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A new approach to analyzing the type of moisture inside the filter cake of Hematite concentrate

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ABSTRACT

Filters are widely used for dewatering in the mining industry. In general, different parameters affect vacuum filtration, such as solid percentage, vacuum level, particle size distribution, filter cloth, and chemical additives. These parameters can influence filtration properties such as cake moisture, throughput, and filter cloth lifetime. Moisture and throughput usually are used to determine the quality of filtration. In this study, new variables were used to express the filtration and characteristics of filter cake at a microscopic scale. The quality of the filter cake can be precociously analyzed using the void fraction and density of the filter cake. The present study aimed to propose some new variables to properly analyze the filtration process, improve the filtration rate, and decrease the cake moisture of Gol-E Gohar iron ore concentrate. In this regard, a series of filtration experiments were implemented using laboratory-scale bottom top-feed vacuum filters. The results showed that an increase in the solid percentage decreased the void fraction from 0.45 to 0.40 and increased cake density from 0.30 to 0.33 gr.cm^{-3}, respectively. Increasing the particle size increased the void fraction from 0.415 to 0.43. Furthermore, the type of structural or capillary moisture of the filter cake could be determined using a void fraction.

Keywords: *Vacuum filter, Magnetite concentrate filtration, Void fraction, Iron Concentrate.*

1. Introduction

Water recovery is a crucial subject for the world community and is more important in areas with dry and hot climates[1]. Mineral processing plants involve four main parts: grinding, concentration, dewatering, and pulp transportation [2]. Mineral processing industries are one of the Largest water consumers. Generally, some procedures such as thickening, filtration, and tailing dumps are used to recover water [1] and decrease freshwater consumption.

Filtration is a process in which solid-liquid mixtures should be separated by a medium (like a filter cloth). The solid particles are kept on the filter medium, and the liquid (generally water) passes through it. Different filter clothes such as polyester, polypropylene, and polyamide are used as filter mediums [3]. In some new types of filters, ceramics are used instead of filter cloth. A ceramic capillary action disc filter can decrease specific energy consumption through the use of an alumina membrane, which is fully regenerated, and air impermeable [4].

Several kinds of filtration equipment are used in mineral processing, such as belt filters, drum filters, disk filters, pressure filters, etc. The filtration equipment is classified into the pressure mechanism and the feeding procedure. The pressure mechanism can be in a press or vacuum type, and the procedure of feeding relies on top or bottom ways [5][6]. Although the maximum level of pressure drop in the vacuum type with filter cloth is limited to 0.7 bar [9], it could be up to 1.0 bar in ceramic types [4].

Bottom feed is one kind of vacuum filtration in which the slurry is under the filter cloth during the feeding time and the cake forms on the filter cloth using a vacuum. Another kind of filtration is top feed in which the slurry is fed on the filter cloth during the feeding time. Generally, each vacuum filtration process has three steps cake formation, dewatering, and cake discharge[7]. The surface of the drum has several sections which are covered by filter cloth. Some sections are connected to a vacuum pump and a vacuum is applied [8]. In some cases, chemical and non-chemical additives are applied to improve the filtration process [9][10]. Filter aids are chemical reagents or physical materials that can improve the dewatering process. For instance, adding R31 filter aid to the Hematite concentrate pulps from 0 to 1800g/t decreased the moisture by about 2% [11] or CO_2 addition in the filtration process improved 36% filtration rate at the same moisture level which is directly related to zeta potential from pH 7-7.5 compared to the pH 11-11.5 [12].

Flocculants are one of the chemical reagents widely used in thickening which can change the pulp viscosity. Flocculants increase filtration rate and apparent cake porosity generally but lead to increased moisture, too [13]. The particles, which can be separated by gravity-assisted sedimentation, aggregate by flocculants. Fine particles interact with these polymers, which can be non-ionic, anionic, or cationic, and under the influence of gravity settle rapidly in the form of aggregated flocs [14]. Although polymeric flocculation increases filtration kinetics, raises cake moisture. The water entraps within the floc structure [2]. The stability of flocs is varied by some parameters such as ionic strength, PH of the pulp, and the additive dosage of coagulants and flocculants

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[11]. Flocculants change particles' surface charge and, by dispersion or agglomeration, help reduce or accelerate the rate of sedimentation [15].

The filter cake can be incompressible and compressible, depending on the solid materials in the slurry [15, 16]. This crucial factor influences the procedure of design and selection of the filtration equipment. Moreover, the level of cake compressibility is important in modeling and simulation [17]. The suitable dewatering equipment for a plant is scaled up by implementing a series of dewatering experiments at a laboratory scale.

The quality of filtration is expressed by the moisture of the cake and the amount of production in general. Filter throughput is defined as the equation (1) [18]:

$$\text{Throughput} = (W*3600)/(T*A*1000) \quad (1)$$

Where W is the weight of dried cake remaining on the filter medium (g), T is the total filtration time (seconds), and A is the filter surface area (m^2).

In addition, the moisture of the filter cake is calculated using equation (2) [19]:

$$M\% = (W_{wet}-W_{dry})/W_{wet}\times 100 \quad (2)$$

where W_{wet} and W_{dry} are the weight of the filter cake and dried cake remaining on the filter medium (g), respectively.

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Where W_{wet} and W_{dry} are the weight of the filter cake and dried cake remaining on the filter medium (g), respectively.

When the moisture content is considerably high, a moist layer is formed on particle surfaces, which is the reason for cohesive forces in the form of liquid bridges and porous particles, like zeolite; firstly, moisture is absorbed in the particle pores, increasing particle density [20].

Void fraction is defined as the equation (3) [13]:

$$\varepsilon = \frac{(V_{cake}-V_{solid})}{V_{cake}} \quad (3)$$

where ε is the void fraction, and V is the volume of cake or solid (m^3).

It might be necessary to form a cake and displace the liquid from the pores in the cake with gas flow displacement to achieve a dry cake successfully.

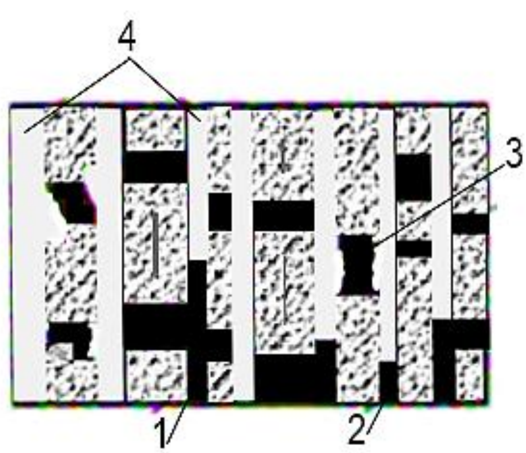


Figure 1. Capillary pressure and gas displacement. 1) Local zone, 2) capillary moisture, 3) structural moisture, and 4) working channels [11].

At the small diameters of capillary, the liquid in the pores is affected by the surface tension at the gas-liquid interface, and a certain pressure is required to overcome the capillary forces. A differential air pressure more than the capillary pressure is needed to penetrate the pores [13].

Furthermore, the density of the filter cake is calculated as:

$$\rho = \frac{M}{V} \quad (4)$$

Where M is the weight of the cake (Kg), and V is the volume of the cake (m^3).

The void fraction and density of the cake explain how the solids are packed together. When the filter cake is forming, the particles tend to form loose packing. Applying more pressure compresses the particles [13]. It is reported that the void fraction for spherical particles is lower than for non-spherical particles due to the shape factor. Moreover, buoyancy and viscous forces have a strong effect on void fraction [22].

Gol-e-Gohar Industrial Complex involves an iron mine, several magnetite processing plants, hematite plants, etc. This investigation aimed to improve the performance of vacuum drum filters of a hematite iron ore concentrate plant. The hematite plant has three bottom-feed drum filters. In this investigation, by using the one-factor method of design of the experiment, the effect of pressure, solid percent, and flocculant were analyzed simultaneously. In addition, the type of moisture (structural or capillary) was adjusted with the void fraction parameter.

There are limited investigations on the mechanism of cake formation and microscopic structure. The major part of research in the dewatering and filtration field focused on the operational parameters such as throughput and moisture, and rare of them paid attention to the microscopic scale and type of moisture inside the cake filter. In this study, in addition to the moisture and throughput, the type of filter cake moisture was investigated at a microscopic scale. Void fraction and cake density were used to measure the solid properties and structure of the filter cake.

2. Materials and Methods

The fresh feed of the Gol-e-Gohar hematite plant is a combination of two slurry flows with different characteristics. The dry solid rate of the first slurry is steady at 65 t/h, while the dry solid rate of the second slurry is variable, and it could be 10 t/h and 20 t/h. These fluctuations in the solid rate of slurry influence filtration performance.

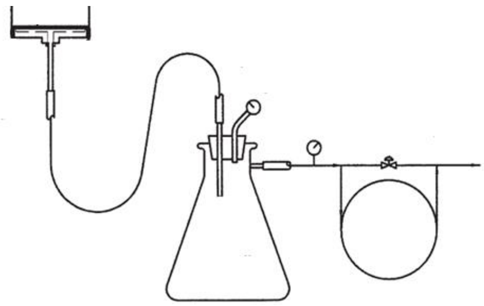
Hematite iron concentrate samples were obtained from the filter cake of the hematite processing plant in two states of the operation (75 t/h or 85t/h). The first and second samples were taken when the dry solid rates of slurries were 75 t/h and 85 t/h, respectively. The process carried on approximately two weeks to obtain the representative sample in various working shifts. Notably, the stability of the plant had been checked before any sampling. To provide a unique feed for all experiments, first, all the samples dried in the oven and then were blended. In the next step, to assign the sample characteristics, they were prepared to determine the particle size distribution using laser analysis and a wet laboratory vibrating screen of Gol-e-Gohar mining and industrial company the research institute.

Initially, some screening tests were applied to determine the main parameters to handle the experiment. Some of them, such as filter aid and PH of slurry removed from the analysis, while the solid percent, vacuum pressure, and Flocculant were known as the most effective parameters on the filtration process and cake moisture. After specifying the major items, by using Design Expert 7 software structure and level of experiments were determined in the one-factor method.

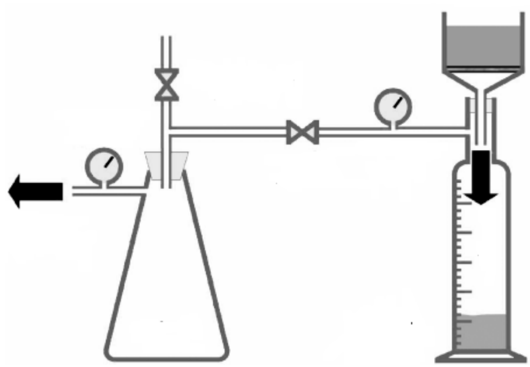
The initial tests are often carried out using either the Buchner funnel or immersed leaf type of laboratory filtration apparatus to design and select the proper vacuum filter for dewatering [22]. Special equipment was built to implement the tests in the bottom feed procedure.

The time of cake formation and dewatering in the bottom-feed procedure can be controlled by varying the drum speed at a wide range for the drum filters, while the time of cake formation in the top-feed filters like belt filters is not controllable. In the bottom feed procedure, the time of cake formation and dewatering for all the tests were 20 and 40 seconds, respectively. In the top-feed procedure, the dewatering time in all tests was 40 seconds, while the time of cake formation was variable.

Finally, the results were evaluated in pairs. Besides the understanding role of each parameter in the process, the type of moisture inside the filter cake was denoted by the void fraction.



A. Bottom Feed



B. Top Feed

Figure 2. Different filtration procedures.

3. Results and Discussions

In this section, first of all, the chemical and physical characteristics of the sample are expressed. Then, some physical results were detailed, such as the solid percentage, level of vacuum pressure, etc. In addition, the effect of flocculant as a chemical additive was also investigated. New variables were reported and discussed to describe the quality of filter cake.

3.1. physical characteristics of the sample

The sieve analysis of particle size was described as D_{50} and D_{80}, while the laser analysis was stated as D_{20}. The mean of 20%, 50%, and 80% of particles were smaller than a certain size are shown in Table 1.

As fine particles have a major role in the filtration process, reporting of D_{20} is common. D_{20} of the first and second samples were 41 and 36µm, respectively. The differences between the particle size distribution of samples are expressed in figure 3.

3.2. Effects of the physical parameters on filtration

When the filter cake is forming, a layer of particles with water is deposited on the filter cloth. If the solid percentage increases, the volume of water in this layer decreases. Also, it should be expected that the void fraction decreases.

The bottom-feed filtration was used to show this fact. The solid percentage was 65 and 77. As it is shown in figure 4, the increasing solid percentage from 65 to 77 led to a fall in the void fraction by approximately 0.05 units, which was adjusted by 0.4. Although the variation of void fraction seems to be unconsiderable, the standard deviation for that was 0.013, and this small number stated that the fluctuation of void fraction in this range was significant.

To explain the void fraction, when it shows a high level, it means that the solid percentage is low in the cake formation, and consequently, the total water in the initial filter cake should be at a high level.

Table 1. D_{80}, D_{50}, and D_{20} of the first and second hematite samples.

Sample	D_{20} (%)	D_{50} (%)	D_{80} (%)
1	8.7	33.7	80.9
2	8.5	28.4	75.2

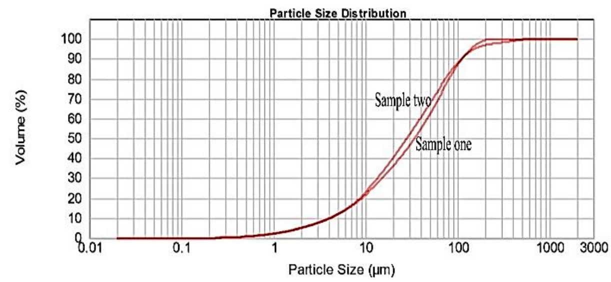


Figure 3. Particle size distribution of the first and second hematite samples.

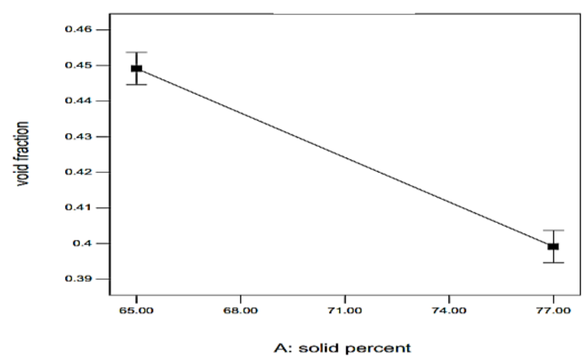


Figure 4. The effects of solid percentage on the void fraction.

Whereas in contrast, as the void fraction decreases, the particles are compressed at a higher rate, and the space between the particles decreases. So, logically the space between the particles can be filled with air or water.

Despite a decrease in the void fraction, the moisture of the filter cake increased. Figure 5 shows the variation of the moisture by changing the solid percentage. When the solid percent was uplifted, the moisture content of the cake filter experienced growth from 13.4% to 14.4% simultaneously.

According to Figure and 1, the increase in moisture is related to capillary or structured moisture. The capillary moisture will be evacuated if the pressure increases, while structured moisture cannot be evacuated. Figure 6**Figure** shows the moisture variations against pressure. The pressure, one of the main parameters in vacuum filtration, was boosted from 55 kPa to 75 kPa, and this stronger air sucking lifted down the moisture from approximately 14.2 % to 13.6 %. Regarding the standard deviation for the moisture, which was 0.63, the difference between the two moisture levels was significant.

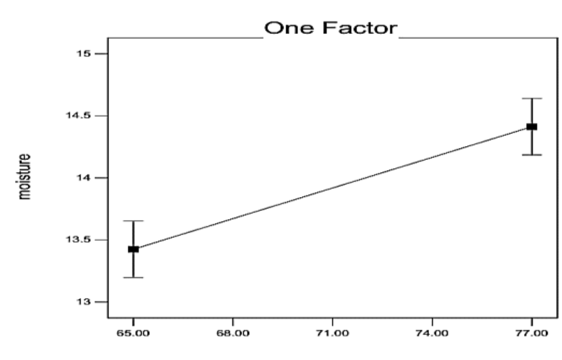


Figure 5. The effects of solid percentage on the moisture.

Based on the void fraction and diagram of pressure, the type of increased moisture is certainly related to capillary moisture. Therefore, it can be concluded that when the solid percentage increases, the thickness of the filter cake increases. As a result, the resistance of the cake increases, and the water cannot leave the cake easily. Figure 7 shows this fact. The standard deviation for the thickness is 0.92, and it saw an enhancement from 10 mm to about 16 mm.

Since the density of the solid is higher than water or air, the cake density should increase by decreasing the void fraction. Figure 8 shows the variations in cake density against the solid percentage. As can be seen, the solid percent fluctuation between 67 % and 77 % caused the increase in density from 3 to 3.3 gr/cm^3. The standard deviation for the density was 0.064, so the difference between the figures was reliable.

When the particle size decreases, the space between the particles decreases; consequently, the void fraction reduces. Therefore, it should be expected that the finer particles have a lower void fraction. Figure 9 shows the effects of particle size on the void fraction in which by increasing the particle size from 82 microns to 94 microns, the void fraction showed a slight increment. Another prominent influence of particle size is on moisture. as its variation in mentioned range caused the capillaries forces to work better, decreasing moisture. Therefore, it is expected that the moisture will decrease by using sample one and increasing particle size. According to Figure 10, while particle size experiences considerable growth, the moisture content increases by almost 0.7 % as well. It seems that the increase in particle size increased the moisture, but it is related to the feed specifications and mineralogy.

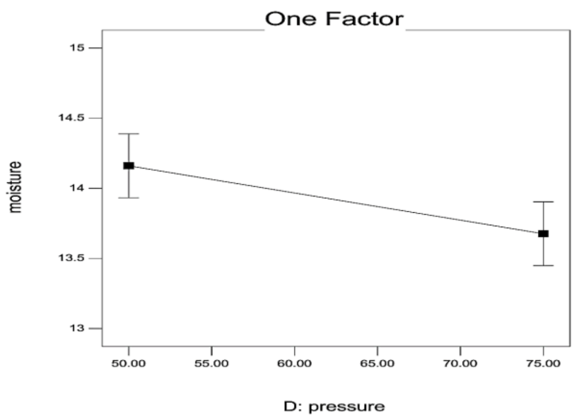


Figure 6. The effects of pressure on moisture.

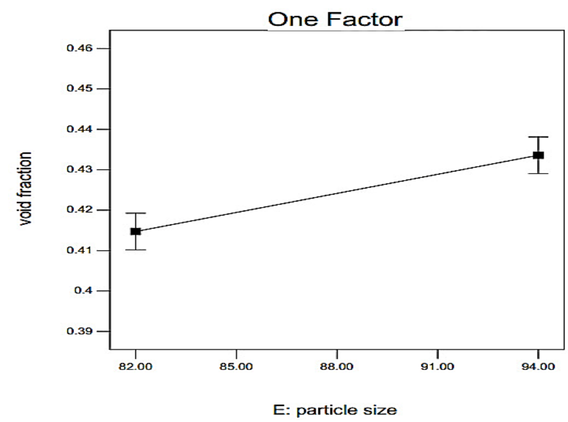


Figure 9. The effects of particle size on the void fraction.

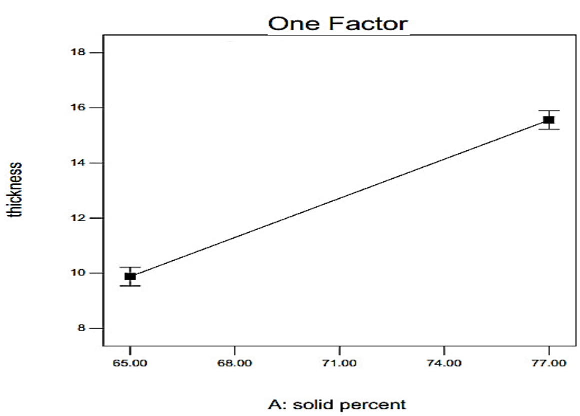


Figure 7. The effects of solid percentage on the filter cake thickness.

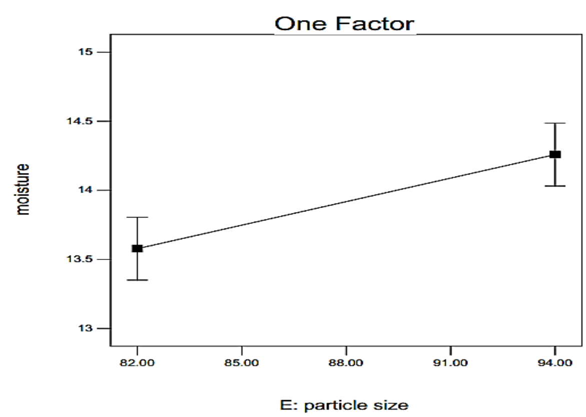


Figure 10. The effects of particle size on the moisture of the filter cake.

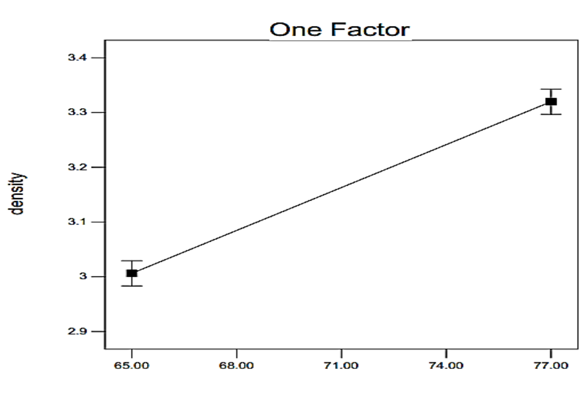


Figure 8. The variation in cake density against the solid percentage.

Table 2 shows the mineralogical differences between samples 1 and 2.

Table 2. The mineralogical specifications of samples 1 and 2

Sample number	1	2
Unit	%	%
L.O.I	2.23	1.58
MgO	1.02	1.18
Al_2O_3	0.79	0.68
SiO_2	3.07	3.41
P_2O_5	0.25	<0.1
SO_3	0.58	0.52
CaO	0.92	0.84
Fe_2O_3	91.13	91.79

If the increased moisture is related to the sample mineralogy, it can be concluded that the type of moisture is structural (figure 1). In this condition, by increasing pressure, the total moisture should not change significantly. This result is very important and explains the type of moisture exactly.

This fact can be seen better by using flocculants. Some top-feeding experiments were carried out by anionic flocculants with high molecular weight.

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3.3. Analytic Analysis

The model showed that the most important variable on moisture was solid percent among those who participated in this investigation. After that, the particle size was the second main variable effective on moisture. These results have been shown in ANOVA table as below:

Table 3. ANOVA table for Moisture variable.

	P-value	Sum of Squares	Df
Model	<0.0001	13.40	3
A-Solid percent	0.0001	7.81	1
D-Pressure	0.0379	1.88	1
E- Particle size	0.0048	3.71	1

The suggested model for the moisture by DX7 is according to follows:

$$moisture = +13.92+0.49*A-0.24*D+0.34*E \quad (5)$$

Where A is solid percent, D is pressure (kPa), and E is particle size (micron).

Regarding the explanation in the above sections, the void fraction is affected by solid percent and particle size. The ANOVA table expresses this fact as below:

Table 3. ANOVA table for void fraction variable.

	P-value	Sum of Squares	Df
Model	<0.0001	0.024	3
A-Solid percent	<0.0001	0.020	1
E- Particle size	0.0002	0.0028	1
BE-Particle Size * Flocculant	0.0358	0.0076	1

This parameter can be predicted as the following model:

$$void\ fraction = +0.42-0.025*A+9.437E-003*E-4.874E-003*B*E \quad (6)$$

where A is solid percent, B is flocculant (g/ton), and E is particle size (micron).

3.4. The effects of flocculant on filtration

Flocculants can make some hydrated flocs between particles. The water in flocs is structural, and it is hard to separate. The amount of this water depends on the type of flocculants. Flocculants with high molecular weight and long chains keep more water inside their structures. Figure 11 shows the effect of flocculants on the void fraction.

As flocculants stick to fine particles to each other and make particles bigger, it is expected that the void fraction increases. On the other hand, the coarse particles lead to better performance of capillary tubes compared with the fine particles. So, it was predicted that the moisture of the filter cake shall decrease. figure 12 shows the effects of flocculants on the moisture of the filter cake Although the flocculant addition increased the void fraction, it was not significant.

The moisture of the filter cake increased by adding flocculants. This was due to flocs formation, indicating that the moisture was certainly structural. Therefore, since vacuum filtration was limited up to about 700 kpa, this level of pressure was not sufficient to decrease the moisture of flocs.

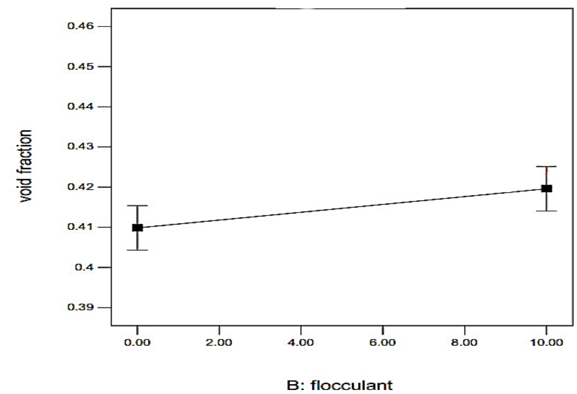

Figure 11. Effects of flocculants on the void fraction.

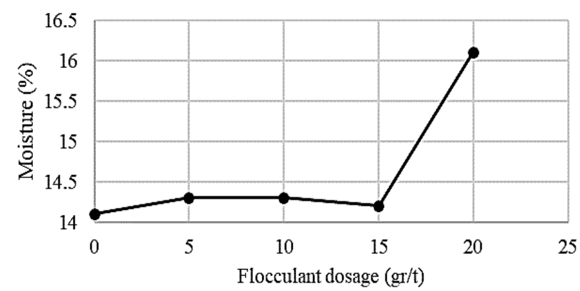

Figure 12. The effects of adding flocculants on the moisture of the filter cake.

4. Conclusions

The moisture of the iron concentrate filter cake, which can be of the capillary or structural type in the filter cake, is a critical parameter for downstream plants, particularly pelletizing plants. In this study, the void fraction variable was introduced to describe the type of moisture infiltration. The type of moisture was precisely determined by using the variables of the void fraction and pressure that can be used to design and select the type of filtration. The results showed that bringing up the solid percentage from 65% to 77% led to increased filter cake thickness from 10 to 15.5 mm. The total moisture also increased from 13.4% to 14.4%.

As the type of moisture subject was focused on in this investigation, the increase in moisture was stated undoubtedly due to the capillary moisture. This fact was proved by uplifting the pressure. The rise of pressure from 50 to 75 kPa decreased the moisture of the filter cake from 14.2% to 13.7%.

Another novelty of this research was using flocculant to make the filtration process in a low amount of dosing. The effects of adding flocculant on the moisture at the values of <10 $g.ton^{-1}$ were insignificant, but the values >10 $g.ton^{-1}$ increased the final structural moisture. The capillary moisture decreased by the increase in pressure while the structural moisture was not. The void fraction analyzed the quality of dewatering and final moisture. So, flocculant usage of less than 10 $g.ton^{-1}$ was suggested to produce a cake filter with lower moisture content. The reason for this positive effect is sticking the fine particles and higher performance of working channels inside the cake filter.

In this study, the flocculant addition at 10 $g.ton^{-1}$ to the slurry increased the void fraction from 0.41% to 0.42%. when the void fraction increased, the moisture grew, and the moisture was structural. The claim is proved by increasing the pressure that did not affect the moisture, which was almost constant.

The behavior of flocculant for lower-grade iron concentrate can be different. It can be a topic of future study to determine the amount of structural or capillary moisture at the condition of tails, especially the clays.

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