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Effect of Particle Size Distribution and Type of Mineral on the Blaine Number

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ABSTRACT

This study investigates factors affecting the Blaine number, including type, shape, and size distribution of the grains, d_{80} effect, and retention time of materials in the mill. Samples were taken from different locations in production lines of the Golgohar and Chadormalu plants in Iran. For iron minerals, Davis tube tests were performed in four stages to assess the functionality of the magnetic separator to ensure matching conditions between the plant and laboratory. The Blaine air permeability system was used to analyze the Blain number. Results indicated that the samples with the same d_{80} but different grain size distributions had different Blaine numbers. More specifically, increasing the percentage of grains finer than 45 microns resulted in higher Blaine numbers. Moreover, in the Golgohar Hematite and desulfurization plant, the grain size distribution was relatively fixed, and minor variations in the percentages of grains finer than 45 microns led to a change in the Blaine number, and this was consistent between different days. During the concentrate production processes, higher grades of iron concentrate and lower grades of non-iron minerals were associated with lower Blaine numbers, which could be explained by the removal of iron-free minerals finer than 45 microns, including clay. Moreover, a 1% reduction in the clay minerals led to a 400-unit reduction in the Blaine number. Several samples of hematite concentrate and clay minerals with the same grain size distribution were analyzed to investigate the influence of density and the shape of grains on the Blaine number of magnetite concentrate. Here, compared to magnetite and hematite with irregular shapes, plate-shaped clay minerals showed higher Blaine numbers. Moreover, when the feed of the magnetic separator was grinded, the reduction in the grain size increased the Blaine number. In the Chadormalu plant, a retention time of 4.5 minutes in the mill was associated with the highest Blaine number as well as the least recovery of phosphorous minerals.

Keywords : *Blaine number, Specific surface, Grain size distribution curve, Davis tube test*

1. Introduction

The concentrate of iron ore processing plants is often in the form of fine iron minerals, which is of no use in such a physical shape. These soft materials decrease the permeability of gas within the feed of the blast furnace and reduce the functionality of the direct reduction plant. Therefore, the soft parts of iron concentrate should be changed to pellets, which are considered as a mid-product for iron and steel production furnaces [1]. Since pellets are regarded as the primary materials, they should have favorable mechanical, chemical, and temperature properties, including uniform distribution of dimensions, uniform porosity, high mechanical solidity, and resistance against friction [1, 2]. Some of these properties depend on the smallness of the particles, which are measured by the Blaine number [1, 3]. Therefore, the investigation of factors affecting the Blaine number is crucial for achieving desirable pellet properties. Previous studies suggested 2000 - 2100 cm^2 per gram as the acceptable range of the Blaine numbers for the pellet production process [1] and confirmed that the grain size distribution and the mineral type are two important factors controlling the Blaine number [1, 4, 5]. However, the relationship between the Blaine number and the type of mineral is not yet well studied. Moreover, the effect of shape and size distribution of minerals, as well as the number of fine particles and iron in minerals on the Blain number, has remained unknown. Therefore, for the current study, the Blaine tests were conducted on magnetite and hematite concentrates as well as clay mineral samples, each with different particle nature and densities, to assess the influence of type, size distribution, smallness, and iron content of minerals on the Blaine number. In addition to the laboratory tests, the role of mineral type on the relationship between grain size distribution (d_{80}) and the resultant Blaine number was further assessed using in situ data obtained from a hematite and desulfurization plant (Golgohar, Iran) and an iron ore plant (Chadormalu, Iran).

1.1. Factors affecting the quality of pellets

- **Crystalline structure of materials**

The crystalline structure, especially for minerals containing iron, plays an important role in forming the pellets and their solidity. The clayey and adhesive components, as well as the shape and nature of the surface of minerals, are considered as effective factors in pellet production. The shape and nature of particles may differ in different combinations of materials [1]. Table 1 shows how the combination of different minerals affects particle shape.

- **Additives**

The commonly used additives in pellet production include bentonite, lime, and sodium silicate. It is known that these additives enhance the production of pellets by increasing the solidity of raw, dry, and baked pellets and regulating the chemical composition and quality of baked

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pellets [1].

Table 1. The effect of different mineral combinations on particle shape [1].

particle shape	Crystalline Structure
Plate, Granular	Hematite, Goethite, Quartz, Kaolin
Plate, Fiber	Hematite, Goethite, Quartz, Calcite
Plate, Cubic	Magnetite, Hematite, Goethite, Quartz
Cubic, spherical	Hematite, Goethite, Quartz

- **Grain size distribution and specific surface**

In iron ore concentrating processes, a softer grain size results in higher energy consumption in the mills, higher degrees of freedom of impure particles in iron ore, and the highest possibility of separation. On the other hand, the size and grain size distribution of particles may affect the speed of pellet production and their properties. When grinding continues, the particles become softer, and their specific surfaces increase. As a consequence, this increases the compression between components of raw pellets in the production process while their porosity decreases due to the increase in their specific mass. Therefore, a higher percentage of particles finer than 45 microns may result in increased pressure stability of the raw and baked pellets as well as improvement in resistance against friction [1]. Based on the findings of previous studies, a higher percentage of materials finer than 45 microns is associated with higher pellet production from soft parts. However, since a lower grain size and a higher specific surface necessitate higher energy consumption in mills and lower porosity, the percentage of small particles should be limited to an optimum value. Here, the optimum condition in terms of grain size is suggested to be 70-80 percent of particles finer than 45 microns [1].

2. Materials and methods

2.1. Measuring the specific surface

In 1943, the United States National Institute of Standards and Technology (NIST) introduced a method for measuring the specific surface of particles (Blaine ASTM C204), which is commonly used as a criterion for studying the smallness degree of cement using air permeability systems [6, 7]. The softness of mineral is usually expressed by the specific surface defined as the total surface area of particles in cm^2 per gram or m^2 per kg cement, which is known as “Blaine number” [6-8].This method can be used to measure the softness degree of various materials, including iron [6].

2.1.1. Principles of Blaine system

The Blaine air permeability system sucks in a given amount of air through a polished surface of cement with a given porosity [4, 8, 9]. The number and size of the pores in a polished surface with given porosity is a function of particle size and intensity of current flow through the surface [9]. The following paragraphs explain how to calculate the amount of the test sample and the resultant Blaine number.

2.1.2. Calculating the weight of sample

The amount of sample for the test is determined based on the mineral density, porosity of bed, and the specific volume of space for the sample in the cell. The sample weight is calculated using the following equation [7, 9].

$$m=\rho\times v \times 0.5 \qquad \text{(Eq. 1)}$$

Where m is the weight of sample in g, V is the volume of the space at the end of the cell (1.75 cc), and ρ is the density of mineral (g/cm^3). The factor “0.5” indicates the porosity of iron mineral bed (this can be different for different materials (e.g., it is 0.2 for cement)).

2.1.3. Calculating the Blaine number

After calculating the amount of sample, conducting the test, and obtaining the time of air passing in seconds, the Blaine number can be calculated using the following equation [9]:

$$B=\frac{K*\sqrt{t}}{\rho} \qquad \text{(Eq. 2)}$$

Where B is the Blaine number (cm^2/g), K is the correction coefficient, which depends on the laboratory conditions (the correction coefficient is determined through testing the standard sample with a given Blaine number and density), t is the airflow time in seconds and ρ is the density of sample (g/cm^3).

2.1.4. Implementing the Blaine test

The Blaine system is composed of a U-shaped cylindrical tube containing an oily liquid. One end of the tube is connected to a cylinder that contains the sample, and the other end is open. The tube is connected to a valve, which is used for creating a vacuum and regulating the liquid in the cylinder (Fig. 1). Before starting the test, the Blaine system needs to be calibrated. Calibration is carried out by ensuring that the heights of liquid in both sides of the U-shaped tube are leveled. After calibration, a disc is placed in the cylinder, and a filter paper is placed at the bottom of the cylinder. Then the sample is placed in the cylinder in a way that the porosity remains intact (the compaction of the sample may affect the rate of airflow through the grains). Then, another filter paper is placed on the sample, and the cylinder cap is closed. Afterwards, the cylinder is placed at the end of the U-shaped tube, and the air is sucked in using a vacuum pomp. The flow time of the manometer liquid between the two indices on the tube is measured using a chronometer. Finally, the Blaine number of the sample is calculated using equation 2 [9].

Fig. 1. Blaine system [10].

2.2. Theoretical and empirical modeling

2.2.1. Materials and sampling methods in Golgohar

In order to determine the relationship between the grain size distribution and the Blaine number, samples were taken from line 300 in the hematite recovery and desulfurization plant in the Golgohar industrial and mine complex. Sampling was conducted six times per day, in three days, and each lasted for one hour to keep the feed fluctuation as low as possible. It should be noted that sampling was done when the control room confirmed the stability of the circuit. Samples were taken from the input and output feeds of the grinding systems of the plant, and their Blain numbers were calculated after determining the grain size distribution and density. The sampling locations in line 300 of the plant are shown in Fig.2.

- ***Materials and sampling methods in Chadormalu***

In order to study the effect of grinding on the Blaine number and confirming the results obtained from the Golgohar plant, the necessary laboratory tests were conducted. The tests aimed to assess the current condition of the plant and the effects of changes in the grinding and magnetic separation processes at the laboratory scale. The test methods and laboratory conditions are explained in the following paragraphs.

- ***Laboratory scale functionality of magnetic separators in Chadormalu***

In order to investigate the functionality of magnetic separators in the concentrate production line at the cleaner stage, the samples were taken from their feed, and the Davis tube tests were conducted in four stages. Fig.3 shows the Davis tube test system.

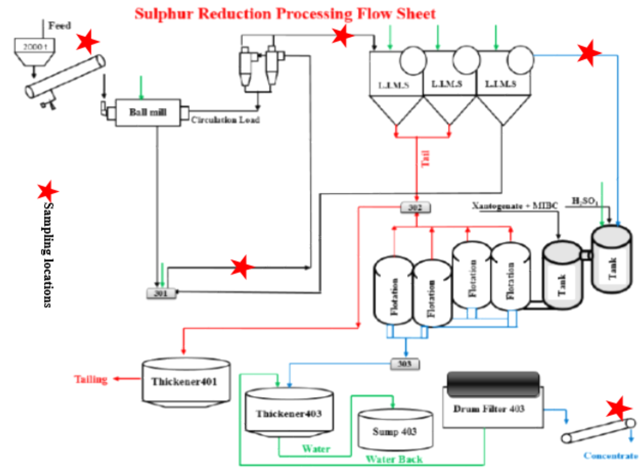

Fig. 2. Sampling locations in line 300 of the plant.

Fig. 3. Davis tube test system.

- ***Sample preparation in Chadormalu***

The test sample was taken from the magnetite concentrate production line 2. The sampling stations included cleaner feed, magnetite concentrate, hematite concentrate, and the final concentrate of the production line. Sampling was conducted in a time range of 2 hours for 24 hours to obtain a representative sample. Finally, two-kilogram samples were taken from sampling stations, which were then reduced to the amounts required for the test, using a Riffle sample divider (Fig.4).

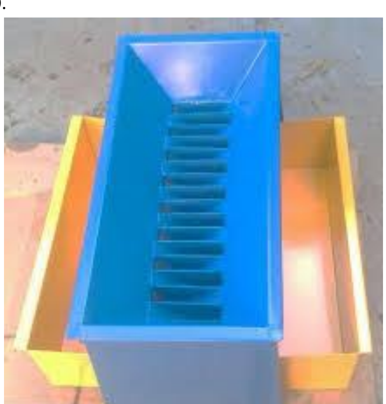

Fig. 4. Riffle system for dividing the samples.

- ***Laboratory conditions of Davis tube test for Chadormalu's samples***

Table 2 shows the laboratory conditions of the Davis tube test.

Table 2. Laboratory conditions for the Davis tube test.

Gauss	3500 G
Ampere	1.7 A
Flowrate of input water	1 L/MIN
Retention Time	1 MIN

It should be noted that the Davis tube test was conducted in four stages to create an identical plant and laboratory environment. Since the final concentrate of the Davis tube test is very low and the condition of the Davis tube test is ideal and is not similar to that of industry, each of the four stages was replicated for five times to provide an adequate sample for the Blaine test and chemical analyses in the next steps.

3. Results and discussion

3.1. Results of samples from line 300 of Golgohar

The line feed was re-grinded in the ball mill and became finer, and its d_{80} value reduced from 350 microns to 75 microns, and after being transferred to the hydrocyclone, d_{80} of the overflow changed to 60 microns (Table 3). During these stages, the materials became finer, and therefore the Blaine number increased; however, d_{80} increased after passing the materials through the magnetic separator and flotation cells, which consequently decreased the Blaine number.

Table 3. The results of the samples collected from the line 300.

Row	d_{80} (mic)	Density (g/cm³)	Time (S)	Blaine (cm²/g)
Feed	350	4.86	1	271
Mill product	75	4.9	20	1202
Hydrocyclone over flow	60	4.85	30	1487
Magnetic separation product	65	5.02	25	1312
Concentrate (flotation product)	78	5.04	17	1077

Regarding data in Tables 3 and 4, during the stages of concentrating, an increase in iron grade and reduction in iron-free minerals (such as clay minerals) were associated with lower Blaine numbers. As small-grained minerals, the clays are often finer than 45 microns [11]. Therefore, removing the clay minerals may lead to a reduction of porosity and lower Blaine numbers.

Table 4. The analysis results for the chemical composition in concentrating stages of line 300.

Row	Fe%	FeO%	S%	SiO_2%	Al_2O_3%	MgO%
Feed	66.59	26.9	1.02	2.02	0.29	2.34
After mill	66.85	27.3	1.03	1.85	0.25	2.18
After hydrocyclone	66.33	26.81	1.05	2.25	0.3	2.41
After magnetic separators	68.73	28.24	0.38	0.67	0.08	1.43
Concentrate	69.57	28.02	0.37	0.53	0.08	1.40

Using a Scanning Electron Microscope (SEM), the samples taken from hydrocyclone overflow and the concentrate were imaged with the same magnification to further investigate the reasons for changes in the Blaine number. As shown in Fig.5, coarse particles in the sample taken from hydrocyclone overflow are surrounded by small particles, which leads to a reduction in the porosity and an increase in the specific surface of the samples. In the concentrate, removing the fine particles and clay minerals (which leads to an increase in the grade) were associated with higher porosity and lower specific surface. Here, a one percent reduction in clay minerals in the concentrate was associated with a 400-unit reduction in the Blaine number.

3.2. Relationship between the Blaine number and d_{80}

Three samples with different grain size distributions and identical d_{80} values from the concentrate of line 300 of hematite and desulfurization plant were compared to examine the relationship between the Blaine number and d_{80} (Table 5). Since finding samples with the same d_{80} but different size distributions was not practical, sampling was done artificially. Briefly, the samples were categorized into different ranges regarding the size distribution. Those in the range of 0 to 45 microns were allocated to the range of 45-100 µm, and therefore, the weight of particles below 150 microns remained unchanged. As a result, 80 percent of the particles were finer than 150 microns in size.

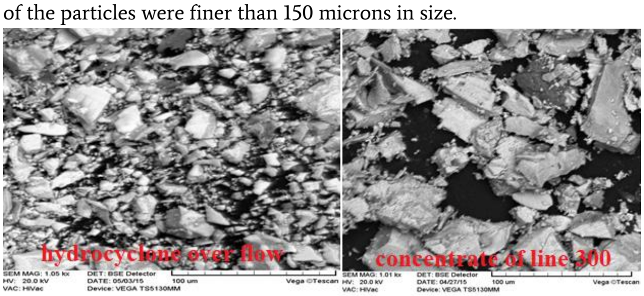

Fig. 5. Scanning electron microscope images from the hydrocyclone overflow (left) and concentrate (right) of line 300.

Table 5. Artificial samples with consistent d_{80} values obtained from the concentrate of line 300.

Row	<45 µm	45-100 µm	100-150 µm	150-200 µm	200-250 µm	Sample weight (g)	Blaine (cm²/g)
1	4	10	2	1	3	20	1150
2	10	2	4	2	2	20	1720
3	2	4	10	3	1	20	550

As shown in Fig.6, the samples with the same d_{80} had different Blaine numbers. Sample 2, with a higher percentage of particles finer than 45 microns, had a higher Blaine number.

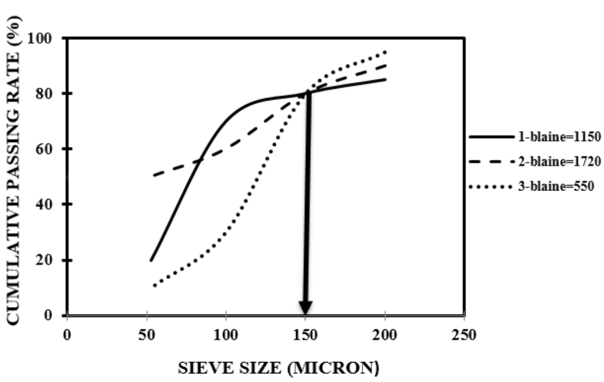

Fig. 6. Grain size distribution for samples with the same d_{80} taken from line 300.

The relationship between the Blaine number and grain size distribution was assessed using the results obtained from the Golgohar hematite and desulfurization plant. Here, the results obtained from different time points, when similar d_{80} but different Blaine numbers were recorded (Table 6).

Table 6. The grain size distribution of the concentrate of line 300 at different time points when similar d_{80} values were recorded.

Sieve (microns)	Cumulative passing rate (%)					
	2014/7/27	2014/7/28	2014/8/2	2014/8/3	2014/8/10	2014/8/11
180	99	99.2	99.4	99	99.4	99.6
125	95.2	96.2	95.4	94.8	95.4	95.8
90	89.6	89.6	90	89.4	88.4	87.6
45	54.4	54.6	53.8	54	57.2	59.2
Blaine (cm²/g)	1412	1436	1400	1436	1471	1549

As shown in Fig.7, the grain size distribution of the samples was relatively consistent (same d_{80} values) on different days. The difference was in the percentage of particles finer than 45 microns, which was considered as one of the reasons for variation in Blaine numbers.

3.3. Effect of mineral type on the Blaine number

In order to investigate the effect of mineral type on the Blaine number, clay mineral and concentrate samples from the hematite and desulfurization plant with similar grain size distributions were compared (Table 7). It should be mentioned that the clay sample taken from the tailing of the high-intensity magnetic separator and chemical analysis of the sample showed a 92 percent clay content.

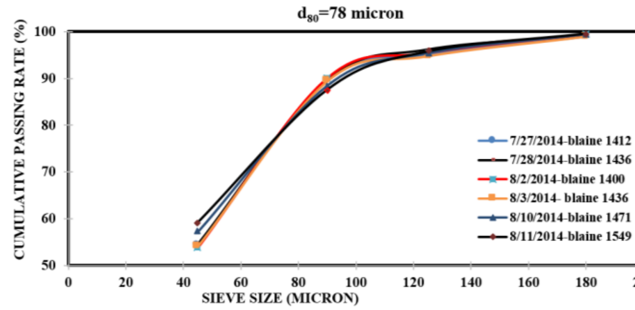

Fig. 7. The grain size distribution of the concentrate obtained from line 300 at different dates when consistent d_{80} values were recorded.

Table 7. Comparison between clay and concentrate samples of line 300 with the same grain size distribution.

Row	<38 microns	38-45 microns	45-53 microns	Total sample weight (g)	Density (g/cm³)	Blaine (cm²/g)
Clay sample	14	4	2	20	2.28	2770
Iron concentrate	14	4	2	20	5.14	1579

Regarding the small size of clay minerals compared to magnetite and hematite concentrates, Blain numbers of the samples were compared for particles finer than 38 microns [11]. The clay and iron concentrate samples with the same grain size distributions had different Blaine numbers (Table 7), which can be explained by their different densities.

The hematite and magnetite concentrate samples taken for the laboratory of pellet production plant and the clay samples collected from the tailing of the Sloan device in the Golgohar industrial and mine complex were analyzed and the results are listed in Table 8.

Table 8. The Blaine number for hematite and magnetite concentrates and clay samples.

Row	Density (g/cm³)	Time (S)	Blaine (cm²/g)
Clay sample	2.28	127	6509
Magnetite concentrate	5.05	140	3174
Hematite concentrate	4.94	83	2498

Based on Table 8, the magnetite and hematite concentrate samples had different Blaine numbers compared to the clay samples with the same grain size range, which could mainly be due to differences in the nature of particles.

A scanning electron microscope with ×80 magnification (provided by the Geoscience Laboratory of the Golgohar Industrial and Mine Complex) was used to image the hematite and magnetite concentrate and clay samples with grain sizes finer than 38 microns.

Clay minerals include Montmorillonite and Kaolinite, of which Kaolinite is considered as the most important component. Clay minerals are often characterized by their small size, plate-like shape, and large specific surface. Their small size can explain their high Blaine number compared to hematite and magnetite concentrates with coarser particles (Fig.8) [12].

The crystallization system of magnetite is cubic hexoctahedral, and their particles are angular and sharp with uniform surfaces; however, the crystallization system of hematite is trigonal di-trigonal scalenohedron, and their particles are plate-shaped, granular, compact and irregular [1]. These different structures are well depicted in Fig.8.

3.4. Blaine number for Golgohar's samples

3.4.1. Comparison between magnetic separator concentrate (cleaner stage) and concentrate of Davis tube test for Chadormalu's samples

Fig.9 shows a comparison between the grain size distribution of the feed and magnetic separator concentrate (cleaner). In addition, Table 9 presents the properties of magnetic separation of the plant and the Davis tube test.

Despite similar d_{80} values, the feed and the concentrate of cleaner had different Blaine numbers (Fig. 9 and Table 9), which was consistent with the result concluded from Fig. 6 in section 2-3 for the Golgohar plant. In fact, after passing the materials through the magnetic separator, the Blaine number became smaller, mainly due to the increase in the iron grade.

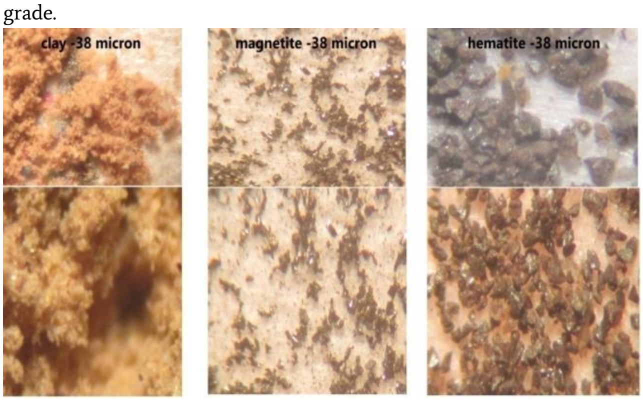

Fig. 8. Scanning electron microscope images of the hematite and magnetite concentrate and clay samples.

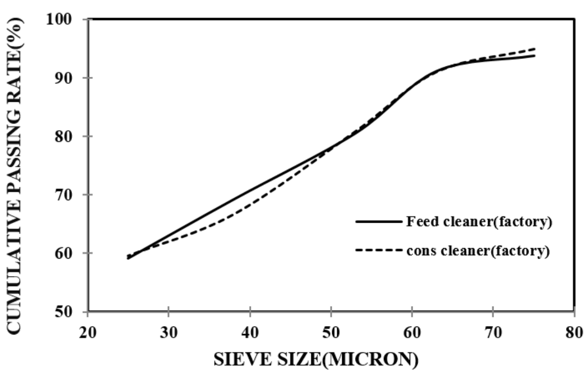

Fig. 9. Comparison between grain size distribution of the feed and the concentrate of magnetic separator (cleaner).

Table 9. Sample properties of the magnetic separator of the plant and the Davis tube test.

	d_{80}(mic)	Blaine number	%Fe	%FeO	%P
Cleaner feed	53	1546	62.61	15.49	0.596
Final concentrate of cleaner	53	1486	69.38	27.14	0.124

As shown in Table 10 and Fig. 10, the magnetic separator concentrate (cleaner stage) and the Davis tube test concentrate of the feed entering the cleaner stage had relatively similar grain size distributions and chemical properties. Therefore, the Davis tube test can be effectively used to study the functionality of industrial separators.

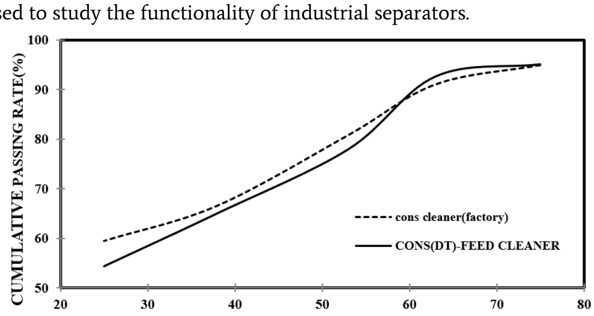

Fig. 10. Magnetic separator concentrates of the plant and the Davis tube test concentrate.

Table 10. Comparison between the properties of magnetic separation of the plant and the Davis tube test.

	d_{80}(mic)	Blaine number	%Fe	%FeO	%P
Final concentrate of cleaner	53	1486	69.38	27.14	0.124
Davis tube test concentrate (the feed entering the cleaner stage)	54	1500	68.87	26.19	0.155

3.4.2. Effect of grain size distribution on functionality of magnetic separators and concentrate Blaine number at laboratory and industrial scales

In order to study the effect of grain size distribution on the functionality of the magnetic separator and the concentrate Blaine number at the laboratory scale, the feed of magnetic separators (cleaner stage) was grinded at three stages (using ball mills), and then the Davis tube test was conducted. Table 11 shows the laboratory condition of the ball mill.

Table 11. The laboratory condition of the ball mill test.

Laboratory condition	State 1	State 2	State 3
Sample weight (g)	500	500	500
Mill speed (rounds per minute)	86	86	86
Retention time (minutes)	1.5	3	4.5

After grinding the feed of magnetic separators, the Davis tube test was conducted on three stages (different retention times). The laboratory conditions chosen for the Davis tube test were set similar to the operating conditions in the plant. The optimal duration of material grinding was selected based on the experience and through a try and error procedure. The following picture shows the ball mill used in this study.

Fig. 11. Ball mill.

- ***Comparison between the grain size distributions of the feed of magnetic separators (cleaner stage) in Chadormalu and the grinded samples***

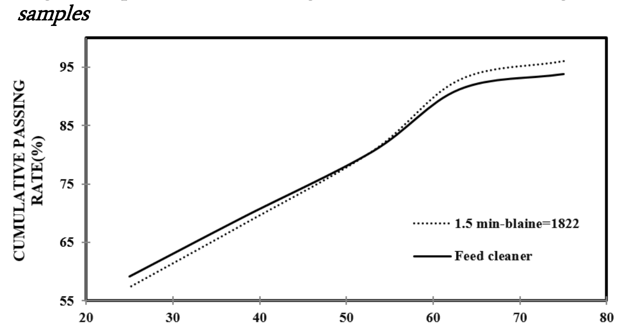

Fig. 12. Comparison between grain size distributions of the cleaner feed and the ball mill product with a retention time of 1.5 minutes.

Table 12. The properties of cleaner feed and the grinded sample with a retention time of 1.5 minutes.

	d_{80} (microns)	Blaine number	Percentage of particles<38 microns
Cleaner feed	53	1546	68
Grinded sample (1.5 min)	52	1822	68

According to the results shown in Fig.12 and Table 12, it can be concluded that the materials with a retention time of 1.5 minutes inside the mill and the cleaner feed had consistent $d_{80,}$ and therefore the difference found in their Blaine numbers might be due to the difference in the number of fine particles.

According to Fig.13 and Table 13, it could be concluded that an increase in grinding time was associated with a decrease in d_{80}, an increase in particles finer than 38 microns, and an increase in the Blaine number.

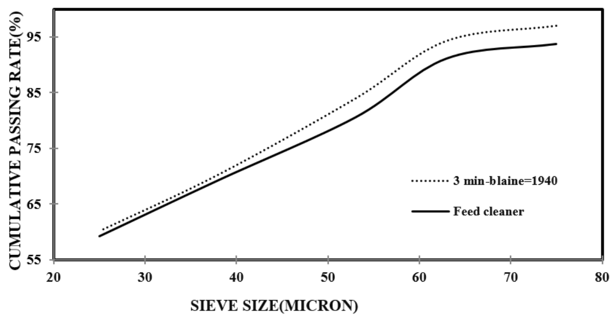

Fig. 13. Comparison between grain size distributions of the cleaner feed and the ball mill product with a retention time of 3 minutes.

Table 13. The properties of cleaner feed and the grinded sample with a retention time of 3 minutes.

	d_{80} (microns)	Blaine number	Percentage of particles<38 microns
Cleaner feed	53	1546	68
Grinded sample (3min)	49	1940	70

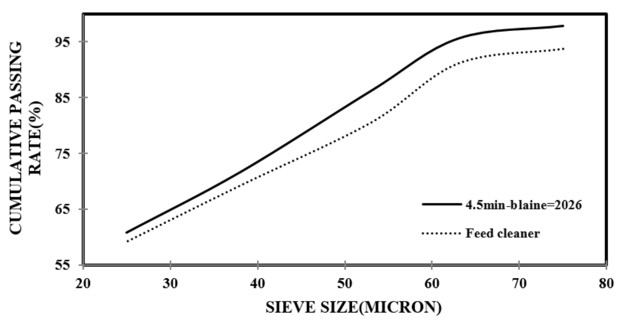

Fig. 14. Comparison between grain size distributions of the cleaner feed and the ball mill product with a retention time of 4.5 minutes.

Table 14. The properties of the cleaner feed and the grinded sample with a retention time of 4.5 minutes.

	d_{80} (microns)	Blaine number	Percentage of particles<38 microns
Cleaner feed	53	1546	68
Grinded sample (4.5min)	47	2026	71

According to Fig.14 and Table 14, it could be concluded that an increase in the grinding time was associated with a decrease in the particle size and an increase in the Blaine number. Moreover, according to the effect of fine particles on Blaine number, an increase in grinding time was found to be associated with an increase in the percentage of particles finer than 38 microns and an increase in the Blaine number.

- ***Comparison between concentrate of the magnetic separators (cleaner) of the Chadormalu plant and the concentrate of grinded feed in the Davis tube test.***

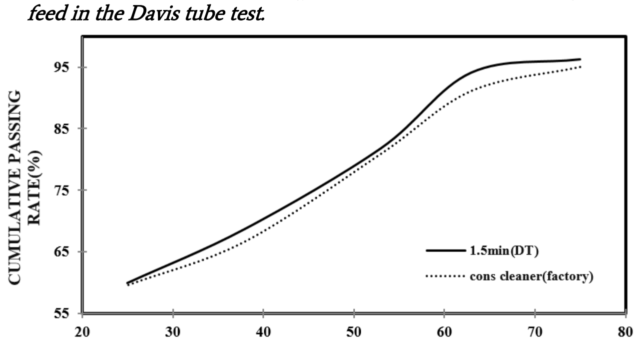

Fig. 15. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded sample with a retention time of 1.5 minutes.

According to Figure 15 and Table 15, it can be concluded that despite similar grain size distributions, the Davis tube test concentrate of the grinded samples with a retention time of 1.5 minutes had a higher Blaine number. The Fe and FeO contents were very close to the original state. Here, the difference in the Blaine numbers might originate from the difference in the content of fine particles.

Table 15. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded samples with a retention time of 1.5 minutes.

	d_{80} (microns)	Blaine number	%Fe	%FeO	%P	a
Final concentrate of cleaner	53	1486	69.38	27.17	0.124	66
Davis tube test concentrate of (1.5min) the grinded sample	51	1770	69.15	26.80	0.126	68

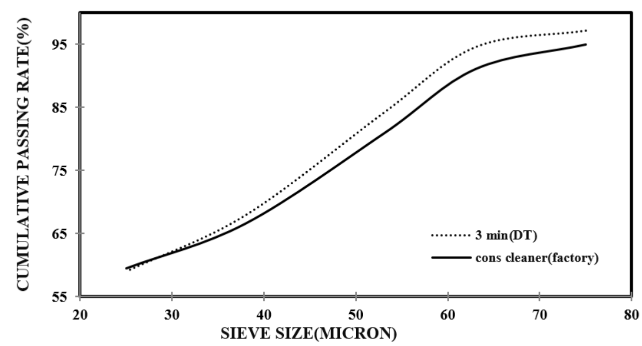

Fig. 16. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded samples with a retention time of 3 minutes.

Table 16. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded samples with a retention time of 3 minutes.

	d_{80} (microns)	Blaine number	%Fe	%FeO	%P	Percentage of particles<38 microns
Final concentrate of cleaner	53	1486	69.38	27.17	0.124	66
Davis tube test concentrate of the grinded samples (3 min)	50	1830	69.37	26.69	0.118	68

According to Figure and Table 16, it could be concluded that when particles became finer, the Blaine number increased, which led to an improvement in the magnetic separation process as well as the reduction of phosphorous contents.

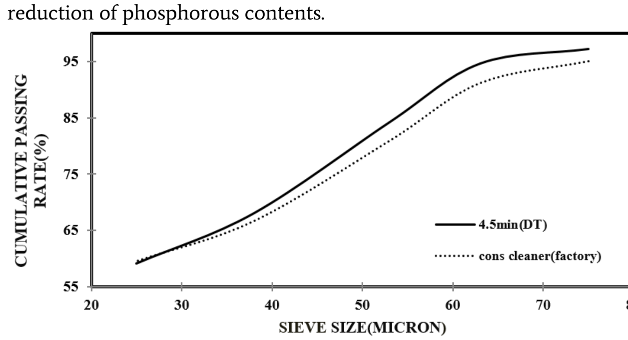

Fig. 17. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded samples with a retention time of 4.5 minutes.

Table 17. Comparison between the concentrate of cleaner and the Davis tube test concentrate of the grinded samples with a retention time of 4.5 minutes.

	d_{80} (microns)	Blaine number	%Fe	%FeO	%P	Percentage of particles<38 microns
Final concentrate of cleaner	53	1486	69.38	27.17	0.124	66
Davis tube test concentrate of the grinded samples (4.5 min)	44	1980	69.45	26.74	0.109	74

Comparison between Tables 16 and 17 indicates that an increase in the grinding time led to an increase in the Blaine number and a decrease in the recovery of phosphorus mienrals (Table 17 and Fig.17).

4. Conclusion

1. The percentage of particles finer than 45 microns had the highest influence on the Blaine number. For similar particle size distributions, minor changes in the ratio of particles finer than 45 microns led to significant changes in the Blaine number.

2. There was no clear relationship between the Blaine number and d_{80} of Golgohar's sample because some samples with similar d_{80} had different Blaine numbers. The grain size distribution and the percentage of particles finer than 45 microns had significant effects on the Blaine number.

3. During different mineral processing stages, by increasing the iron grade and removing the iron-free minerals such as clay, a decrease in the Blaine number was observed from one stage to another. This may be because of the removal of the clay minerals, which are often finer than 45 microns. It should be mentioned that a 1% reduction in the clay percentage caused a 400-unit reduction in the Blaine number of Golgohar's samples. Minor changes in the particle size distribution and d_{80} caused a significant increase in the Blaine number of Chadormalu's samples, and therefore it could be concluded that minor variations in the percentage of fine particles might cause significant changes in the Blaine number.

4. Besides the particle size distribution, the mineral type was also found to be an effective factor affecting the Blaine number. Clay minerals had a higher Blaine number (due to their plate-like shapes) compared to magnetite and hematite concentrates.

5. Within the same range of size distribution, magnetite particles had higher Blaine numbers compared to hematite particles because the former one had uniform shapes and better sorting, while the later had irregular and non-uniform shapes.

6. The Davis tube test was used to examine the functionality of the magnetic separators in the cleaner stage; the results were reliable and comparable to the industrial state. Moreover, the concentrate of the magnetic separator and the Davis tube test concentrate had very similar properties.

7. Where the feed of the magnetic separator was grinded and their particle size was decreased, an increase in the Blaine number was observed.

8. Different grinding times led to different Blaine numbers and recoveries. The highest Blaine number and the least recovery of phosphorus contents were found for a retention time of 4.5 minutes.

9. Comparing the recovery of phosphorous contents in different states of the re-grinding process showed fine particles were responsible for the lower recovery of phosphorous minerals.

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