gangue particles and achieve the desired final concentrate grade. The results of the three-stage WHIMS tests demonstrated a clear relationship between feed particle size and separation performance. As the feed size range was reduced from d_{90} = 150 µm to d_{90} = 38 µm, the iron grade in the concentrate increased from 59.19% to 62.18%. In contrast, iron recovery decreased from 22.71% to 13.60% and weight recovery declined from 17.87% to 10.18% (Fig. 8). This inverse relationship between concentrate grade and recovery is consistent with the classical grade–recovery trade-off inherent to all selective mineral separation processes (Svoboda, 2004; Oberteuffer, 2003). The observed decline in weight recovery and iron recovery with decreasing particle size can be attributed to several interrelated factors. First, hematite, the dominant iron-bearing mineral in the Tang Zagh ore sample, exhibits relatively low magnetic susceptibility compared to magnetite, making its fine-grained particles particularly difficult to capture under the applied field conditions (Zheng et al., 2015; Rayner & Napier-Munn, 2000). Second, progressive size reduction generates a substantial proportion of ultrafine particles, which experience a reduced magnetic force relative to competing hydrodynamic and gravitational forces, thereby escaping capture in the magnetic matrix (Oberteuffer, 2003). The magnetic force acting on a particle scales with particle volume, whereas hydrodynamic drag scales with particle diameter (proportional to d), meaning that the ratio of magnetic to drag force decreases sharply with decreasing particle size, rendering WHIMS increasingly less efficient for ultrafine fractions (Svoboda, 2004; Zheng et al., 2015). These findings are consistent with those reported by Zare et al. (2023) and Nunna et al. (2022), who similarly observed reduced iron recovery for fine hematite and goethite fractions processed by magnetic separation.

C. RESULTS OF THREE-STAGE GRAVITY SEPARATION TESTS

The gravity separation tests were performed using a Multi Gravity Separator (MGS) in three stages. The results showed (Akbari et al., 2018; Zare et al., 2023) that the inclination angle of the MGS had a significant effect on separation performance. A decrease in the drum inclination led to higher iron recovery and weight recovery, but lower concentrate grade. In contrast, increasing the inclination angle improved the concentrate grade, while reducing both iron recovery and weight recovery. Therefore, a lower inclination angle was selected for the rougher stage to maximize the initial recovery of iron-bearing particles. In contrast, higher inclination angles were applied in the cleaner and re-cleaner stages to improve the final concentrate grade. In addition to operating conditions, feed particle size also played an important role in MGS performance. The feed size was reduced from d_{90} = 150 µm to d_{90} = 38 µm. The results shown in Fig. 9 indicate that by decreasing the feed size, the concentrate grade increased from 52.4% to 60.56%. However, the iron recovery decreased from 54.84% to 39.13%, and the weight recovery decreased from 48.97% to 29.9%. Microscopic studies of the T_3 tailings from the MGS at d_{90} = 38 µm show that the device can effectively separate clay minerals at this size, and a significant portion of these impurities is removed during separation. Fig. 10 shows the mineralogical results.

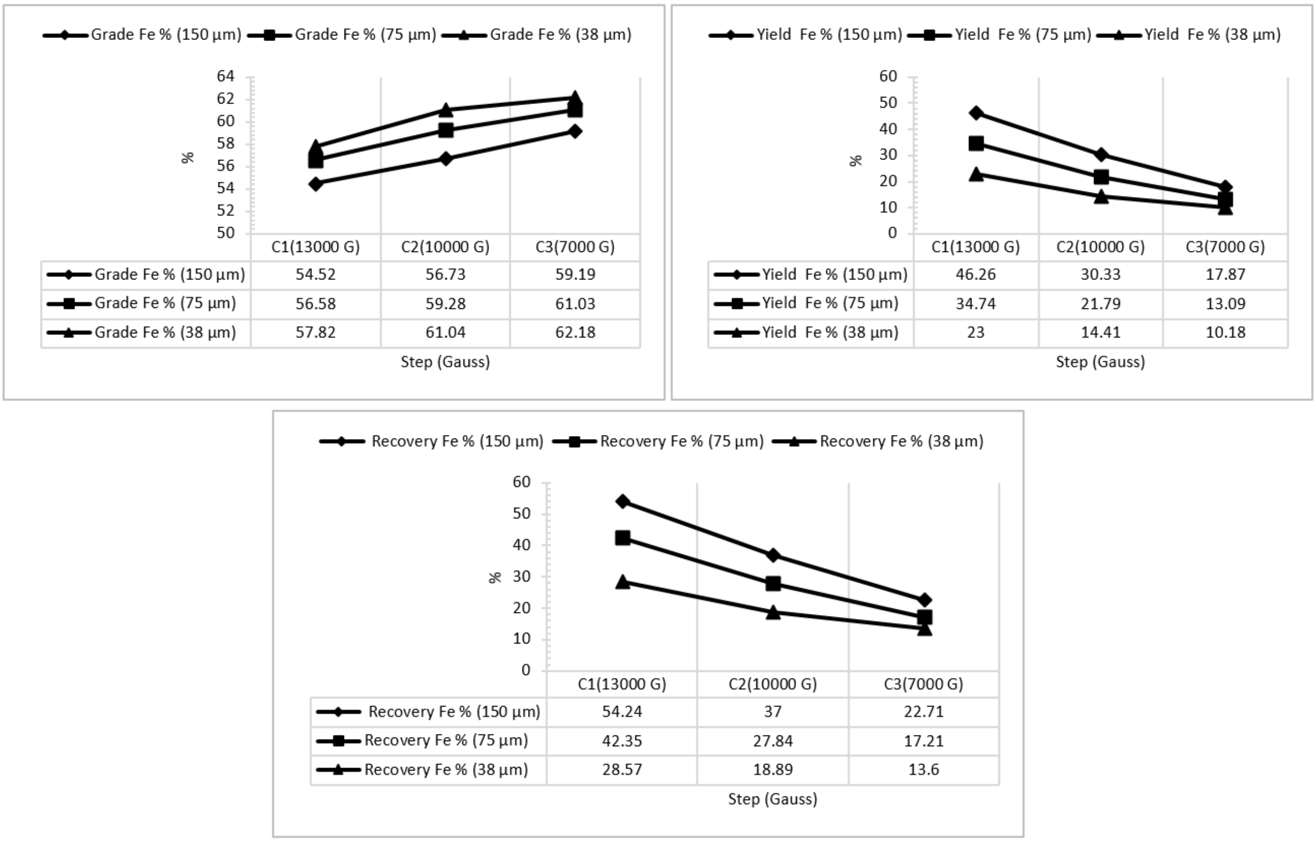

Fig 8. Grade, recovery, and yield (weight recovery) charts of the concentrates from the three-stage WHIMS tests of sample AZ_B

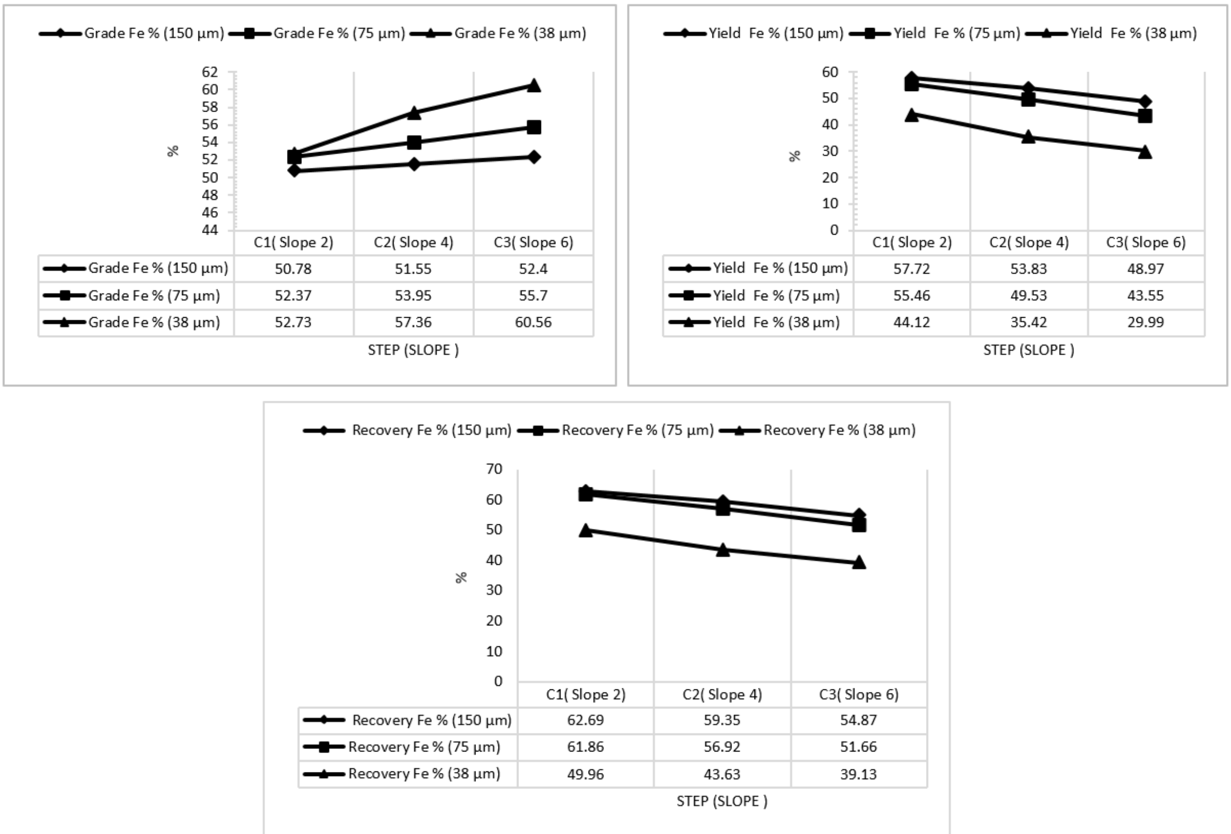

Fig 9. Grade, recovery, and yield (weight recovery) charts of the concentrates obtained from the three-stage MGS tests on sample AZ_B

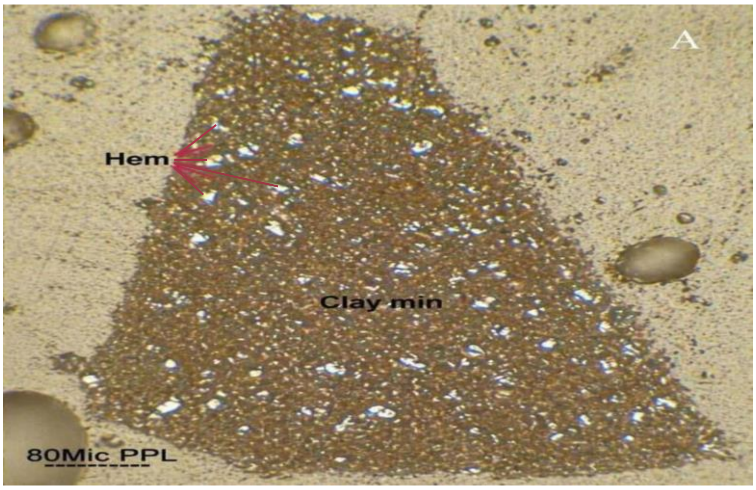

Fig 10. Separation of clay minerals in the T_3 tailings at a particle size range d_{90} = 38 µm

D. RESULTS OF COMBINED GRAVITY AND MAGNETIC SEPARATION TESTS

To evaluate the performance of the combined test, its results were compared with those of the individual tests using the separation efficiency (S.E.) index. Separation efficiency (S.E.) is a metallurgical performance index used to evaluate the overall effectiveness of a beneficiation process by combining both recovery and grade into one. The S.E. was calculated using Eq. (1):

$$S.E. = \frac{c(f-t)(c-f)(100-t)}{f(c-t)^2(100-f)} \times 100 \quad (1)$$

where c, t, and f are the Fe grades (%) of the concentrate, tailings, and feed, respectively (Schulz, 1970). The metallurgical evaluation based on the S.E. index in Fig. 11 indicates that the three-stage MGS tests achieved the highest S.E. among the beneficiation methods. Furthermore, considering the technical and economic requirements of the mineral processing market for a marketable concentrate grade exceeding 58%, the three-stage MGS process demonstrates the most efficient performance in the ultra-fine particle size range d_{90}=38 µm (Fig. 12). Analyzing the performance of three-stage magnetic tests (WHIMS) reveals that while this method attained impressive grades exceeding 60% in both the 38 and 75 µm size ranges (reaching 62.18% and 61.04%, respectively), it suffered from a significant reduction in both iron recovery and weight recovery. This decline is attributed to the substantial decrease in magnetic attractive forces within the fine fractions of particles. However, the operational integration of these two methods into a combined MGS-Magnetic circuit resulted in an improvement in metallurgical indices. Compared to the standalone magnetic separation method, both iron and weight recovery parameters were significantly enhanced and optimized. The results are presented in Tables 3 and 4. Fig. 13 presents the proposed flowsheet.

Table 3. Results of the combined MGS and WHIMS test for the size fraction with d_{90} = 38 µm

Test number	Step	Slope (Degree)/ Field intensity (Gauss)	Product name	Yield (%)	Grade (%)	Recovery (%)
1	MGS	2	Concentrate	44.12	52.73	49.96
			Tailings	55.88	41.7	50.04
			Total	100	46.57	100
2		4	Concentrate	35.42	57.36	43.63
			Tailings	8.69	33.86	6.32
			Total	44.12	52.73	49.96
3		6	Concentrate	29.99	60.75	39.13
			Tailings	5.43	38.46	4.51
			Total	35.42	57.36	43.63
4	WHIMS	7000	Concentrate	20.79	62.1	27.72
			Tailings	9.20	57.7	11.40
			Total	29.99	60.75	39.13

Table 4. Results of the combined MGS and WHIMS test for the size fraction with d_{90} = 75 µm

Test number	Step	Slope (Degree)/ Field intensity (Gauss)	Product name	Yield (%)	Grade (%)	Recovery (%)
1	MGS	2	Concentrate	55.46	52.37	61.86
			Tailings	44.54	40.2	38.14
			Total	100	46.95	100
2		4	Concentrate	49.53	53.95	56.92
			Tailings	5.93	39.19	4.95
			Total	55.44	52.37	61.86
3		6	Concentrate	43.56	55.7	51.64
			Tailings	5.99	41.2	5.26
			Total	49.53	53.95	56.92
4	WHIMS	13000	Concentrate	27.07	60.79	34.92
			Tailings	16.47	47.7	16.73
			Total	43.56	55.7	51.64

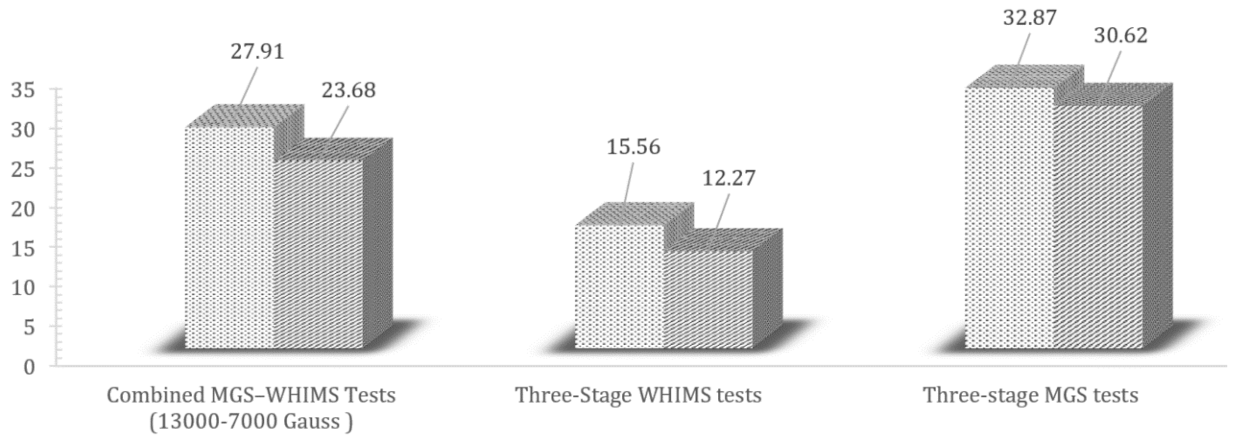

Fig 11. Comparison chart of S.E. in different size fractions (d_{90} = 38, 75 µm) for the three-stage gravity, three-stage magnetic, and combined separation tests

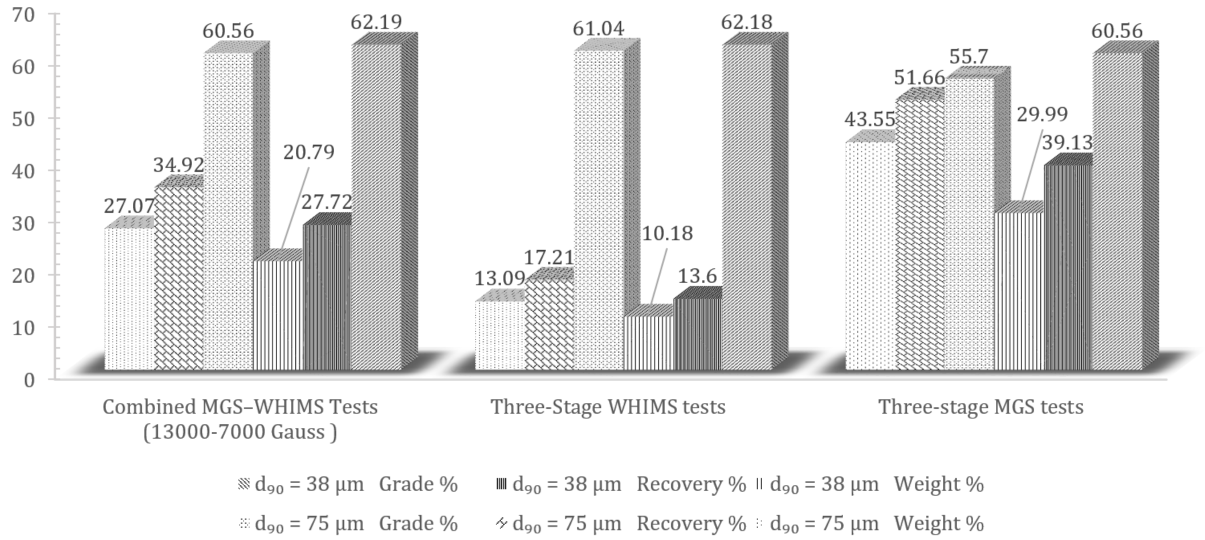

Fig 12. Fe grade, iron recovery, and weight recovery in different size fractions (d_{90} = 38, 75 μm) for the three-stage gravity, three-stage magnetic, and combined separation tests

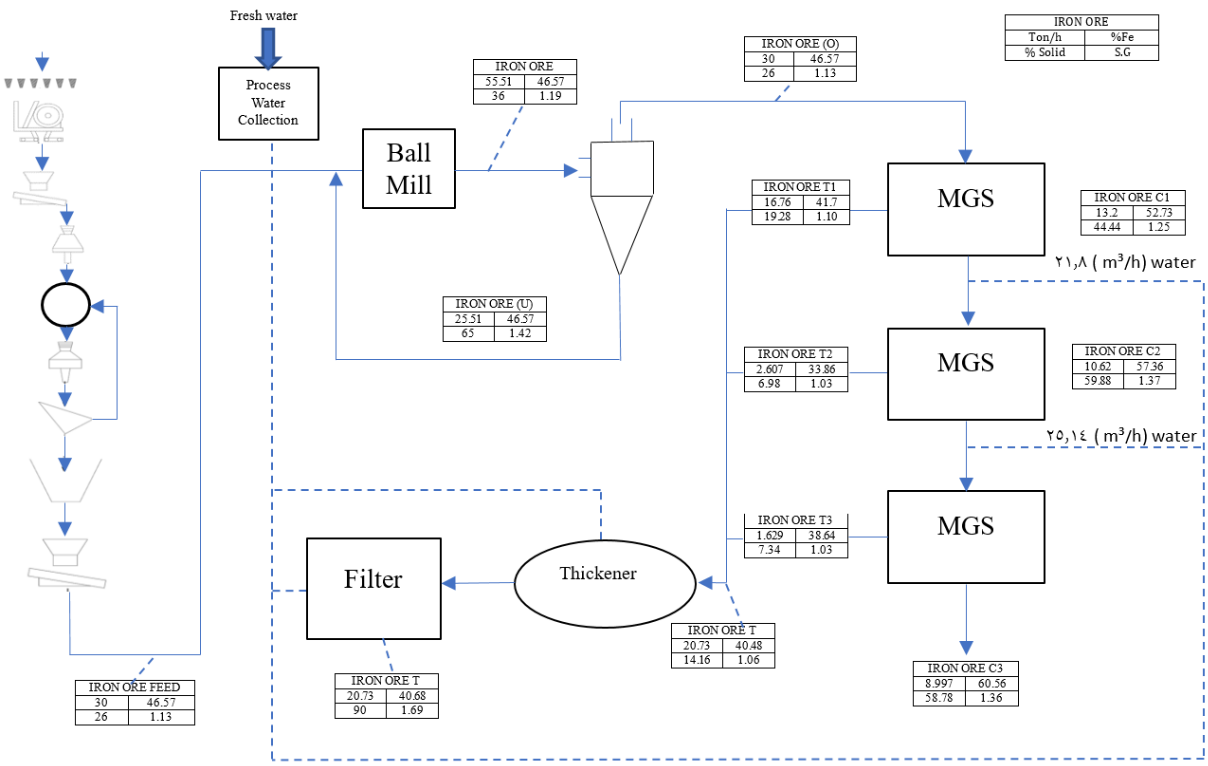

Fig 13. Flowsheet of the proposed base recovery of iron ore from the low-grade Tang Zagh ore sample

IV. CONCLUSION

This study evaluated multi-gravity separation (MGS), wet high-intensity magnetic separation (WHIMS), and their combination for upgrading the fine-grained, low-grade hematite–goethite iron ore from the Tang Zagh deposit. Mineralogical and chemical characterization confirmed a total iron content of 45.56% (Fe_2O_3 = 65.5%), a moderate Bond work index of 9.74 kWh/t, and a fine liberation size, with hematite closely associated with iron hydroxides, quartz, and calcite, confirming the need for advanced fine-particle beneficiation. Both WHIMS and MGS displayed a consistent grade–recovery trade-off as feed size decreased from d_{90} = 150 to 38 μm, WHIMS grade increased from 59.19% to 62.18% Fe while recovery decreased from 22.71% to 13.60%, and MGS grade rose from 52.4% to 60.56% Fe while recovery declined from 54.84% to 39.13%. Comparison of the two methods using the separation efficiency (S.E.) index showed that the three-stage MGS circuit consistently outperformed WHIMS and was the only standalone process able to reach a marketable concentrate grade above 58% Fe in the ultra-fine (d_{90} = 38 μm) fraction while maintaining recovery. WHIMS, although capable of producing higher grades (up to 62.18% Fe), suffered substantial recovery losses in the fine fractions due to the low magnetic susceptibility of hematite and the unfavorable magnetic-to-drag force ratio at small particle sizes. Integrating MGS and WHIMS into a combined circuit improved performance. For the d_{90} = 38 μm fraction, the final concentrate reached 62.1% Fe at 27.72% recovery, and for the d_{90} = 75 μm fraction, 60.79% Fe at 34.92% recovery; both of these recoveries were considerably higher than those obtained by standalone magnetic separation at comparable grades. Overall, the three-stage MGS circuit provided the best overall metallurgical performance and is therefore the most effective route among the tested options for the fine-grained, low-grade Tang Zagh iron ore; the combined MGS–WHIMS circuit may be considered only as an alternative when higher concentrate grades are specifically required.

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