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International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 59-2 (2025) 165-170

DOI: 10.22059/IJMGE.2025.395655.595259

The upgrading of low-grade iron ore: optimization of recovery and reduction of feed volume

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Article History:

Received: 01 March 2025.
Revised: 10 May 2025.
Accepted: 31 May 2025.

ABSTRACT

The present study investigated the potential for iron recovery from magnetite-bearing iron ore tailings at the Sangan Company's old dumps, aiming to reduce environmental challenges through wet magnetic separation as a pre-beneficiation stage. This method selectively removed coarse gangue while maximizing magnetite recovery. A full factorial experimental design evaluated the effects of magnetic field intensity (1200, 2700, 3400 gauss), drum speed (1, 1.4 m/s), and pulp solids content (25%, 35%). Concentrate analysis was performed using titration and Satmagan methods. Partial Least Squares (PLS) modeling revealed that higher magnetic field intensities significantly improved magnetite recovery, enabling a feed mass reduction of 18–22% with negligible magnetite loss (~2–3%). Magnetite recovery from tailings represents a novel approach, achieving up to 97.21% recovery under optimal conditions. Davis Tube tests confirmed that lost magnetite, with iron grades below 13.63%, is unsuitable for the final concentrate, enhancing overall concentrate quality by its removal. This pre-upgrading process improves concentrate quality, reduces operating costs, and supports sustainable tailings management.

Keywords: *Low-grade Iron ore, Magnetic separation, Upgrading, Pre-processing, Design of experiments.*

1. Introduction

Steel is the foundation of industrial development. It is widely used in various fields, such as construction, the automotive industry, industrial equipment, transportation, and energy (Comtois & Slack, 2016). Iron ores are crucial for providing raw materials to the steel industry. Notable iron minerals encompass hematite (Fe_2O_3), magnetite (Fe_3O_4), goethite (FeO(OH)), and siderite (FeCO3). Iron ores, such as hematite and magnetite, have been effectively processed for a long time. However, significant iron reserves remain unexploited due to technical and economic challenges, accumulating as tailings in mines (CLu, 2015; armignano et al., 2021). With increasing global demand and limited primary resources, recovering iron from mine tailings has become critical for preserving resources and minimizing environmental degradation (Arol & Aydogan, 2004; Jyolsna et al., 2016).

Iron ore beneficiation occurs in processing plants to produce materials suited for iron smelters. These methods include flotation (Ghasemi et al., 2019), combined gravity and magnetic techniques (Zare et al., 2023), magnetic roasting (Li et al., 2010), and magnetic separation (Herrera-Pérez et al., 2024; Luttrell et al., 2004). Importantly, particularly in the recovery of valuable materials from iron ore tailings, many of these technologies are also widely used (Roy & Das, 2008). Conventional processing methods are often cost-prohibitive or inefficient for low-grade tailings due to their complex mineralogy and high gangue content. Magnetic separation, an effective mineral processing technique, relies on differences in the magnetic properties of iron minerals (Chen & Xiong, 2015). This method is highly efficient for extracting magnetite from iron ore tailings (Sahin, 2020). Recent studies on magnetite processing highlight diverse approaches to enhancing the efficiency of magnetic separation. One study utilized a hydrocyclone prior to high-intensity wet magnetic separation, achieving a recovery of 89.2% (Jyolsna et al., 2016). Similarly, another investigation combining hydrocyclone and magnetic separation produced a concentrate with a grade of 63% and a recovery of 70.7% (Jena et al., 2015). Additionally, a different study employing low-intensity magnetic separation yielded a concentrate with a grade of 47.5% and a recovery of 68.56% (Behnamfard & Khaphaje, 2019). Another research suggested increasing the size of ultra-fine magnetite particles as a method to reduce losses during magnetic separation (Arol & Aydogan, 2004). Among magnetic separation techniques, the wet method is considered an efficient and cost-effective option for tailings containing magnetite due to its superior particle attraction, energy efficiency, and suitability for the mineralogical properties of the tailings. These findings underscore the importance of optimizing processing conditions and selecting appropriate methods to achieve higher efficiency in magnetic separation processes.

As a pioneer in the iron ore mining and processing industry in Iran, Sangan Company has deposited a large amount of low-grade material and mischievous ore in storage sites over the years. Despite their low initial grade, these deposits offer significant potential for recovery and reuse in production due to their high magnetite content. Pre-processing these tailings, particularly using magnetic separation, can be considered an economic and environmental solution. However, optimizing this process faces challenges, including the oxidation of magnetite to hematite, high operating costs, and varied mineralogical properties.

The main objective of this study is to selectively remove a significant portion of the coarse-grained gangue in the pre-processing stage. For this purpose, the magnetic separation method was used, which is considered to be an efficient and cost-effective method in mineral processing. This study also seeks to substantially reduce the feed rate of

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material entering downstream processing stages by optimizing pre-processing. To this end, experiments were designed using a full factorial experimental design, investigating key parameters of magnetic separation, including magnetic field intensity, separator speed, and pulp solids content. The results were analyzed using the Partial Least Squares (PLS) method to optimize the efficiency of magnetic separation.

2. Material and methods

2.1. Material

The initial representative sample, weighing 900 kg, was prepared after grinding to a maximum particle size of 6 mm. Particle size analysis (see Fig. 1) indicated that 80% of the particles were smaller than 2700 µm. These particle sizes are well suited for wet magnetic separation of magnetite, particularly with medium-to-high magnetic field intensities.

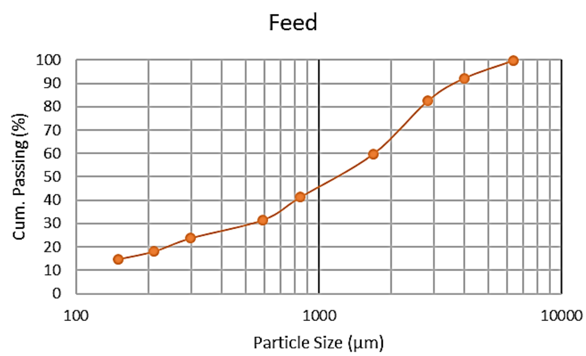

Fig. 1. Feed size analysis for initial representative sample.

In this study, experiments were conducted using a drum magnetic separator in the mineral processing laboratory of Sahand University of Technology, Tabriz. This apparatus, capable of adjusting the drum speed via electric current control, allowed experiments across a range of drum speeds. The separator was equipped with an adjustable mechanical feeder and agitator to control the feed rate and mixing speed. This allowed for uniform feeding, ensured a constant flow rate, and ensured optimal pulp homogeneity.

2.2. Experimental design

The efficiency of the magnetic separation process depends on key operating parameters. Accurate identification of these factors and the extent to which each influences the process is of particular importance. The experimental design of this study involved the use of a full factorial design, which was implemented after conducting preliminary experiments and identifying salient factors. The experimental design was used to conduct a comprehensive investigation of the effects of three variables: magnetic field intensity, separator speed, and pulp solids content. These variables were found to have a significant effect on two primary indicators: grade and recovery of iron and iron oxide. The range of these parameters was determined based on preliminary studies and is presented in Table 1.

Table 1. The range of variation of operating parameters.

Parameters	Intensity (G)	Speed (m/s)	Solid (%)
Levels	1200	1	25
	2700	1.4	35
	3400	-	-

2.3. Results analysis method

Mineralogical studies of the sample were performed through the preparation of thin and polished sections. The sections were analyzed using a polarizing microscope equipped with a digital image processing system. Chemical analysis of the concentrates obtained from the experiments was carried out using two methods: titration and Satmagan magnetic analyzer.

Experimental data were analyzed using the PLS regression in MODDE software. PLS was chosen for its ability to simultaneously examine the relationships between independent and dependent variables while handling multiple response variables. Unlike multivariate linear regression (MLR), which ignores the covariance between responses, PLS enables robust analysis of variable relationships by taking into account their covariance and variance. Given the presence of several related and non-independent responses in this study, the PLS method was selected as a more robustapproach than MLR. This approach made it possible to extract more accurate information from the data structure and identify complex relationships between process parameters (Eriksson et al., 2000).

2.4. Mineralogical studies

Mineralogical analyses of the sample using an optical microscope revealed that the main transparent minerals predominantly consist of, in turn, alkali feldspars, quartz, and plagioclase. Amphiboles and micas were also identified in thin sections, with investigations indicating that amphiboles and biotite transformed into epidote and chlorite assemblages in early alteration stages and into actinolite and serpentine in more advanced stages. Furthermore, the saussuritization process in plagioclases and alkali feldspars was observed, resulting in the formation of secondary iron-bearing minerals, such as epidote and zoisite. Magnetite, the primary iron ore, constitutes over 40% of the sample's composition. Microscopic examinations showed that magnetite fragments by 5-10 microns in size were present within the silicate gangue. Silicate gangue with 5-10 microns in size was observed within the magnetite particles. In some cases, martitization, the alteration of magnetite to hematite, was noted, particularly at crystal edges and along fracture surfaces.

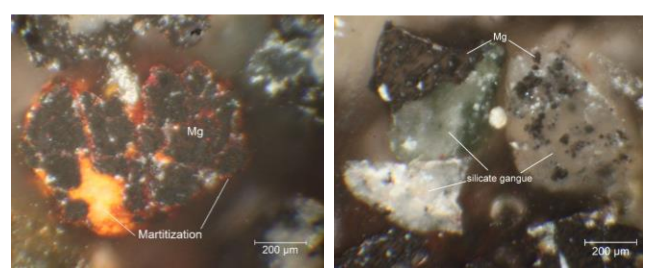

Fig. 2. Magnetite and martitization phenomenon in fractures and edges (left), magnetite within silicate gangue (right), (-60 microns).

2.5. Initial experiments

In this section, the effects of magnetic field intensity and speed of the separator, on the separation performance was investigated. Initially, initial experiments were designed with a constant pulp solids content of 35%, magnetic field intensity at three levels of 1200, 2700, and 3400 gauss, and separator linear speed at two levels of 1 and 1.4 m/s. It is noteworthy that the inlet pulp flow rate and the washing water flow rate were kept constant at 3 liters per minute (L/min) and 2 L/min, respectively, throughout all experiments.

2.6. Supplemental experiments

Preliminary tests demonstrated that a high-intensity magnetic field is essential to prevent further magnetite loss and enhance process efficiency. These tests were conducted with the magnetic field intensity adjusted to 2700 and 3400 gauss, the separator linear speed set at 1 and 1.4 m/s, and the pulp solids content configured at 25% and 35%. Notably, other parameters, such as inlet pulp and washing water flow rates, were kept constant throughout the experiments.

2.7. Assessing the quality of lost magnetite

According to the results of the initial beneficiation stage, the optimal FeO Satmagan recovery, representing magnetite recovery, reached 97.39%, indicating approximately 2.61% magnetite loss. To evaluate the quality of the lost magnetite, a series of experiments were conducted using a Davis tube. Tailings from the initial beneficiation were crushed to a final grind size below 63 µm, and reference samples were prepared. Magnetic separation tests were performed at field intensities of 1000, 2000, 3500, and 5000 gauss.

3. Results and discussion

3.1. Initial Experiment Results

The experimental conditions, the results obtained, and the metallurgical calculations are presented in Table 2. Based on the data presented in Table 2, the total iron grade in the sample under study varied between 48.11% to 50.21% depending on the operating conditions and the weight recovery of the concentrate ranged from 77.90% to 81.98%. Also, the total iron recovery ranged from 93.62% to 96.08% and the recovery of FeO based on the Satmagan analysis ranged from 97.05% to 98.83%. Since the Satmagan analysis fairly reflects the amount of magnetite present in the concentrate, it can be concluded that the recovery of magnetite in the pre-upgrading process was very satisfactory and more than 97% of magnetite could be recovered. A comparative analysis of iron oxide content obtained through titration and Satmagan methods revealed that titration consistently yielded higher values. This is attributed to the presence of divalent iron in non-magnetite iron-bearing minerals, such as silicates or secondary oxides, which are not detected by the Satmagan method.

The analysis of the results highlights the critical influence of operational parameters on separation performance. Specifically, increasing the magnetic field intensity of the separator was found to enhance both magnetite and total iron recovery, likely due to the stronger attraction of fine magnetite particles to the magnetic field. Conversely, an increase in the linear speed of the magnetic separator led to a relative decrease in concentrate grade, possibly because higher speeds reduce the residence time of particles on the rotating drum , allowing some non-magnetic gangue minerals to be entrained in the concentrate. These findings were consistent with the mineralogical characteristics of the sample.

From an industrial perspective, the high magnetite recovery (>97%) achieved in this study underscores the efficiency of high-intensity wet magnetic separation for processing magnetite-rich ores. This approach not only minimizes losses but also aligns with energy-efficient and cost-effective beneficiation strategies, as discussed previously. However, the slight reduction in concentrate grade at higher separator speeds suggests a trade-off between recovery and quality, which warrants careful optimization in large-scale operations. These findings contribute to the optimization of magnetic separation processes and provide a foundation for further research into enhancing concentrate quality and minimizing losses in magnetite ore processing.

3.2. Supplemental experiment results

The experimental conditions, results, and metallurgical calculations for the magnetic separation process are summarized in Table 3. The data presented in Table 3 illustrate the significant influence of operating parameters—namely magnetic field intensity, separator linear speed, and pulp solids content—on the performance and quality of magnetic separation during the pre-beneficiation stage. The total iron grade of the concentrate ranged from 50.82% to 52.55%, reflecting the combined effects of these parameters. The weight recovery of the concentrate varied between 76.70% and 80.11%, indicating a direct correlation with operating conditions. Specifically, lower pulp solids content and optimized field intensities contributed to higher weight recoveries by improving the selectivity of magnetic separation. Total iron recovery ranged from 92.27% to 94.97%, with higher recoveries observed at elevated magnetic field intensities, consistent with the enhanced attraction of magnetite particles under stronger fields. The recovery of iron oxide (FeO), as determined by Satmagan analysis, ranged from 96.68% to 98.47%, underscoring the exceptional efficiency of the pre-beneficiation process for magnetite recovery. Additionally, the FeO content in the concentrate, measured by Satmagan, varied between 12.40% and 14.47%, influenced primarily by magnetic field intensity and pulp solids content. These results align with earlier mineralogical findings, where magnetite was identified as micron-sized grains dispersed within a silicate gangue matrix, necessitating high-intensity separation to achieve optimal recovery.

From an industrial perspective, the high FeO recovery (up to 98.47%) achieved in this study demonstrates the efficacy of high-intensity wet magnetic separation for processing magnetite-rich ores. This approach not only maximizes resource utilization but also aligns with energy-efficient and cost-effective beneficiation strategies, as noted in earlier sections. However, the observed trade-off between concentrate grade and drum speed underscores the need for careful process optimization to balance recovery and quality in large-scale operations. For instance, operating at moderate speeds (e.g., 1 m/s) with high field intensities could strike an optimal balance, as evidenced by the upper range of iron grades and recoveries reported.

In conclusion, the findings from supplementary experiments demonstrated that increasing magnetic field intensity, combined with precise control of separator speed and pulp solids content, significantly enhanced iron recovery and minimized magnetite loss. Specifically, optimal conditions of 3400 gauss, 1 m/s separator speed, and 35% pulp solids content achieved a magnetite recovery of 97.21%, as determined by Satmagan analysis. A final flowsheet illustrating this optimized process is presented in Figure 3. These results confirm the high efficiency of wet magnetic separation in the pre-beneficiation process for magnetite recovery. The iron grades and recoveries obtained, supported by the optimal performance under these conditions, are highly satisfactory and efficient in ore processing.

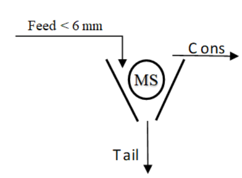

Fig. 3. Final flowsheet. Feed finer than 6 mm was separated by a wet magnetic separator.

Table 2. Initial test conditions and results.

Test ID	Parameters		Concentrate				Recovery			Head (Cal)		
	Intensity (G)	Speed (m/s)	C/F (%)	Fe (%)	FeO (%)	FeOsat (%)	RFe (%)	RFeO (%)	RFeOsat (%)	Fe (%)	FeO (%)	FeOsat (%)
R1	3400	1.4	81.52	48.11	13.19	12.40	95.79	93.72	98.83	40.95	11.47	10.23
R2	3400	1	81.98	48.27	13.80	13.33	96.08	94.50	98.77	41.18	11.97	11.06
R5	2700	1.4	79.58	48.11	13.80	12.71	94.73	93.73	97.73	40.42	11.72	10.35
R12	2700	1	79.71	49.51	14.40	14.01	94.65	93.09	98.62	41.70	12.33	11.32
R16	1200	1.4	77.90	50.21	14.85	12.96	93.62	92.90	97.05	41.78	12.45	10.40
R17	1200	1	80.66	49.20	14.05	13.48	95.20	93.98	98.53	41.69	12.06	11.04

3.2.1. PLS modeling

Following the implementation of the PLS model, the model fit criteria were utilized to assess the model's performance. In this diagram, it is imperative to examine R2 and the discrepancy between R2 and Q2. The R2 parameter, designated as the "goodness factor," quantifies the extent to which the raw data aligns with the regression model. Its value ranges from zero to one. A higher R2 value indicates a better fit between the raw data and the regression model. However, it is imperative to note that the R2 parameter is subject to limitations. Specifically, if there are many terms in the model, it may artificially produce a large value. Another appropriate index that shows the usefulness of the regression model is the Q2 index, known as the model's goodness of prediction. This parameter estimates the predictive power of the model. For a very good model, the R2 and Q2 parameters should have high values and their difference should not exceed 0.3. The next index in the summary fit plot is the repeatability and reproducibility index, whose high values indicate a lower repeatability error compared to the overall design variability, a value less than 0.5 for this index indicates a large net error and poor control of the experimental steps (Eriksson et al., 2000).

The model fit diagram is shown in Figure 2. By examining the values of the aforementioned indices on the multiple responses in the model, it is observed that the fitted model is both appropriate and acceptable.

	R2	Q2	Model Validity	Reproducibility
Grade	0.80	0.57	0.80	0.80
Recovery	0.93	0.82	0.58	0.97

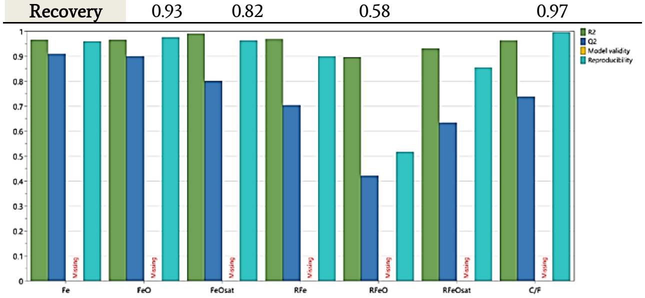

Fig. 4. The summary of the fit for the PLS model.

3.2.2. Variable importance

The Variable Importance Plot (VIP) of the final model to examine the parameters that affect all the responses is shown in Figure 3. As can be seen from the VIP diagram, the quadratic expressions of solid percentage, magnetic intensity, and separator speed have the greatest impact on the responses, with a VIP value of 1.257. After the quadratic terms, the solid percentage parameter has the largest impact, followed by the speed by solid percentage interaction (spe*sol), the speed parameter, the magnetic intensity by speed interaction (int*spe), and the magnetic intensity by solid percentage interaction (int*sol). Finally, the magnetic intensity with a VIP value of 0.63 has little effect on the responses. The insignificant effect of magnetic intensity may be due to the ferromagnetic property of magnetite and the proximity of the factors levels to each other, this property causes the recovery of magnetite even at low magnetic intensities.

3.2.3. Interaction effects

The interaction between magnetic intensity and separator linear speed is one of the interaction effects on the responses of iron oxide and recovery from iron ore, as shown in Figure 4. However, there are some other interaction effects that have a lesser effect on the responses and are not shown here. From Figure 4, it can be seen that in the response of the iron oxide grade from the iron ore at low speed, the grade increases slightly with increasing magnetic intensity, but after an intensity of 3050 gauss, the grade increases with a steep slope. Conversely, at high speed, with increasing intensity, the grade initially decreases, but beyond 3050 gauss, it increases slightly. It appears that with increasing speed of the magnetic separator, due to the ferromagnetic nature of magnetite, the iron grade recovered from the iron ore shows an almost increasing trend at bot speeds, with the rate of increase being greater at lower speeds.

The interaction between magnetic intensity and separator speed on the response related to the recovery of iron oxide obtained from the iron ore shows that at low speeds, with increasing magnetic intensity, the recovery initially increases, but after a magnetic intensity of 3050 gauss, the recovery decreases. At high speeds, with increasing magnetic intensity up to 3050 Gauss, the recovery increases with a steep slope, but after a magnetic intensity of 3050 gauss, the recovery increases gently.

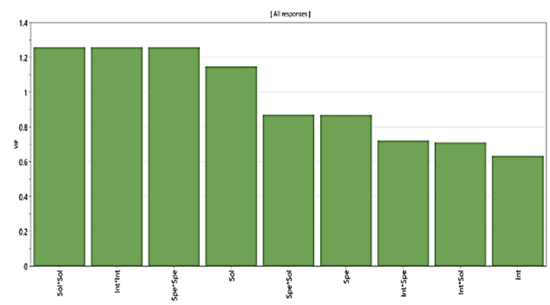

Fig. 5. Variable importance plot of the final model.

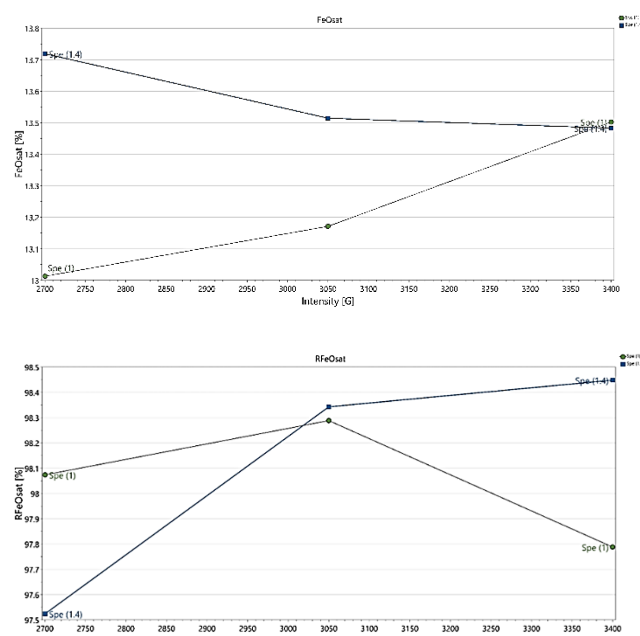

Fig. 6. The interaction of parameters on the responses of grade and recovery of iron oxide from satmagan.

3.2.4. Contour plots

After studying the effects of the parameters on the process, equipotential surfaces were created to better understand the model. The purpose of constructing equipotential surfaces is to find the appropriate range of parameters for the experiments. Figure 5 shows the changes in the responses of the grade and recovery of iron oxide from the slag in terms of magnetic intensity and separator speed, and the intermediate limit of the solid percentage parameter is considered. The results obtained show that high grades can be obtained by setting the separator speed to the maximum and the magnetic intensity to the lowest limit. In addition, the speed and magnetic intensity simultaneously affect the recovery of iron oxide from the slag so that the highest recovery is obtained at the maximum speed and magnetic intensity. According to the explanations, it is clear that the effect of both speed and intensity parameters on the above responses is large.

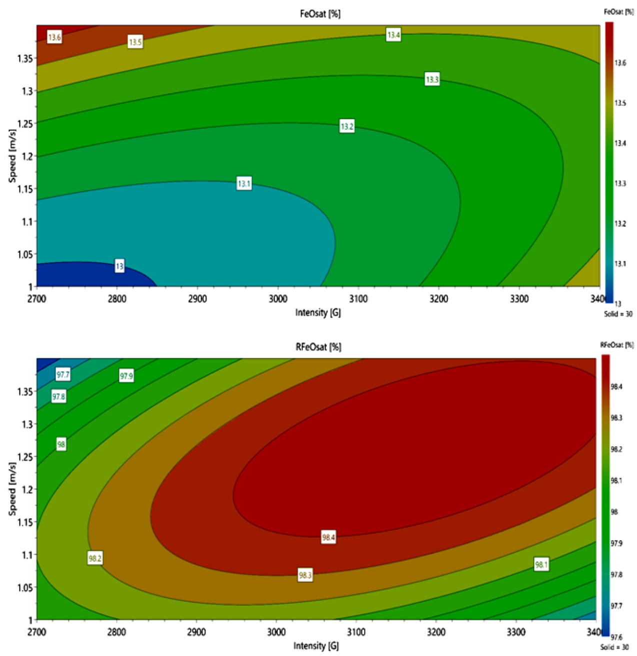

Fig. 7. Contour plots related to the grade response and recovery of iron oxide from the satmagan.

3.3. Lost Magnetite Quality Assessment Results

The results of the quality assessment of lost magnetite, derived from Davis Tube tests, are presented in Table 4. These experiments were conducted to evaluate the characteristics of magnetite lost during the pre-beneficiation stage. According to the data in Table 4, the weight recovery of magnetic materials from the tailings was consistently low, ranging from 0.30% to 0.84% across magnetic field intensities of 1000, 2000, 3500, and 5000 gauss, corroborating the high efficiency of the pre-upgrading process reported previously. As magnetic field intensity increased, the iron and FeO content in the concentrates, as determined by titration analysis, decreased progressively. Specifically, the iron content ranged from 63.13% at 1000 gauss to 57.22% at 5000 gauss, while FeO content varied from 21.30% to 17.0% over the same range.

These results indicate that the magnetite recovered from the tailings via the Davis Tube has low quality. This low quality is likely attributable to the presence of fine-grained, disseminated magnetite inclusions entrapped within the silicate gangue matrix, as observed in earlier mineralogical analyses. The small particle size (<63 µm, as prepared for these tests) and the association with non-magnetic gangue minerals further explain the poor quality of the recovered magnetite. Consequently, it can be inferred that the magnetite lost during the pre-beneficiation stage is not suitable for inclusion in the final concentrate, as its incorporation would likely reduce the overall concentrate grade.

Table 4. The conditions of the Davis test and the results together with the metallurgical calculations.

Test ID	Parameters	Concentrate			Recovery		Head(Cal)	
	Intensity (G)	C/F (%)	Fe (%)	FeO (%)	RFe (%)	RFeO (%)	Fe (%)	FeO (%)
H1	1000	0.30	63.13	21.30	2.10	1.80	8.86	3.50
H2	2000	0.49	61.26	21.50	3.40	3.02	8.86	3.50
H3	3500	0.67	59.40	19.80	4.50	3.80	8.86	3.50
H4	5000	0.84	57.22	17.30	5.41	4.14	8.86	3.50

The low quality of the lost magnetite supports the strategic advantage of allowing minor magnetite losses in the pre-beneficiation stage to enhance the quality of the final concentrate. The Davis Tube results suggested that the small fraction of magnetite lost (approximately 2–3%, as noted earlier) consists primarily of low-grade material, which, if recovered, could compromise the high-grade concentrate achieved. Thus, the trade-off of sacrificing a minor portion of low-quality magnetite is justified to maintain the superior quality of the final product.

minerals. The findings demonstrated the successful removal of carbonate minerals by reverse flotation, resulting in a final product with more than 30% P_2O_5 content and more than 70% recovery. The final process flowsheet is presented in Fig. 9. The acid scrubbing step (Section 2.5.1) enhanced the selectivity of carbonate flotation by desorbing collectors from the concentrate. It has been established that phosphoric acid and sulfuric acid are effective depressants for reverse flotation of phosphate ores under acidic conditions (Huang & Zhang, 2024). Previous studies have confirmed that using a mixture of sulfuric and phosphoric acids is more effective for apatite depression than using either acid alone. This is why a mixed acid system was used in the present work. The mixed acid system decreases the contact angle of apatite to the lowest state, which is effective depression (Lai et al., 2023). The mechanism for the depression of apatite by phosphoric acid and sulfuric acid at pH 4.5 involves further chemical adsorption of H_3PO_4 onto apatite surfaces, leading to the formation of hydrophilic species including $CaHPO_4$, $Ca(H_2PO_4)_2$, and $CaH_2PO_4^+$, which restrict collector adsorption on apatite surfaces. Among these, $CaHPO_4$ is considered the primary species responsible for effective apatite depression (Liu, Ruan, et al., 2017; Huang & Zhang, 2024). In addition, sulfuric acid contributed further to the overall effect by forming a poorly soluble $CaSO_4$ layer on apatite surfaces, preventing collector access to the calcium sites (Liu, Luo, et al., 2017; H. Zhang et al., 2025). These results indicated that reverse flotation is a suitable complementary method to direct flotation, improving the quality of the apatite concentrate for industrial use. These grade and recovery values can be further optimized by adjusting collector consumption in this stage or by fine-tuning pH during the acid scrubbing or preparation with sulfuric and phosphoric acids for apatite depression. These findings show that these tailings can be processed as an apatite source, offering an economic resource while reducing tailings and reusing them for environmental preservation.

4. Conclusions

In conclusion, the results underscored the efficacy of high-intensity wet magnetic separation for valorizing magnetite-bearing tailings at the Sangan Company. The optimal conditions (3400 gauss, 1 m/s, 35% solids) achieved a magnetite recovery of 97.21% and an FeO content of 14.47%, demonstrating the process's ability to produce high-quality concentrates while reducing tailings mass by 18–22%. The low quality of lost magnetite, as confirmed by Davis Tube tests, justified the strategic acceptance of minor losses to enhance final concentrate quality. PLS modelling further elucidated the critical influence of quadratic parameter interactions, providing a robust framework for process optimization. These findings contributed to sustainable tailings management by enabling efficient magnetite recovery and reducing waste volume. From an industrial perspective, the process aligns with cost-effective and resource-efficient beneficiation strategies, offering significant potential for large-scale implementation. Conducting pilot-scale trials with industrial wet magnetic separators under optimal conditions (3400 gauss, 1 m/s, 35% solids) to assess scalability, throughput, and economic viability is proposed.

Acknowledgement

The author is grateful to Sangan Company for the provision of representative samples of waste in its depots and to Sahand University of Technology for access to its laboratory facilities, which were used in the conduct of this research.

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