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Recovery of Iron Ore From The Tailings of Tang Zagh Iron Beneficiation Plant: A Comparative Study of Gravity and Magnetic Separation Methods

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ABSTRACT

Based on the importance of recovering iron ore tailings due to the decreasing high-grade deposits and the challenge of managing mining waste, this study focused on the recovery of hematite from the fine particles of the tailings dam sample prepared from the Tang Zagh processing plant. Analysis and characterization of the sample revealed that 52% of the sample's weight is in the -38 micron size fraction, and roughly 55% of the iron is distributed within this size fraction. The main minerals in the sample include hematite, quartz, goethite, and occasionally magnetite. Additionally, the sample contains 46% total iron and 0.67% FeO. To achieve the degree of liberation for various tests, the sample size was reduced to -38 microns. Furthermore, three different approaches (gravity, magnetic, and a combination of gravity and magnetic) were employed for ore concentration. Through the Multi-Gravity Separator (MGS) at three stages, with angles of 2, 4, and 6 degrees, a concentrate with a 57.92% grade and 38.9% iron recovery was produced. Utilizing the High Gradient Magnetic Separation (HGMS) method across three stages, magnetic field intensities of 7000, 10000, and 13000 Gauss, using the Box Mag device, yielded a concentrate with a 61.92% grade and 12.76% iron recovery. Considering the market potential for the concentrate with approximately 58% Fe grade, the best approach for ore enrichment is the Multi-Gravity Separator (MGS), which surpasses the magnetic method in terms of higher recovery and economic feasibility. Moreover, the results indicate that a combination of the Multi-Gravity Separator and magnetic tests can be employed to increase iron grade and recovery. Using this approach, a concentrate with a grade of 62.32% Fe and 17.87% recovery was achieved.

KEYWORDS

Fine Hematite Particles, Multi-Gravity Separator (MGS), HGMS, Tang_Zagh Mine

I. INTRODUCTION

Iron ore tailings are solid waste produced during the beneficiation process of iron ore concentrate. Among various types of solid mineral wastes, these tailings are one of the most common types of solid mineral wastes in the world due to their high output and low recovery ratio (Tang et al., 2019). In Iran, due to the growth of the iron and steel industries, the production of iron ore tailings has rapidly increased, requiring significant economic costs for their management and causing serious environmental problems. Over time, as iron ore resources diminish and prices increase, iron ore tailings have become valuable resources. Currently, processes for utilizing iron ore tailings can be mainly divided into two categories: recovering iron ore from tailings and using the tailings as raw materials (Rao et al., 1985). Many methods for recovering iron tailings have been developed, including gravity separation, magnetic separation, flotation, and magnetizing roasting methods to convert oxidized iron minerals (such as hematite, goethite, and limonite) to magnetite, followed by low-intensity magnetic separation methods (Rao et al., 1985; Sakthivel et al., 2010). Among these methods, gravity separation has lower costs compared to magnetic and flotation methods and other methods considered newer in the field.

Hematite ore, compared to magnetite ore, has lower magnetic properties and greater mineralogical complexities, making its processing more challenging. Therefore, most of the tailings from iron ore processing plants consist of hematite. Typically, these tailings contain very fine particles, making their processing and achieving the desired grade and recovery difficult. Research has shown that devices such as a Multi-Gravity Separator (MGS) (Fig. 1) and a High Gradient Magnetite Separator

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(HGMS) can be used for processing these particles (Nunna et al., 2022).

The Tange-Zagh iron mine in southern Iran is located 120 kilometers from Bandar Abbas towards Sirjan, the iron ore of this mine is mostly hematite and goethite, and magnetite ore is rarely seen. To process the iron ore, a processing unit has been established near the mine, where the extracted materials are transferred to the spiral unit after the crushing and grinding stages. In this plant, following concentration, a concentrate with a grade of 65% is produced, yielding between 30 to 40%, depending on the feed grade. The spiral tailings are disposed of in the tailings dam after dewatering by thickeners and filtration.

This study aims to investigate operational procedures for selecting the best method, such as gravity, magnetic, or a combination of these methods, for the recovery of fine iron particles (hematite) from tailings dams. For this purpose, a representative sample was obtained from the tailings dam, and various experiments were conducted on it, the results of which are presented in this article.

II. MATERIALS AND METHODS

In order to conduct experiments, a sample was taken from the tailings dam of the Tange-Zagh processing plant, and approximately 250 kilograms of the sample were transferred to the mineral processing laboratory of the School of Mining Engineering, University of Tehran. After homogenization, a representative portion of the sample was prepared for XRD and XRF analyses, sieve analysis, and mineralogical studies. The results of sieve analysis and mineralogical studies, as well as XRD and XRF analyses, indicated that approximately 52% of the total sample weight and about 55% of the iron distribution are in the -38 micron size fraction and the d_{80} of the sample is 170 microns (Fig. 4). Additionally, the results suggested that the main constituent minerals of the sample include hematite, quartz, goethite, and rarely magnetite (Fig. 2), (Fig. 3), (Table 1) Furthermore, the results showed that the sample contains 46% total iron, 17.09% SiO2, 3.84% Al_2O_3, and 0.67% FeO (Table 2).

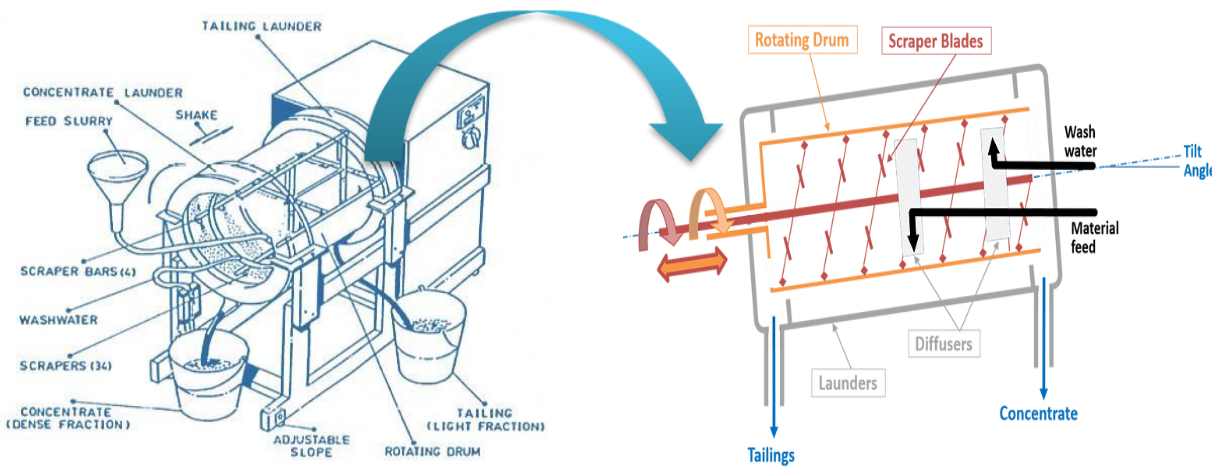


Fig .1. Schematic of the structure of the Multi-gravity separator (MGS) device on a pilot scale (Sobhy, 2022)

Table 1. Mineralogical study results of prepared samples.

Metallic minerals	Hematite, Limonite, Goethite, Magnetite, and Manganese minerals
Non-metallic minerals	Feldspar, Quartz, Calcite, Clay mineral, Mica

Table 2. Results of XRF and titration analysis

Fe(total)	FeO	SiO_2	Al_2O_3	S	P	TiO_2	CaO	MgO	MnO	LOI
46	0.67	17.09	3.84	0.44	0.54	0.19	1.17	0.43	0.86	5.79

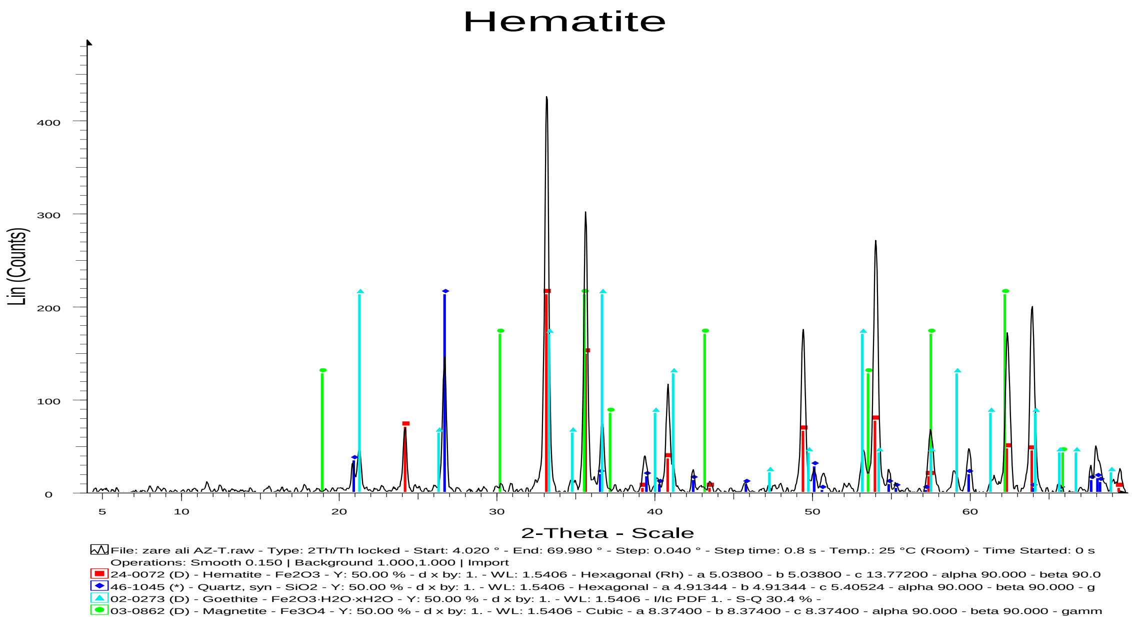


Fig. 2. XRD analysis graph of the sample

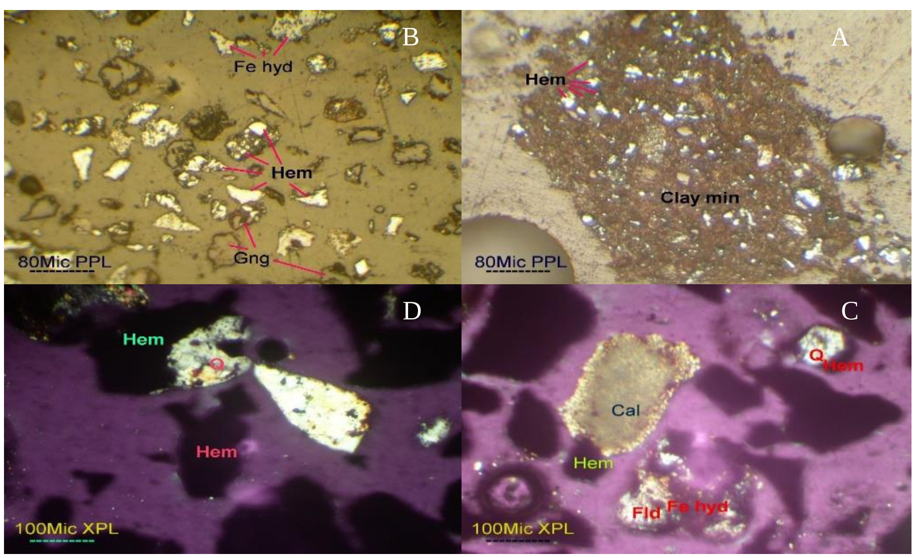


Fig. 3. (A) Hematite particles among clay, (B) Interactions between hematite particles and gangue, (C) Interactions between hematite, quartz, and calcite, (D) Interaction between quartz and hematite.

III. LABORATORY TESTS

1) *MULTI-GRAVITY SEPARATION (MGS) TEST*

The Multi-Gravity Separator (MGS), also known as the Enhanced-Gravity Separator (EGS), was developed in the late 1980s to early 1990s for concentrating fine and ultra-fine heavy minerals. Initially, its focus was on minerals such as cassiterite, chromite, celestite, and magnetite (Chan et al., 1991). The device functions based on principles akin to a shaking table but employs rotational motion to produce centrifugal forces surpassing those of gravity. This augmented force facilitates enhanced separation, particularly at finer particle sizes (Fitzpatrick et al., 2018). The key design and operational variables of the MGS are outlined in Fig. 1. The pilot scale of the MGS device (Mozley) with a Capacity of 200 kg/hour (presently known as Model: SCMG1/ C 900) which can treat 500 microns to 1 micron size (Rao et al., 2017), was used in this experimental work. The variable parameters of this device included device slope, washing water, inlet water (Solid weight percentage), and drum speed (Fig. 1). A review of this research literature reveals that the rotational velocity of the drum has been identified as the most important factor in grade and recovery (Ahmadabadi et al., 2012; Venkateswara et al., 2014). Based on the results of Akbari et al, and preliminary tests, the optimal conditions for this sample were achieved. For the MGS test, approximately 5 kilograms of samples were prepared in the -38 micron size fraction. Subsequently, the prepared sample was subjected to the MGS test. The experiments were conducted under identical and optimized conditions: 7 minutes duration, a washing water flow rate of 4 liters per minute, an inlet water flow rate of 2 liters per minute, and drum speed 180 rpm, in three stages rougher, cleaners, and re-cleaners at three different slopes: 2, 4, and 6 degrees and the flowsheet of the three-stage test is presented in Fig. 5. The purpose of this stage is solely to investigate the application of gravity separation (MGS) technique.

2) *THREE-STAGE HIGH-GRADIENT MAGNETIC SEPARATION (HGMS) TEST*

For this test, the Box Mag magnetic device (HGMS) was used. The three-stage test was conducted using 5 kilograms of sample with a solid weight percentage of 50 and a particle size of -38 micron size fraction, with magnetic field intensities of 7000, 10000, and 13000 Gauss. Initially, the magnetic test was performed with a field intensity of 13000 Gauss as the rougher test, followed by intensities of 10000 and 7000 Gauss as cleaner and re_cleaner tests, respectively, as illustrated in the flowsheet in Fig. 6. The purpose of this stage is solely to investigate the application of magnetic separation.

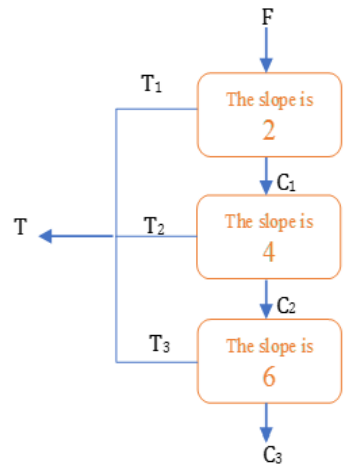
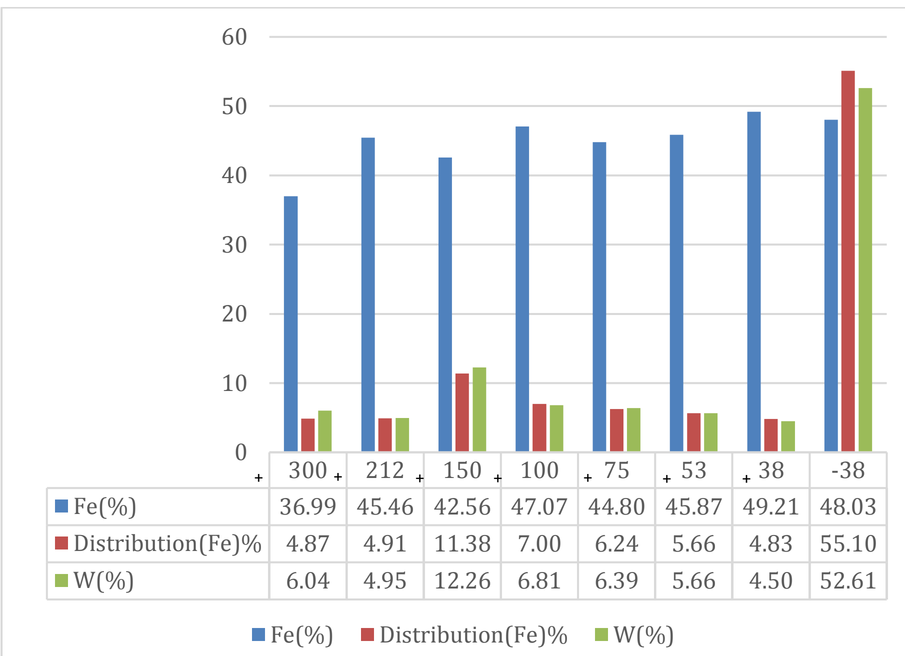


Fig .5. Flowsheet of the three-stage multi-gravity separation



	+300	+212	+150	+100	+75	+53	+38	-38
Fe(%)	36.99	45.46	42.56	47.07	44.80	45.87	49.21	48.03
Distribution(Fe)%	4.87	4.91	11.38	7.00	6.24	5.66	4.83	55.10
W(%)	6.04	4.95	12.26	6.81	6.39	5.66	4.50	52.61

Fig. 4. Distribution of metal content and iron grade, and weight percentage of mineral in different size fractions

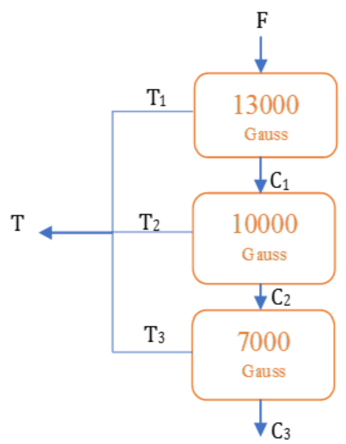


Fig. 6. Flowsheet of the three-stage magnetic separation.

3) COMBINED MULTI-GRAVITY AND MAGNETIC TEST

In this test, as per Fig. 7, the sample in the dimensional range -38 micron size fraction was subjected to the MGS using a rougher, cleaner, and re-cleaner setup. Subsequently, two magnetic tests were conducted on the concentrate of the MGS device using magnetic field intensities of 10000 and 7000 Gauss (after performing the three-stage multi-gravity test, the magnetic test was conducted).

IV.RESULTS

A. RESULTS OF THE THREE-STAGE MULTI-GRAVITY

After conducting the three-stage test with the MGS device on samples sized -38 microns, it was found that this device is capable of producing a concentrate with a grade of 57.92% and an iron recovery of 38.9%. Furthermore, microscopic examinations on feed, tailings, and concentrate samples showed that this device could effectively separate gangue materials such as quartz, clay minerals, and alumina from the size range of -38 microns from the primary feed. The results are presented in Table 3.

B. RESULTS OF THREE-STAGE HIGH GRADIENT MAGNETIC SEPARATION (HGMS)

After conducting the three-stage test with the Box Mag magnetic device, a concentrate with an iron grade of 61.92% and a recovery of 12.76% was obtained. The duration of the first test (Rougher) was 1 minute and 50 seconds long, the second test (Cleaner) was 1 minute, and the third test (Re_cleaner) was 50 seconds. The results indicate that due to the presence of clay particles within the size range of -38 microns and the lower magnetic susceptibility of hematite (The main mineral in the sample), the recovery of the magnetic device decreases. Nevertheless, a high grade is achieved (Table 4).

C. RESULTS OF COMBINED MULTI-GRAVITY AND MAGNETIC TEST (HGMS)

The combined MGS and magnetic test was conducted on samples sized -38 microns, resulting in a concentrate with an iron grade of 62.32% and a recovery of 17.87% iron (Table 5). The duration of the magnetic tests was 57 seconds for 10000 Gauss and 30 seconds for 7000 Gauss. Based on the results, it can be concluded that the combination of the Multi-gravity and magnetic tests can lead to an increase in grade and recovery compared to separate multi-gravity and magnetic tests.

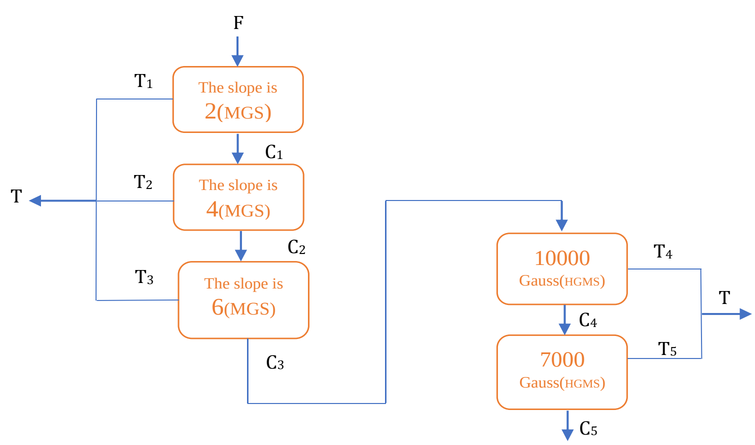


Fig. 7. Flowsheet of the combined multi-gravity and magnetic separation test

Table 3. Results of the three-stage multi-gravity separation test

Test number	Step	Slope (Degree)	Product name	Yield (%)	Grade (%)	Recovery (%)
1	Rougher	2	Concentrate	45.61	52.22	51.77
			Tailing	54.39	40.8	48.23
			Total	100	46.01	100
2	Cleaner	4	Concentrate	37.82	55.63	45.73
			Tailing	7.79	35.67	6.04
			Total	45.61	52.22	51.77
3	Re-cleaner	6	Concentrate	30.9	57.92	38.9
			Tailing	6.92	45.38	6.82
			Total	37.82	55.63	45.73

Table 4. Results of the three-stage magnetic test

Test number	Step	Field intensity (Gauss)	Product name	Yield (%)	Grade (%)	Recovery (%)
1	Rougher	13000	Concentrate	22.5	58.38	28.22
			Tailing	77.5	43.12	71.78
			Total	100	46.55	100
2	Cleaner	10000	Concentrate	13.85	60.92	18.12
			Tailing	8.65	54.32	10.09
			Total	22.5	58.38	28.22
3	Re-cleaner	7000	Concentrate	9.60	61.92	12.76
			Tailing	4.25	58.71	5.36
			Total	13.85	60.92	18.12

Table 5. Results of the combined MGS and magnetic test

Test number	Step	Slop (Degree)/Field intensity(Gauss)	Product name	Yield (%)	Grade (%)	Recovery (%)
1	Multi-gravity	2	Concentrate	45.61	52.22	51.77
			Tailing	54.39	40.8	48.23
			Total	100	46.01	100
2		4	Concentrate	37.82	55.63	45.73
			Tailing	7.79	35.67	6.04
			Total	45.61	52.22	51.77
3		6	Concentrate	30.90	57.92	38.90
			Tailing	6.92	45.38	6.82
			Total	37.82	55.63	45.73
2	Magnetic	10000	Concentrate	19.04	60.4	24.99
			Tailing	11.86	53.9	13.9
			Total	30.90	57.92	38.90
3		7000	Concentrate	13.20	62.32	17.87
			Tailing	5.84	56.15	7.13
			Total	19.04	60.4	24.99

V. CONCLUSION

This study aimed to investigate the recovery of hematite from the fine particles of tailings at the processing plant of the Tange-Zagh mine. The prepared sample underwent various analyses, revealing that 52% of the sample weight falls within the size range of -38 microns, with approximately 55% of the iron metal distribution in this range. The main minerals in this sample were hematite, quartz, goethite, and occasionally magnetite. Additionally, it was determined that the sample contains 46% total iron and 0.67% FeO. To achieve the desired degree of liberation for conducting various tests, the sample was sized to -38 microns. The results of separation tests conducted in three different conditions indicated that considering the marketability of a concentrate with approximately 58% grade, the best method for upgrading this sample is the use of the MGS device in three stages. Using this device, a concentrate with a grade of 57.92% and an iron recovery of 38.9% was produced. This result showed a higher recovery compared to the High-Gradient Magnetic Separation (HGMS) method using the Box Mag magnetic device, which produced a concentrate with a grade of 61.92% and an iron recovery of 12.76% over three stages. Furthermore, the results demonstrated that

combining gravity tests (MGS) and magnetic tests could increase both grade and recovery. In this study, such a combination yielded a concentrate with a grade of 62.32% and an iron recovery of 17.87%.
Furthermore, considering the marketability of a concentrate with approximately 58% grade, lower operational costs, and higher recovery of the MGS device compared to the magnetic device (HGMS). The proposed basic flowsheet for concentration plant tailings is presented in Fig. 8.

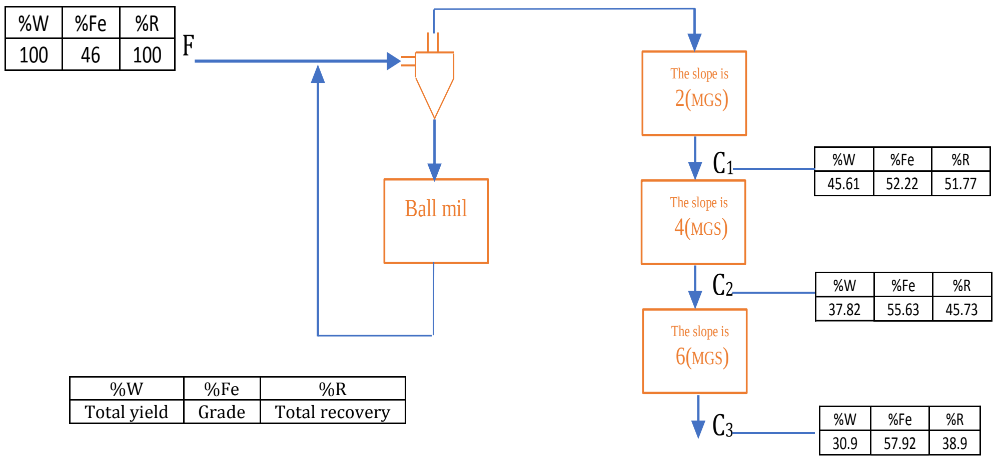


Fig. 8. Flowsheet of the proposed base recovery of iron ore from the tailings of Tang Zagh iron beneficiation plant

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