IJE TRANSACTIONS B: Applications Vol. 35, No. 08, (August 2022) 1608-1618

International Journal of Engineering

Journal Homepage: www.ije.ir

Optimization of Line of Magnetite Recovery from Wet Tailings by Creating Second Medium Intensity Magnetic Field (Case Study: Processing Plant of Gol-e-Gohar Hematite)

M. Hosseini Nasab*[a], R. Rezazadeh[b]

[a] *Mining Engineering Department, University of Sistan and Baluchestan, Zahedan, Iran*
[b] *Mining Engineering, Head of Golgohar's Hematite Factory, Sirjan, Iran*

PAPER INFO

Paper history:
Received 04 September 2021
Received in revised form 15 May 2022
Accepted 19 May 2022

Keywords:
Gol-e-Gohar
Magnetite
Wet Tailing Process
Pulp
Magnetic Separator

ABSTRACT

The primary raw material of the steel industry is iron. This paper aims to optimize magnetite recovery from wet tailings by increasing the iron content in the concentrate of the line. To manage tailings, a Wet Tailing Processing (WTP) line constructed at Gol-e-Gohar Iron Ore Company to recover the magnetite. The dominant crystalline phases in these tailings were quartz, albite, talc, hematite, and calcite. The line feed is 45 microns, which is not suitable for the gravity method. Thus, separation can achieve using only the magnetic method. Because of the high iron content in the tailings, a wet magnetic separator is used. According to the results, the proposed medium-intensity separator and the associated circuit modifications increase iron recovery from 7 to 30 percent; resulting in 150 tons of annual production; preventing loss of iron through concentrator plant tailings, and increasing the Blain number by 50 to 100 units in the hematite plant. Furthermore, water consumption is significantly reduced by replacing old wet tailings of the concentrator plant with new wet tailings as the feed, which is another significant achievement of this research. Instead of fresh water, saline water with flow rate of 250 cubic meters per hour are used.

***doi**: 10.5829/ije.2022.35.08b.17*

NOMENCLATURE

FOB	Free On Board	D80	The 80% passing size

1. INTRODUCTION

In recent years, steel applications have been developed [1-3]. The significant raw material of the steel industry is iron. There are several methods to increase the iron grade of its ore, the most important of which is the magnetic method [4]. In this method, particles containing magnetic properties are affected by magnetic forces [5]. Low-intensity magnetic separators, which comprise one of the most widely employed magnetic separation equipment, in both dry and wet forms, concentrate relatively large and highly magnetic particles [6-8]. Their magnetic field is permanent and is about 1,000 to 2,000 gauss. Low-intensity wet magnetic separators have better efficiency than dry type, and their extracted iron grade reaches to about 70% [6, 7].

Reuse of tailings results in savings cost for dumping and handling of tailing dumps and decreases the pollution of the environment [9].

In general, to produce iron concentrate in Gol-e-Gohar plant, pre-processing stage by the spiral concentrator, wet low and high-intensity magnetic separation and flotation process for desulfurization of the final concentration are performed [10]. Reverse flotation of pyrite is done at pH= 4.5 by 300 g/t potassium amyl xanthate collector with maximum foaming time. The rotation speed of the cylinder, the intensity of the magnetic field, and the degree of crushing are the main factors to effect the iron recovery from the tailings [11].

---

*Corresponding Author Institutional Email: hosseininasab@eng.usb.ac.ir (M. Hosseini Nasab)

Please cite this article as: M. Hosseini Nasab, R. Rezazadeh, Optimization of Line of Magnetite Recovery from Wet Tailings by Creating Second Medium Intensity Magnetic Field (Case Study: Processing Plant of Gol-e-Gohar Hematite), ***International Journal of Engineering, Transactions B: Applications,*** Vol. 35, No. 08, (2022) 1608-1618

Gol-e-Gohar hematite plant, located in the southeast of Iran (Sirjan), includes 1.2 billion tons of geological reserve and an annual production of 7 million tons of iron ore concentrate. This plant has three separate lines: Line 100 (L1), used for hematite recovery from dry tailings of the concentrator plant; Line 200 (L2), used for magnetite recovery from Wet Tailings Processing (WTP); and Line 300 (Line 3), used to desulfurize the concentrate obtained from the concentrator plant. The tailings from the three lines combine to enter the thickener. Solid pulp concentration can increase using the thickener, and the recovered water re-enters the line.

Hematite is the dominant mineral containing iron in Gol-e-Gohar. Sulfur impurities in the feed, which causes environmental problems in discharging the tailing [12], are due to iron-bearing minerals such as muscovite and biotite. Nearly 67 percent of the iron ore particles in the plant are smaller than 38 microns in diameter. Approximately 80 percent of WTP tailings pass through a screen opening (D_{80}), 70 microns in diameter. The iron ore locked with gangue minerals is observed at the smallest level, and the best degree of liberation under 38 microns is 40 percent. The small size of the feed particles complicates the recovery process [13].

Wet magnetic drums[1] use to extract iron particles from ore, increase efficiency, and obtain higher-quality output[2]. These magnetic drums are classified into three groups: Low-Intensity Magnetic Separators (LIMS) [14-16], Medium-Intensity Magnetic Separators (MIMS) [14], and High-Intensity Magnetic Separators (HIMS) [14, 17].

Wet magnetic drums are composed of a housing[3] (stainless steel[4]) and a cylindrical shell (made of anti-abrasion stainless steel) which generates a constant magnetic field. Magnetic drum separation obtained by the rotation of a cylindrical surface around a permanent magnetic field. Once the feeder releases raw materials onto the roller of the separator, non-magnetic materials move along the typical path and are removed appropriately; in contrast, the iron attracted onto the shell continues to rotate to the last magnetic point and is discharged at the back of the roller [18-20]. Based on working conditions, three types of wet drums can employ: co-current, counter-current, and counter-flow. Advantages of wet magnetic drums include high strength, anti-abrasion stainless steel shell, very high magnetic attraction, automatic separation of iron particles, a permanent magnetic field without a supply source, and various designs with different magnetic field intensities. Wet drums are also helpful in mining industries such as mining iron ore, processing silica, and separating iron particles in mines using wet methods[3].

Extensive research has been conducted on increasing the iron ore grade by magnetic methods in recent years, as mentioned below.

Shao et al. [21] investigated the processing of Esmalon iron ore by magnetic separation method. They obtained a 63% iron grade concentrate and a 65% recovery rate by a low-intensity wet magnetic separator. Zhang et al. [22] developed a novel method for iron recovery from iron ore tailings with pre-concentration followed by magnetization roasting and magnetic separation. In the first stage, they obtained 42% iron grade and 74.43% iron recovery in the size of +74-149 microns and the intensity of 1200 gauss. Then the obtained concentrate was milled, and in the second stage, in the power of 2000 gauss, it resulted in a concentrate with a 62.79 % iron grade and 98.23% iron recovery. Dwari et al. [23] concentrated low-grade iron ore in a low-intensity wet magnetic separator. They obtained a concentrate with 67% iron grade and 90% iron recovery of a particle size distribution smaller than 200 microns [23]. Behnamfard and Khaphaje [24] increased the iron grade of low-grade iron ore in a low-intensity dry magnetic separator and obtained a concentrate with a grade of 47.15% and weight recovery of 68.56%. Behnamfard and Khaphaje [24] used a dry magnetic separator (1000 Gauss) and freshwater to process the Sangan iron ore, not exploit the tailings, and not consider the profitability of their research.

Argimbaev et al. [9] studied chemical composition, the mineral petrography of thin and polished sections, grain size distribution, and physical-mechanical properties of iron-containing tailing of enrichment of combined mining and processing in Kursk magnetic anomaly of Russia. Their research showed that iron-containing tailings of processing plants could find an increased absorption capacity due to the presence of clay minerals in them.

According to Qaredaqi and Rafizadeh [13], the low magnetic sensitivity of fine hematite particles precludes the use of a LIMS. However, Wang et al. [8] showed the use of auxiliary permanent magnets, which are embedded in the main permanent magnets, could capture a wider range and finer particle size in low-intensity magnetic separators.

The most well-known wet magnetic separator is the Jones separator [20]. The HIMS is often used with fine and magnetically weak iron particles [23-27]. The first implementation of the separator dates back to 1972 in Brazil, when it was used to increase the fine-grained hematite content in the feed [18]. In 1996, Shao et al. [21] proved that the dimensions of the particles are relatively insignificant when using a HIMS. However, the high

---

[1] - Wet cylindrical-magnetic separators

[2] http://www.papkomagnetics.com/product/p2.htm

[3] - A housing is a metallic container or cover for mechanical parts such as filters, bearings, and gears.

[4] - Refers to a group of iron-based alloys containing at least 10.5 percent chromium; the chromium content rarely exceeds 30 percent, while iron grade rarely falls below 50 percent [24].

hematite content in WTP prevents using a HIMS in the studied plant.

To produce iron-containing concentrate in Gol-e-Gohar plant, the iron ore extracted from the mine after initial crushing transfers to a gyratory crusher. Then the materials in the dry autogenous mill are re-crushed, and are sent into the dry magnetic separators after passing through the air classifier, the cyclone, and the two-layer sieve (in a closed circuit with a mill). This step has three outputs. The first output is the final dry concentrate sent to the dry concentrate silo for sale. Cleaner tailing and scavenger concentrate are the middle product of the wet line feed of the plant. Scavenger tailing, as dry tailing, firstly transports by conveyor to the storage silo of dry tailing and then sent to a dry tailing dump.

The objective of this paper is to design an optimal circuit for the WTP line and investigate its efficiency under actual conditions in the plant. Thus, in the following, the WTP line in the plant is described.

The wet tailings of the plant, after being stored in a 2000-ton container, transport from the lower part of the container to the washing drum using a conveyor belt. The separation process requires 60 cubic meters of water per hour. The developed pulp transfer onto the vibrating screen; materials larger than 1.5 mm, comprising a small portion of the materials, are carried out by the conveyor belt. The remaining particles using a pump move to three LIMS: rougher, cleaner, and re-cleaner. In the first stage, iron ore particles separate using a magnetic separator, and the concentrate advances to the second stage. The final tailings developed by the rougher and cleaner separators subsequently move to the tailing thickener. The tailings from the last separator return to the cleaner. The concentrate from the re-cleaner is the final concentration of the plant. The pulp containing iron concentrate separate in three stages and subsequently sent to the filtration stage. Concentrate with an iron content of 69 percent is transferred outside using the conveyor belt. The stages of the process can be summarized as follows:

1. Preventing the formation of lumps
2. Eliminating particles larger than 1.5 mm
3. Three-stage LIMS
4. Dewatering

A schematic representation of the WTP line (L2) is illustrated in Figure 1. The line was created in 2016.

Figure 2 presents the input grade at the beginning of Line 2 operations and compares the designed and actual grades. As is shown, by design, iron content was predicted to reach 52 percent; however, actual values do not exceed 46 percent on average, which contributes to the low efficiency of the line.

During its early days, a large number of problems were observed in Line 2, the most significant of which are as follows:

1. Extremely low efficiency (below ten percent)
2. Flawed processing circuit design which is inadequate for the input feed (the old tailing pond in the concentrator plant, briefly described in Section 3)
3. High iron content in the tailings (nearly 40 percent)

These problems caused the line to come to a halt from 23/09/2017 to 14/11/2017.

2. Materials and Methods

Experimental studies carried out with magnetite ore particles less than 45 µm. 80 percent of WTP tailings pass through a screen opening (D_{80}), 70 microns in diameter.

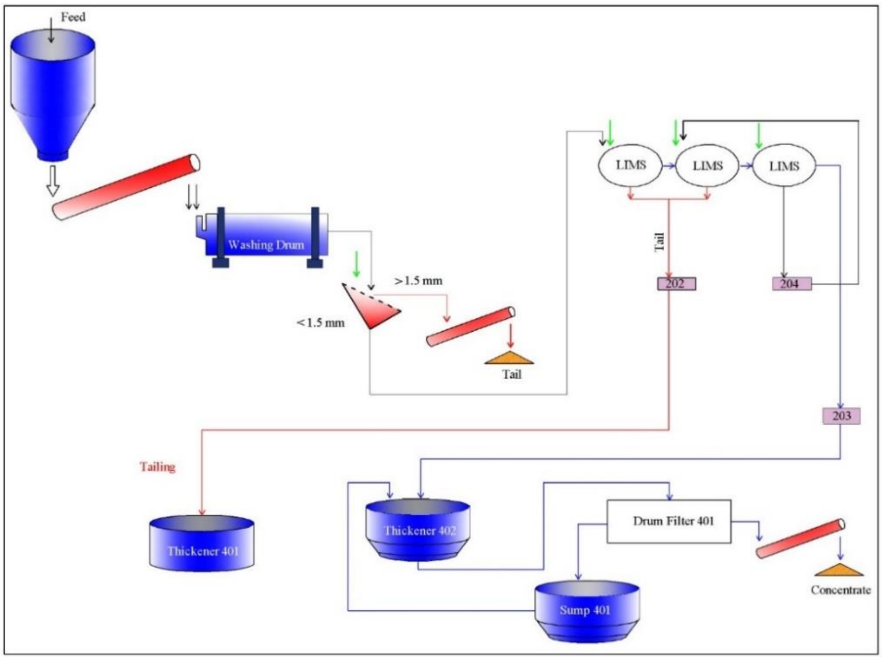

Figure 1. Flowsheet of Line 2 in the plant

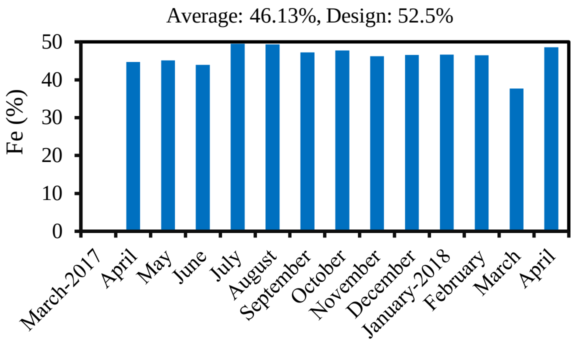

Figure 2. Input iron content for the first two years of line operation

Not only it is not necessary to spend more on crushing, but also by crushing more and reducing D_{80} from 70 to 57 µm, the flotation performance of the coarser-grained feed in all four cases for grades of iron and sulfur in the concentrate, the recovery of non-pyrite iron, and the removal of pyrite will be slightly better. Because of the high iron content in the tailings, a wet magnetic separator had to be used. A sampling of the magnetic separation circuit of the WTP line was done. Samples after drying and dividing were screened then for determining the iron content were analyzed. Iron and sulfur grades in feed, tailing and concentrate, screen analysis for obtaining cumulative percentage smaller than the particular dimensions, and Blain Number in every modified circuit were determined. Finally, calculations of the project profitability were done.

The mineralogical composition of the tailings is shown in Figure 3. The results of XRD analysis revealed that quartz, albite, talc, hematite, calcite, and riebeckite (amphibole) are the dominant crystalline phases (>10%) in these tailings. Magnetite, antigorite, dickite, and dolomite, which are sub-minerals, constitute 2-10% of these tailings. Feldspar, quartz, and calcite were seen in the image prepared using the polarizing light microscope (Model: Zeiss Axioplan-2), and muscovite was formed as a substitute in feldspar (Figure 4).

3. RESULTS AND DISCUSSION

The modifications have done in three steps as follows, which will discuss in more detail later:

Step 1: using the new wet tailings instead of old wet tailings from the concentrator plant as the feed
Step 2: adding the MIMS to the WTP Line
Step 3: adding 2nd MIMS

Step 1: using the new wet tailings instead of old wet tailings from the concentrator plant as the feed

Initially, the wet tailings of the plant, also tailings of the dust collector from the concentrator plant, were accumulated in the tailing pond (old wet tailings). These

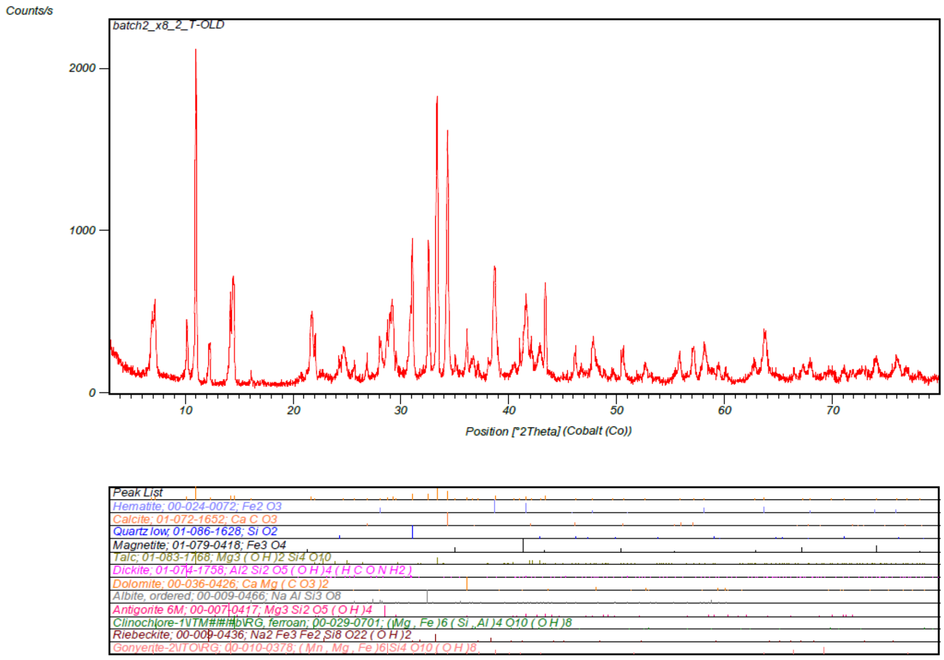

Figure 3. Results of XRD analysis of the tailing sample

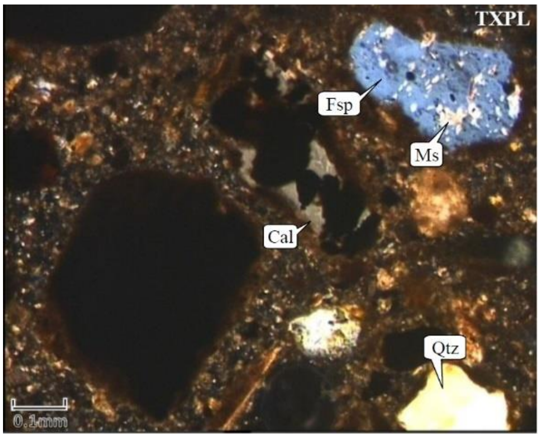

Figure 4. Results of XRD analysis of the tailing sample

tailings were estimated to weigh approximately five million tons; thus, the line was designed to handle a capacity of five million tons of the tailing. In other words, initially, the old wet tailings as the feed were given to the line. However, due to the issues mentioned above and the chemical analysis of the wet tailings (Mixer 102), it was decided that the tailings be fed directly as pulp (Figure 5). The initial modifications mean changing the old tailings to new tailings –the current tailings from the concentrator plant. The new tailings of the concentrator plant are directed as input to the wet tailings line in the concentrator plant (WTP line). In 2017, experimental results from the authors' work showed that iron content in the new wet tailings and FeO content were 26.6 and 9.3 percent, respectively (Figure 6). Therefore, the

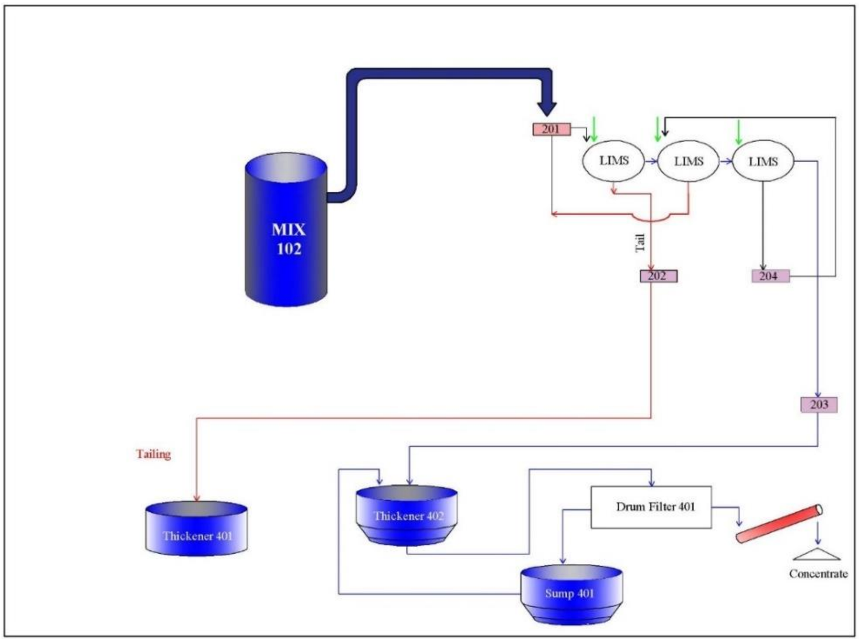

Figure 5. Flowsheet of Line 2 in the hematite plant (after the modifications)

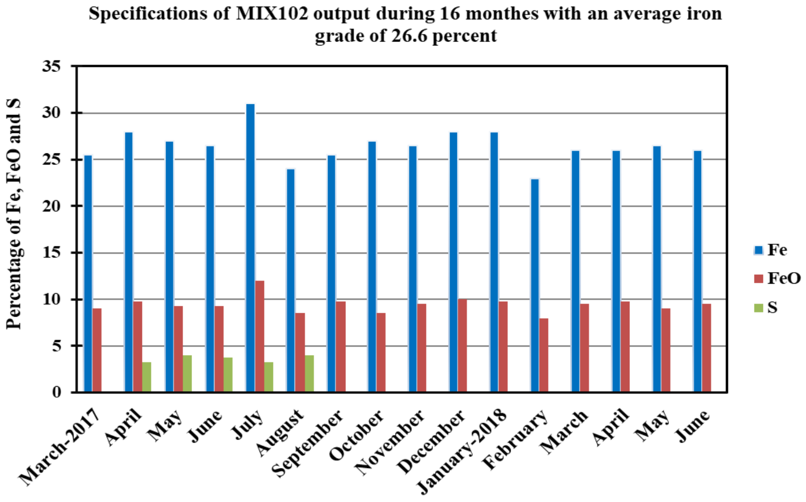

Figure 6. Specifications of the new wet tailings in the concentrator plant (MIX102 output)

TABLE 1. Comparison of Line 2 efficiencies at the initial operation, after the modifications, and by design method

	Percentage of iron in the feed	Cumulative percentage smaller than the X dimensions (%)	Efficiency (%)	Percentage of iron in the concentrate	Percentage of iron in tailings
Before	46.58	7.4	10.7	68.8	45.76
After	47.44	27.2	39.6	68.12	38.57
Design	52.5	40.51	53.39	69.2	41.13

Fe/FeO in the mixer output equals 2.8, which shows the magnetic nature of the load, and that the current circuit of Line 2 is more appropriate for these materials.

Mixer 102 is the new feed to the hematite plant from the wet tailings of the concentrator plant. The tailings collectively known as Mixer 102 tailings are from two sources: the thickener (output of the concentrator plant) and the dust collector.

Table 1 presents the specifications of the old wet tailings (tailing pond) and the new wet tailings (after the modifications).

As stated in Table 1, after doing these modifications, recovery has increased, and the percentage of iron in the tailings has decreased.

A three-dimensional model of the wet and dry tailings (constructed in 2015) showed 24.6 million tons of dry tailings with an iron grade of 37 percent and 3.3 milliontons of wet tailings with an iron grade of 5.42 percent. Further research, however, indicated that the sampling process at the design time had not been representative of the wet tailing deposits. Furthermore, LIMS test results do not lead to adequate efficiency and recovery; the feed with the designed grade constitutes a negligible portion of the deposit.

Advantages of the current pulp in Mixer 102 instead of old tailings are as follows:

1. Increased hourly feeding capacity in Line 200, from 80 to 140 tons.
2. Elimination of critical line equipment (i.e., input hopper[1], input silo conveyor belt, silo, output feeder of the silo, input conveyor belt, washing drum, screen, and an output conveyor belt of the screen)
3. Increased annual production capacity in Line 200, from 170000 to 240000 tons
4. Higher Blain number (from 1000 to 2500)
5. Elimination of line feeding machinery (e.g., excavators, loaders, and trucks)
6. Prevention of material accumulation in the concentration tailing pond
7. Reasonable reduction of tailing grade in Line 200 after processing in the plant (13 percent)
8. Optimized drum filter performance due to higher density and prevention of halts
9. Clearer thickener overflow by preventing the circulation of input materials in the thickener
10. Reduction of water consumption and replacing saline water with fresh water (approximately 250 cubic meters per hour). The fine-grained particles in the dust collector need to be flowed using a fluid; thus, water is used for this purpose. Since the particles required moving toward the tailings, the water inside the mine was used, which has high TDS. Therefore, saline water utilizes for the mixer, and the consumption of fresh water in the hematite plant decreases.
11. Reduction of iron wasted through the tailings

On the other hand, the disadvantages of the current pulp in Mixer 102 instead of old tailings are as follows:

1. Higher sulfur content in the concentrate
2. Five to ten percent reduction of line efficiency

The advantages of the project outweigh its disadvantages; thus, overall, the project is beneficial.

3. 1. Primary Problems of WTP Line after Initial Modifications

Following the modifications, the efficiency issue was somewhat resolved – going from below 10 percent to nearly 30 percent. However, several problems were still outstanding:

1. The high costs associated with the transportation of materials from the tailings pond to the plant using excavators, loaders, and trucks
2. High humidity, lumps in the depot, and transportation problems
3. Blockage in the silo of Line 2 causing fluctuations in the line
4. Extreme sensitivity to the weather, especially rain
5. Issues with the conveyor belt and silo reducing the availability factor[2]of the machinery
6. Limited depot capacity based on the age of the plant (six working years)
7. High (nearly 40 percent) iron content in the tailings as a result of the hematite in the feed

Step 2: adding the MIMS to the WTP Line

After stopping the line, the following modifications applied:

1. The LIMS from the first stage (i.e., the rougher) was replaced with a MIMS
2. Line efficiency increased from 7 to 30 percent. By design, an efficiency of 40 percent had considered;

---

[1]- A hopper (the funnel) is a temporary silo used to store materials (at the beginning of the production line) in processing plants

[2]- Availability factor of a machine is the amount of time it is operating in a working shift divided by the amount of time in the shift. The ratio usually is smaller than 100 percent due to failures and waiting times.

however, a more than 7 percent achieved in operation.

3. The LIMS tailings from the second stage moved to the first.

Figure 7 presents the secondary modifications applied to the WTP line.

The circuit in Figure 7 operationalized in April of 2019. Currently, nearly half of the pulp obtained from Mixer 102 in the concentrator plant (70 tons per hour) fed to Line 2. The remaining materials are transported to the tailings mixer (Workshop 30 in the old tailing pond), and sent to the new tailing pond. The materials contain almost 30 percent iron and 10 percent FeO. However, due to its fine-grained nature (K80 < 40 microns), a perfect load goes to waste.

A sampling of input feed, concentrate, and tailings is carried out during each working shift and sent to the laboratory unit. Determination of the chemical composition of samples is done by XRF analysis. As shown in Table 2, at the beginning of Line 2 operation, the annual average iron and iron oxide contents are 29.6 and 10.9 percent, respectively. From April to September of 2019, the Blain number, determined by a manometer, is generally rising, which is one of the benefits of doing these modifications. According to Table2, the plant during these months is stable a great extent, and the table's data are acceptable.

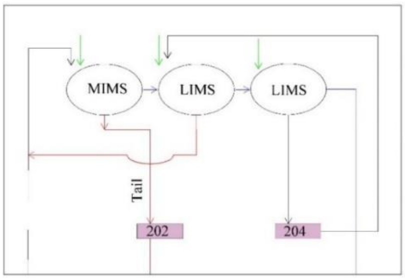

Figure 7. Secondary modifications applied to the WTP line

Using a new MIMS at the beginning of the second stage, instead of LIMS, is due to achieving of maximum hematite recovery. In fact, scavenging of the feed is done at this stage. Therefore, a recommendation was to install a pipeline connecting Mixer 102 in the concentrator plant to Line 2 in the hematite recovery plant to transport the entire output of the mixer to Line 2. Currently, the pulp from concentration enters Sump[1] 201, which is not capable of handling the increase in volume, since a pump cannot be installed underneath it. Therefore, another sump and two pumps (one of which is ready to work) are needed. The pumps feed the pulp as input to the second MIMS. In addition, the concentrate from the second MIMS is fed to the rougher LIMS (second stage). The remaining parts of the line are unchanged (Figure 8). The circuit has been in operation since October of 2020. It should be noted that Sump 401 in Figure 8 is a water sump.

Figure 8 presents the final modifications using two MIMS. Following the modifications, the pulp from Mixer 102 in the concentrator plant with a solid content of 140 tons per hour enters Line 2. Considering an approximate efficiency of 30 percent, during each hour, almost 40 tons of concentrate is produced in Line 2:

$$140 \times 0.3 = 42$$

which shows an increase of 20 tons per hour in the capacity of Line 2.

3. 2. Economic Analysis of the Final Circuit As mentioned earlier, the final WTP model is shown in Figure 8. An estimation of the required investments is summarized in Table 3.

Additionally, installation and power supply cost 2 and 2.5 billion Rials, respectively. Thus, the entire project requires an initial investment of 18.5 billion Rials. In the following, we describe the revenues generated by the project during its first year of operation.

TABLE 2. The operational status of Line 2 from April to September of 2019

Sample type	WTP								
	F_{200}(Feed)				C_{200}(Concentrate)			T_{200} (Tailing)	
	Iron (%)	FeO (%)	Sulfur (%)	K_{80} (micron)	Iron (%)	Sulfur (%)	Blain Number	Iron (%)	FeO(%)
Annual Average	29.6	10.9	2.6	40	65.2	0.9	2479	11.5	3.1
April	27.3	10	2.24	39	65	0.99	2474	11.1	3.1
May	28.2	10.2	2.36	42	65.8	0.8	2497	11.5	3
June	29.7	9.7	2.37	42	66.4	0.72	2424	14.3	3.1
July	30.2	12	2.85	40	64.3	1.04	2495	10.2	3.2
August	32.4	12.6	3.02	39	64.6	1.03	2507	10.3	2.8

---

[1]- A pit for collecting sludge or sewage

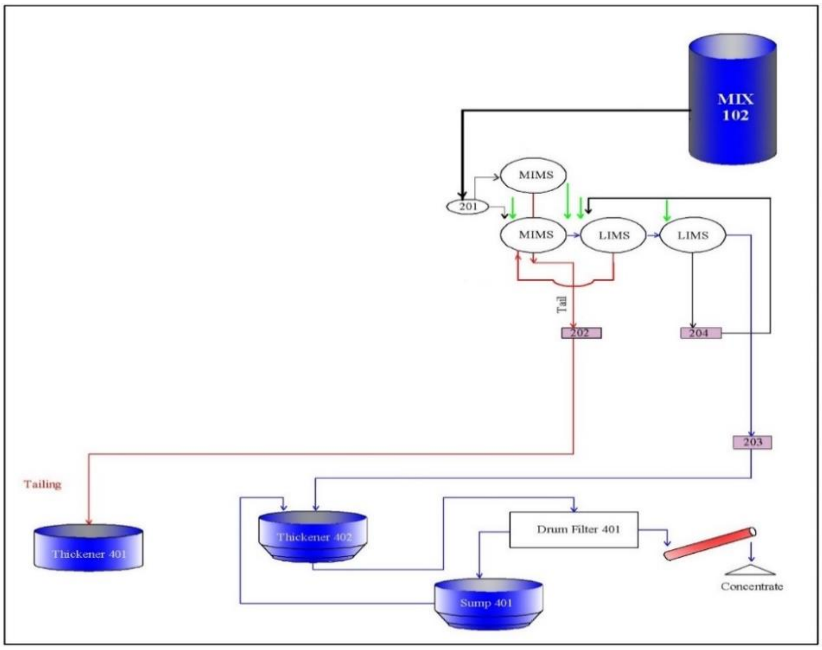

Figure 8. Final circuit of the WTP line to use new wet tailings of concentrator plant

TABLE 3. Investment requirements of the final circuit

Item	Equipment/ Materials	Quantity	Unit Price (Rials)	Total Price (Rials)
1	Piping connecting the concentrator plant to the hematite plant	400 meters	500,000	200,000,000
2	Tailing pipe from the new line to the middle mixer	600 meter	500,000	300,000,000
3	MIMS drum and paraphernalia	2	3500,000,000	7000,000,000
4	Slurry pump	6	1,000,000,000	6,000,000,000
5	New sump	1	500,000,000	500,000,000
	Total cost		14,000,000,000 Rials	

The iron concentrate may be sold either domestically at approved prices or internationally. The two prices are usually different, and the latter achieves easier.

Therefore, an estimated international price is used in our calculations. Assuming that the Free On Board (FOB) price of 65 percent magnetite concentrate is 45 dollars per ton and that shipping costs 10 dollars per ton, each ton will sold with a minimum profit of 35 dollars; which is almost equal to one million Rials.

The profit in selling each ton of FOB concentrate equals 35 dollars or 1,155,000 Rials (excluding production costs). Variable costs for each ton of concentrate include bills by the contractor and energy costs. Because additional workers are not needed, human resource costs are set to zero.

The project requires 300 kWh (based on the number of engines), and 15 kW is used to produce a ton of product. Assuming each kilowatt costs 800 Rials, 12 thousand Rials need for each ton of product. The contractor charges 215,000 Rials per ton of feed; considering a production efficiency of 30 percent, each ton of product needs 715,000 Rials.

Energy costs for each ton of concentrate: 12,000 Rials

Contractor bills for each ton of product: 715,000 Rials

As a result, the net profit from selling each ton of concentrate produced by Line 2 is 428,000 Rials.

The project increases Line 2 production capacity by 20 tons per hour. In 2019, the line operated for 8133 hours. By assuming the 7500 work hours per month, the increased annual production from the project is at least 150 thousand tons. Thus, annual net profits (excluding initial investments) can reach to 64 billion Rials (over 5 billion Rials each month).

An overview of the calculations is given in Table 4: By considering investment costs, the project begins to yield profits after four months. This rate of profitability is significant from an economic point of view.

3. 3. Project Profitability for the Contractor

The increase in line production also results in higher profits for the contractor. This matter can serve as an

TABLE 4. An overview of the calculations of the project profitability

Item	Price (Rials)
Initial investment	18,500,000,000
Profit of exporting each ton of concentrate (FOB)	1,485,000
Transportation and storage costs for each ton of concentrate	330,000
Energy costs for each ton of concentrate	12,000
Contractor bills for each ton of production	715,000
Net profit from each ton of concentrate	1,485,000 – (330,000 + 12,000 + 715,000) = 428,000
Increased production capacity in Line 2	20 × 7500 = 150,000 tons
Annual profits of the project (excluding initial investment costs)	150,000 × 428,000 ~ 64,000,000,000 Rials

incentive to delegate the execution of the project to a contractor. Pertinent calculations have summarized in Table 5:

TABLE 5. A summary of the calculation of the project profitability for the contractor

Item	Price (Rials)
Initial investment	18,500,000,000
Profit from each ton of product	715,000
Operational costs incurred by the contractor for each ton of product in Line 2 (more than current production)	65,000
Net profit from developing each ton of concentrate in Line 2	715,000 – 65,000 = 650,000
Annual profit of executing the project (excluding initial investment)	150,000 × 650,000 ~ 97,000,000,000 Rials

Thus, annual net profit (excluding initial investment) equals 97 billion (over 8 billion each month) Rials. By considering investment costs, the project after three months yield profits.

Therefore, the present study, which was somewhat similar to the research of Behnamfard and Khaphaje [24] increased the iron content economically from 47.15% to 68.12%, while reducing the iron grade in the tailings to 38.57%. However, this amount of iron in the tailings is a significant amount that, in the future, with further research, should decrease.

According to the promising results of the present research, the following cases are recommended to produce suitable iron concentrate for the steel industry from the tailings of the Gol-e-Gohar processing plant:

- Complementary studies of flotation, especially from an electrochemical perspective (Effect of E_h and oxidation rates) in the efficiency of desulfurization operations of both hematite and magnetite concentrate of Gol-e-Gohar Iron Ore Complex
- Dephosphorization studies of hematite concentrate by flotation due to the relatively high amount of phosphorus (>0.05%) in the concentrate produced in this study

4. CONCLUSION

This study optimized the line of magnetite recovery from wet tailings by creating a second medium intensity magnetic field. The main results of this research are summarized as follows:

Based on the presented calculations, the optimization is economically feasible and profitable. The reformation made was associated with some other advantages, as stated below:

1. An increase in150 tons in the annual production to achieve new production thresholds
2. Preventing loss of iron in the form of tailing from the concentrator plant
3. Preventing loss of water in the form of tailing from the concentrator plant and recovering a portion of that water in the hematite plant
4. An increase in 50 to 100 units in the product's Blain number. The Blain number in Line 2 equals 2500 cm^2/g instead of 850 and 1450 cm^2/g in Lines 1 and 3, respectively. Moreover, the value is 1450 – 1500 cm^2/g for the hematite plant. Increasing the hourly production rate by 20 tons nearly doubles production capacity in Line 2. This amount is added to the production of 150 tons per hour with an approximate Blain number of 1500 cm^2/g. By calculating the weight ratios, an overall increase of at least 100 units obtained. However, in contrast to iron grade, the increase in the Blain number cannot calculate using a weight ratio (since the value does not directly relate to K_{80}). Nevertheless, the number expected to be 50 to 100 units larger.

Note that the calculations performed pessimistically; for instance, Line 2 operated for 8133 hours in 2019; however, the value has assumed to be 7500 hours; thus, a lower bound on the profits of these optimizations is determined.

5. REFERENCES

1. Abbasian, A., Ravangard, A., Hajian Nia, I. and Mirzamohammadi, S., "Investigation of microstructure and mechanical properties of newly developed advanced high strength

trip steel", ***International Journal of Engineering, Transaction C: Aspects***, Vol. 35, No. 3, (2022), 567-571, doi: 10.5829/IJE.2022.35.03C.09.

2. Ahadi Akhlaghi, I., Kahrobaee, S., Sekhavat, M., Norouzi Sahraei, H. and Akhlaghi Modiri, F., "Application of artificial neural network and multi-magnetic nde methods to determine mechanical properties of plain carbon steels subjected to tempering treatment", ***International Journal of Engineering, Transaction A: Basics***, Vol. 34, No. 4, (2021), 919-927, doi: 10.5829/IJE.2021.34.04A.18.
3. Gapsari, F., Hidayatia, N., Setyarini, P., Alan, M.P., Subagyo, R. and Andoko, A., "Hydroxyapatite coating on stainless steel 316l using flame spray technique", ***International Journal of Engineering, Transaction B: Applications***, Vol. 34, No. 2, (2021), 493-499, doi: 10.5829/IJE.2021.34.02B.22.
4. David, D., Larson, M. and Li, M., "Optimising western australia magnetite circuit design", ***Proceedings of the Metallurgical Plant Design and Operating Strategies, Perth***, (2011).
5. Xiong, D., Lu, L. and Holmes, R., Developments in the physical separation of iron ore: Magnetic separation, in Iron ore. 2015, Elsevier.283-307.
6. Bulatovic, S. and Salter, R., High intensity conditioning—a new approach to improving flotation of mineral slimes, in Processing of complex ores. 1989, Elsevier.169-181.
7. Wyslouzil, H., "The production of high grade iron ore concentrates using flotation columns", ***Skillings' Mining Review(USA)***, Vol. 86, No. 37, (1997), 4-8.
8. Wang, F., Zhang, S., Zhao, Z., Gao, L., Tong, X. and Dai, H., "Investigation of the magnetic separation performance of a low-intensity magnetic separator embedded with auxiliary permanent magnets", ***Minerals Engineering***, Vol. 178, (2022), 107399, doi: 10.1016/j.mineng.2022.107399.
9. Argimbaev, K., Ligotsky, D., Mironova, K. and Loginov, E., "Investigations on material composition of iron-containing tails of enrichment of combined mining and processing in kursk magnetic anomaly of russia", ***International Journal of Engineering, Transaction A: Basics***, Vol. 33, No. 7, (2020), 1431-1439, doi: 10.5829/IJE.2020.33.07A.31.
10. Amin Saravari, A.S. and Shayanfar, S., "Desulfurization of iron ore concentrate using a combination of magnetic separation and reverse flotation", ***Journal of Chemical Technology and Metallurgy***, Vol. 56, No. 5, (2021), 1002-1110.
11. Panahi, E., Abdollahzadeh, A., Sam, A., Jahani, M., Moghaddam, M.Y. and Mehrani, A., "Desulfurization of hematitic concentrate of iron ore of the gol-e-gohar mine using reverse flotation method", ***Techincal Rep***, (2012).
12. Dehghani, F., Khosravi, R., Pazoki, A., Kebe, M., Jahanian, R., Siavoshi, H. and Ghosh, T., "Application of magnetic separation and reverse anionic flotation to concentrate fine particles of iron ore with high sulfur content", ***Physicochemical Problems of Mineral Processing***, Vol. 58, (2022), doi: 10.37190/ppmp/145420.
13. Qaredaqi, M. and Rafizadeh, A., "Application of different wet high intensity magnetic separators in gole-gohar mine".
14. Tripathy, S.K., Singh, V. and Suresh, N., "Prediction of separation performance of dry high intensity magnetic separator for processing of para-magnetic minerals", ***Journal of The Institution of Engineers (India): Series D***, Vol. 96, No. 2, (2015), 131-142, doi: 10.1007/s40033-015-0064-x.
15. Stener, J.F., Carlson, J.E., Pålsson, B.I. and Sand, A., "Evaluation of the applicability of ultrasonic velocity profiling in conditions related to wet low intensity magnetic separation", ***Minerals Engineering***, Vol. 62, (2014), 2-8, doi: 10.1016/j.mineng.2013.08.005.
16. Stener, J.F., Carlson, J.E., Sand, A. and Pålsson, B.I., "Internal flow measurements in pilot scale wet low-intensity magnetic separation", ***International Journal of Mineral Processing***, Vol. 155, (2016), 55-63, doi: 10.1016/j.minpro.2016.08.008.
17. Padmanabhan, N. and Sreenivas, T., "Process parametric study for the recovery of very-fine size uranium values on super-conducting high gradient magnetic separator", ***Advanced Powder Technology***, Vol. 22, No. 1, (2011), 131-137. https://doi.org/10.1016/j.apt.2010.09.013
18. Wasmuth, H.-D. and Unkelbach, K.-H., "Recent developments in magnetic separation of feebly magnetic minerals", ***Minerals Engineering***, Vol. 4, No. 7-11, (1991), 825-837.
19. Svoboda, J., "The effect of magnetic field strenght on the efficiency of magnetic separation", ***Minerals Engineering***, Vol. 7, No. 5-6, (1994), 747-757, https://doi.org/10.1016/0892-6875(94)90104-X
20. Wills, B.A., "Mineral processing technology: An introduction to the practical aspects of ore treatment and mineral recovery, Elsevier, (2013).
21. Shao, Y., Veasey, T. and Rowson, N., "Wet high intensity magnetic separation of iron minerals", ***Magnetic and Electrical Separation***, Vol. 8, (1970), doi: 10.1155/1996/34321.
22. Zhang, X., Han, Y., Sun, Y., Lv, Y., Li, Y. and Tang, Z., "An novel method for iron recovery from iron ore tailings with pre-concentration followed by magnetization roasting and magnetic separation", ***Mineral Processing and Extractive Metallurgy Review***, Vol. 41, No, 2, (2020), 117-129. https://doi.org/10.1080/08827508.2019.1604522
23. Dwari, R.K., Rao, D.S. and Reddy, P.S.R., "Magnetic separation studies for a low grade siliceous iron ore sample", ***International Journal of Mining Science and Technology***, Vol. 23, No. 1, (2013), 1-5, https://doi.org/10.1016/j.ijmst.2013.01.001
24. Behnamfard, A. and Khaphaje, E., "Beneficiation of a low-grade iron ore by combination of wet low-intensity magnetic separation and reverse flotation methods", ***Journal of Mining and Environment***, Vol. 10, No. 1, (2019), 197-212, doi: 10.22044/JME.2018.7392.1595.
25. Svoboda, J. and Fujita, T., "Recent developments in magnetic methods of material separation", ***Minerals Engineering***, Vol. 16, No. 9, (2003), 785-792, https://doi.org/10.1016/S0892-6875(03)00212-7
26. Makhula, M.J., "Beneficiation of fine ores using the longi wet high magnetic separator", Ph.D. Dissertation, University of the Witwatersrand, Faculty of Engineering and the Built Environment, School of Chemical and Metallurgical Engineering, (2014),
27. Tripathy, S.K., Banerjee, P. and Suresh, N., "Separation analysis of dry high intensity induced roll magnetic separator for concentration of hematite fines", ***Powder Technology***, Vol. 264, (2014), 527-535. https://doi.org/10.1016/j.powtec.2014.05.065

Persian Abstract

چکیده

مهمترین ماده خام صنعت فولاد، آهن است. هدف این مقاله، بهبود بازیابی مگنتیت از باطله‌های تر، با افزایش محتوای آهن در کنسانتره خط است. برای مدیریت باطله‌ها، خط فرآوری باطله تر (WTP) برای بازیابی مگنتیت، در مجتمع سنگ آهن گل‌گهر ایجاد شد. مهمترین فازهای کریستاله در این باطله‌ها، کوارتز، آلبیت، تالک، هماتیت و کلسیت بودند. ابعاد خوراک خط، ٤۵ میکرون بود که برای استفاده از روش ثقلی مناسب نیست. بنابراین، جداسازی فقط با استفاده از روش مغناطیسی می‌تواند انجام شود. بدلیل محتوای بالای آهن در باطله ها، جداکننده مغناطیسی تر استفاده شد. بر اساس نتایج، جداکننده شدت متوسط پیشنهادی و اصلاحات مربوط به مدار، بازیابی آهن را از ۷ به ۳۰ درصد افزایش داد که ۱۵۰ تن تولید سالیانه بدست آمد؛ مانع هدر رفتن آهن از طریق باطله‌های کارخانه تغلیظ شد و عدد بلین را در کارخانه هماتیت به میزان۵۰ تا ۱۰۰ واحد افزایش داد. بعلاوه، با جایگزینی باطله‌های تر قدیمی کارخانه تغلیظ با باطله‌های تر جدید به عنوان خوراک، مصرف آب بطور قابل توجهی کاهش یافت که دستاورد مهم دیگر این تحقیق است؛ در هر ساعت، ۲۵۰ مترمکعب آب شور به جای آب شیرین استفاده می‌شود.