- R E S E A R C H P A P E R -

International Journal of Mining and Geo-Engineering

IJMGE

IJMGE 55-2 (2021) 109-116

DOI: 10.22059/IJMGE.2020.295976.594839

Studies on the effects of physical parameters of filtration process on the fluid flow characteristics and de-watering efficiency of copper concentrate

Amirhossein Rezaei [a], Hadi Abdollahi [a, *], Mahdi Gharabaghi [a], Hassan Mamghaderi [a]

[a] *School of Mining Engineering, College of Engineering, University of Tehran, Tehran 1439957131, Iran*

Article History:

Received: 15 January 2020,
Revised: 23 September 2020,
Accepted: 24 September 2020.

ABSTRACT

The effect of physical parameters such as type of filtration media, solids percent, pressure drop, and pH on resistance to filter cloth (R), specific cake resistance (α), moisture content, and cake formation rate were investigated in this paper. Tests were performed using the Vacuum Top-Feed method and during the tests, no chemicals (flocculants, coagulants, etc.) were used. The optimal response for each factor was considered as the minimum values of the resistance to filter cloth (R), specific cake resistance (α), moisture content, and maximum cake formation rate. The results showed that the Cloth A7 (Fiber: Polyester, Weave: Twill) and Cloth A12 (Fiber: Polyester, Weave: Plain) have the best performance among 16 types of filter media. With increasing solid content from 45 to 65%, the resistance to filter cloths of A7 and A12 increase from 26.29 (1/m×10^{10}) to 101.39 (1/m×10^{10}) and from 25.38(1/m×10^{10}) to 245.67 (1/m×10^{10}), respectively. The highest rate of cake formation in 65% solids for both cloths was 0.077 (mm/s) for cloth A7 and 0.059 (mm/s) for cloth A12. Also, it was found that the compressibility factor is the same for each cloth, so the difference in the compressibility coefficient of the cake depends on the inherent properties of the raw material.

Keywords: *Filtration; Copper concentrate; Physical parameters; Water recovery*

1. Introduction

1.1. Filtration theory and fundamental aspects

Water is widely used as a solvent/liquid in the mineral industry especially in hydrometallurgical and mineral processing. In arid and semi-arid areas, optimizing freshwater usage in mines is essential [1]. On the other hand, industrial processes that involve the usage of water are subject to strict environmental regulations relative to the discharge of effluents therefore, there is a growing demand for the reuse of water in the industry, and water management needs to be improved in minimizing the waste [2].In the mining industry, efficient usage of water in its process and consequently dewatering and recycling is vital [3]. The two main techniques involved in dewatering processes in mineral processing include sedimentation and filtration which are commonly carried out by mechanical filtration followed by a drying process [4, 5]. The higher proportion of the water is first removed by precipitation method in thickener to produce a high-density pulp with a solids content of about 45-65 % [6, 7]. Filtration consists of a porous layer with a pores size allowing the passage of liquid and restricted the movement of the solid particles through the layer using a differential pressure on both sides [8, 9] (Figure 1). This procedure produces a cake with minimum moisture content and maximum operating power (solid production rate per unit area) [10].

Filtration and dewatering operations of slurries are commonly performed with vacuum filters, which provide a robust and reliable technology for industrial dewatering [11]. Continuous vacuum filters are usually used when solids are not fine, they have a high sedimentation rate and produce a permeable cake that can be carried out with a moderate pressure difference in the dewatering process [12, 13]. The performance of a filter depends on the filter properties (fiber mat structure, filter area, filter thickness) and the operating conditions (face velocity and gravitational direction) [14, 15].

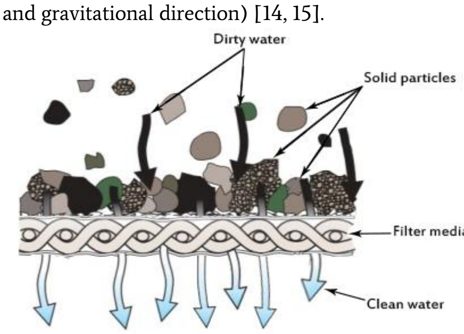

Figure 1. Mechanism of cake formation in the filtration process.

In the constant pressure filtration, the flow rate of a filtrate (Q) can be calculated using equation 1, which is derived from Poiseuille's equation [16].

$$Q = \frac{dv}{dt} = \frac{A\,\Delta P}{\mu\, R} \qquad (1)$$

Where v is the volume of filtrate (m^3), t is filtration time (s), A is filtration area (m^2), ΔP is applied pressure drop (Pa), μ is filtrate viscosity (Pa·s) and R is average resistance to filtration ($^1/_m$).

To obtain the specific cake resistance value, from equation (1):

$$\frac{t}{^v/_A} = \frac{\mu\alpha c}{2\Delta P}\left(\frac{v}{A}\right) + \frac{\mu R}{\Delta P} \;\rightarrow\; av + b \qquad (2)$$

* Corresponding author. Tel./Fax: +98-21-88008838; +98-912-5032335, *E-mail address:* H_abdollahi@ut.ac.ir (H. Abdollahi).

Where $a=\frac{\mu\alpha c}{2A^2\Delta_P}$ and $b=\frac{\mu R}{A\,\Delta_P}$.

Occasionally, excessive pressure can clog filter cloth quickly. To overcome this problem, it is recommended that the pressure be increased slowly [17]. For this purpose and by using equation (2):

$$\frac{t-t_s}{V-V_s}=\frac{\alpha\mu c}{2A^2\Delta_P}(V+V_s)+\frac{\mu R}{A\,\Delta_P} \quad (3)$$

The values of t_s and V_s are selected as the starting points of the constant pressure filtration [17].

In equation (2), parameter C is a ratio of dry solid to filtered fluid, which is called effective solids percent. The following equations can be used to calculate C:

$$C\approx\frac{(M_s)_e}{V_e}\rightarrow C=\frac{\rho_L\,S}{1-m_{av}\,S} \quad (4)$$

Where S is pulp solid content, V_e is filtered fluid volume, ρ_L is water specific gravity, and $(M_s)_e$ is dry cake weight at the end of each test and m_{av} is the ratio of wet cake weight to dry cake weight.

In the final stage of the tests, the t/v graph plotted versus v does not follow a linear pattern. Consequently, by placing the values V_e and m_{av} in the above equations, the correct answer is not obtained for the specific cake resistance and the resistance to filter cloth. Therefore, in this study, the linear section of the diagram was considered for the calculation. In other words, the transfer point data was considered in the above equations.

By using the data recorded during the filtration tests, in addition to the specific cake resistance and the resistance to filter cloth, other parameters are also calculated. One of these parameters is the average cake formation rate (L_{gr}), which is equal to the ratio of cake thickness to the filtration time. This parameter is also used to select the type of filtration device.

$$L_{gr}=\frac{L_e}{t_e}\ or\ \frac{L_e}{t_{tr}} \quad (5)$$

Based on dewatering studies if $\alpha<10^{11}$, the filter cake has a good filtration capability. If $10^{11}\leq\alpha\leq10^{13}$, makes the moderate cake and if $\alpha\geq10^{13}$, the filtration process is difficult [18].

The specific cake resistance is also used to determine the compressibility of the cake. Some cakes produced by filtration are soft and tend to be compressed against pressure changes during filtration. It is worth noting that due to compression, porosity and penetration of cake are decreased [19]. In equation (6), the relation between α and ΔP is expressed:

$$\alpha=\alpha_0(\Delta P)^n \quad (6)$$

Where α_0 is the specific cake resistance at the unit pressure (m/kg), n is the compressibility coefficient or index of filter cake. Table 1 shows the type of each filter cake depending on the value of n [19].

Table 1. The classification type of filter cake based on compressibility coefficient [21].

Value of n	Type of filter cake
n=0	Incompressible
n<0.3	Low compressible
0.3<n<0.5	Middle compressible
0.5<n<1	High compressible

Among the different factors affecting the properties of pulp filtration, particle size distribution, solid percentage, inter-particle interactions with pH changes, the usage of filter aid, and cycle time are so important [20, 21]. In general, the parameters affecting the filtration process can be grouped into three groups: the technical specifications of the filtration device used, the characteristics of the materials to be filtered, and the type of material used to improve the performance of the filtration process which called filtration chemistry [22-24]. One of the most important and influential parameters affecting filtration performance is the filtration media (filter cloth), which has a direct impact on operating costs. The basis of filter cloth selection is based on the characteristics of fluid flow from the pores of the cloth [17].

Mamghaderi et al. (2018) investigated the role of physical parameters in the filtration process. During the tests, it was found that cloth with polypropylene weave is suitable for filtration operation due to minimum flow resistance. After the compression tests, it was found that the cake has a compressive capability of n = 0.56 [25]. Patra et al. (2016) studied and improved the dewatering of iron ore fines by the usage of surfactants. In the primary studies, it was found that the main problem in the dewatering process is the adherence of ultra-fine particles to iron particles. By adding surfactant cetyl trimethyl ammonium bromide, moisture dropped from 12-13% to 9-10% [16]. Castro and Laskowski (2015) studied the effect of flocculants in the flotation of copper-molybdenum ore. The results showed that flocculants polyacrylamide had a negative effect on the recovery. It was also found that flocculent polyethylene oxide is an effective flocculent for molybdenum in a wide range of pH but in any case, affects the molybdenum flotation efficiency [26]. Fan et al. (2015) studied the effect of particle properties on filtration of fine-grained coal pulp and the structure of cake formed. Studies have shown that the addition of kerosene to the pulp has led to an increase in the cake hydrophobicity and a decrease in the moisture content of the cake to 4.41%. The addition of flocculent to the pulp due to bridging between particles or neutralizing the particle surface charge can form large clots so that the filter cake resistance decreases and the permeability increases [27]. Wang et al. (2014) studied the characterization of the dewatering process of activated sludge assisted by cationic surfactants. During the tests, it was found that surfactant cetyl trimethyl ammonium bromide is more effective than surfactant dodecyl trimethyl ammonium bromide for the release of water bond with solid particles [28]. Lihong et al. (2011) studied enhancement of efficiency of filtration process with filter aids such as diatomaceous earth and wood pulp cellulose. Investigations showed that by adding filter aids, filtration rate increased and the moisture content of cake decreased due to changes in structure, porosity, compressibility, hydraulic resistance, and cake permeability [29].

In this study, due to the reduction of water resources and the necessity of maximum recovery of water in mines, the effect of physical parameters of filtration process on different responses including filter moisture content, water recovery, cake formation rate, specific cake resistance, and resistance to filtration cloth using Vacuum Top-Feed method were comprehensively studied. The purpose of this research is to investigate the performance of different filtration cloth, as well as the effect of clothes with the same texture and different types of warp and woof on the filtrate moisture content and cake formation rate, the resistance to the filtration cloth, and the specific resistance of the cake. Also, the effect of other effective parameters such as pressure drop (0.4, 0.6, 0.7, and 0.8 bar), solids content (45%, 50%, 55%, 60%, and 65%), and pH (4.5, 6, 7.5 and 9) on the fluid flow rate from the porous substrate and the determination of the filterability of the cake were examined.

2. Material and Methods

2.1. Sample

The used samples for the tests were originated from the Qaleh Zari copper mine. Sampling was performed at one-hour intervals after the beginning of each shift and during 20 days from concentrate thickener underflow (filter input). At the end of each workday, samples were transferred to the mineral processing laboratory of the Qaleh Zari copper complex and were packed and dried after calculating their solid percent.

Qaleh Zari copper concentrator plant has a 400-ton capacity per day that its feed is entered into flotation cells after two stages of grinding (rod and ball mills). Concentrate of the flotation process is entered into concentrate thickener for dewatering and then is dried by the filter. The optimal performance of the filtration process is led to make a dried and ready-to-sale concentrate and with returning of recycled water to process circuit. It will be a great help to solving the water shortage challenge in that semi-arid area. The final dewatering is done in the circuit with a vacuum drum filter. The capacity, pressure, and power of the vacuum pump are 31 $m^3.min^{-1}$, 530 mm Hg and 55 Kwh, respectively. The volume of the pond is $4m^3$ and the capacity of it is 40-45 ton/day of copper concentrate with a moisture content of 15%.

2.2. Characterization study

The semi-quantitative X-ray diffraction (SQXRD) technique was used to define the main and trace minerals in the sample. X-ray powder diffraction patterns were obtained using a PHILIPS PW1800 diffractometer with Ni-filtered Cu–Ka radiation, and a goniometer speed of 1° 2ϴ/min. The diffraction profiles with a 0.01 precision of d-spacing measurements were conducted from 4° to 60° (2ϴ). Based on the XRD results, chalcopyrite ($CuFeS_2$ = 30%), pyrite (FeS_2 = 23%), quartz (SiO_2=12%), and galena (PbS=10%) were distinguished as the major phases of the representative sample and sphalerite (ZnS) and hematite (Fe_2O_3) were minor phases. These minerals are reported in abundant order in the XRD graph (Figure 2).

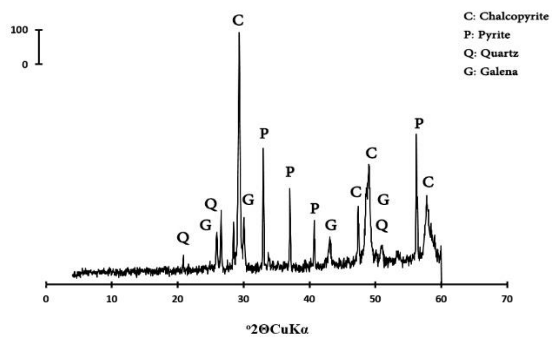

Figure 2. X-ray diffractogram (XRD) of the concentrate sample from the Qaleh Zari copper mine.

The representative sample was also analyzed using the X-ray fluorescence (XRF) technique to determine major and minor elements and oxides. The results of XRF analysis (PHILIPS PW1480) showed that Fe, S, SiO_2, Cu, and Al_2O_3 are major components and other oxides such as CaO, K_2O, MgO, Na_2O, P_2O_5, and TiO_2 are minor presented in the concentrated sample. The XRF results are presented in Table 2. More than 75% of the original sample has been formed from three species of Fe, S, and Cu. Due to the presence of precious metals such as gold and silver in the sulfide sample, the enrichment process works with maximum recovery and minimum grade for the final concentrate.

Table 2. The XRF analysis of the concentrate sample from the Qaleh Zari copper mine.

Major	Component	Fe	S	SiO_2	Cu	Al_2O_3	
	%	38.51	28.52	18.67	10.65	1.97	
Minor	Component	CaO	K_2O	MgO	Na_2O	P_2O_5	TiO_2
	%	0.42	0.31	0.24	0.05	0.038	0.071
	Component	L.O.I			Total		
	%	0.02			99.469		

Density measurement was performed by pycnometer with representative samples twice. Because of the presence of frother in the sample and making mistakes during identifying the density by water, kerosene was used instead of water in one of the tests. After performing the tests by water, density was measured as 4.02 $gr.cm^{-3}$ and after using kerosene, density was 4.025 $gr.cm^{-3}$. In general, the density of 4.03 $gr.cm^{-3}$ was used for the next step of tests. Solid density was evaluated by equation 7.

$$\boldsymbol{\rho_s} = \frac{(P_s - P_o)}{(P_w - P_o) - (P_p - P_s)} * \boldsymbol{\rho_w} \quad (7)$$

Which P_o is the weight of the empty pycnometer, P_s is the weight of the pycnometer and solid, P_o is the weight of the pycnometer and water and solid, ρ_w is the pycnometer and water weight, ρ_w is the density of water and ρ_s is solid density.

Due to the presence of materials with small particle size and also for higher accuracy, the wet screening analysis method was used for determining the size distribution of the sample which its result is demonstrated in Figure 3. As a result, d_{50}, d_{80}, and d_{90} were determined as 66.6, 120.3, and 139.5 microns, respectively.

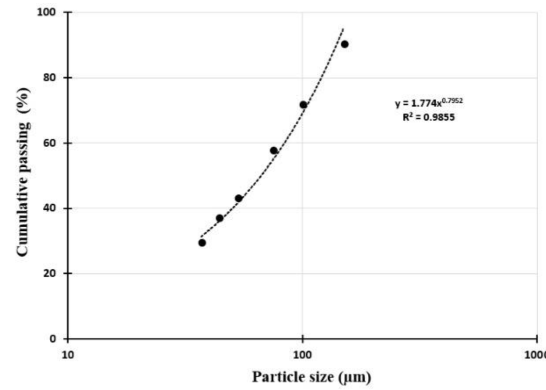

Figure 3. Particle size distribution of the representative sample of copper concentrate.

2.3. Filtration tests and operational apparatus

A vacuum filtration test was performed by using a Vacuum Top-Feed method with a Buchner funnel, one graduated cylinder, and a vacuum manufacturing system (Figure 4). The purpose of performing the tests with this method is to evaluate some responses of the filtration process such as filtration rate, specific cake resistant, cake compression, and resistance to filtration cloth. 350 g of sample was used to perform each test. At the end of each test, the moist cake was placed in the dryer for 24 hours at the temperature of 75°C. The filtrate volume was measured for 10 minutes, in this way which in the first 5 minutes, the intervals were considered 10 seconds, and then intervals were 50 seconds.

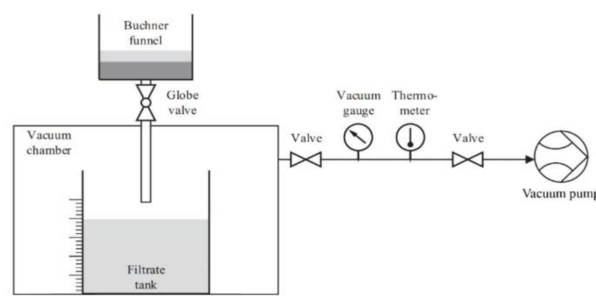

Figure 4. Operational apparatus of filtration process in Lab.

Filtration tests were carried out with 16 types of filter cloth in different solid percentages, pressure drop, and pHs. Also, the water which was used in tests was originated from thickener concentrate overflow. All the tests were carried out without adding chemicals agent (such as flocculant and coagulant).

2.4. Physical parameters

In this research work, influential physical parameters including filter cloth (16 types of filter cloth), solids present (45, 50, 55, 60 and 65%), pressure drop (0.4, 0.6, 0.7 and 0.8 bar) and pH (4.5, 6, 7.5 and 9) were considered (Table 3). The effect of each of the abovementioned parameters (as one factor at a time) on the cake formation rate, cake moisture content, resistance to filter cloth (R), and specific cake resistance (α) were precisely investigated. The correct selection of filtration media is important [17]. Synthetic filter media has porous fibrous structures composed of randomly assembled synthetic fibers or filaments according to the possible combination of web forming technologies such as dry-laid or spun melt processes [30]. Table 4 shows the different types of filter cloth used in this study. The microscopic image of each cloth taken by the binocular microscope (True Chrome matrix model) is also provided in Figure 5.

Table 3 .Parameters and levels examined as a factor in time.

Row	Parameter	Parameter type	Number of levels	Level
1	Filter cloth	Qualitative	16	----
2	Solids present	Quantitative	5	45, 50, 55, 60, 65 (%)
3	Pressure drop	Quantitative	4	0.4, 0.6, 0.7, 0.8 (bar)
4	PH	Quantitative	4	4.5, 6, 7.5, 9

Table 4. Characteristics of the cloth applied for filtration tests.

No.	Code	Fiber type	Thickness (mm)	Weight (gr/m^2)	Weave	Warp Yarn	Woof Yarn
1	A1	Polypropylene	0.8 ± 0.1	480 ± 10	Satin	Multifilament	Multifilament
2	A2	Polyester	1.6 ± 0.1	650 ± 10	Nonwoven	------	------
3	A3	Polyester	0.62 ± 0.1	425 ± 10	Satin	Multifilament	Spun Staple
4	A4	Polyester/ Cotton	1.1 ± 0.1	600 ± 10	Twill	Multifilament	Spun Staple
5	A5	Polypropylene	0.9 ± 0.1	625 ± 10	Plain	Multifilament	Multifilament
6	A6	Polyester	0.8 ± 0.1	580 ± 10	Twill	Spun Staple	Spun Staple
7	A7	Polyester	0.8 ± 0.1	510 ± 10	Twill	Spun Staple	Multifilament
8	A8	Polyester	0.8 ± 0.1	1050 ± 10	Twill	Multifilament	Multifilament
9	A9	Polyester	0.68 ± 0.1	590 ± 10	Plain	Multifilament	Multifilament
10	A10	Polyester	0.98 ± 0.1	580 ± 10	Plain	Multifilament	Multifilament
11	A11	Polyester	0.8 ± 0.1	540 ± 10	Plain	Multifilament	Multifilament
12	A12	Polyester	0.8 ± 0.1	570 ± 10	Plain	Multifilament	Multifilament
13	A13	Polyester	0.44 ± 0.1	330 ± 10	Satin	Monofilament	Multifilament
14	A14	Polypropylene	0.52 ± 0.1	630 ± 10	Twill	Multifilament	Spun Staple
15	A15	Polyester/ Cotton	1 ± 0.1	470 ± 10	Twill	Multifilament	Spun Staple
16	A16	Polyester	0.5 ± 0.1	370 ± 10	Plain	Multifilament	Multifilament

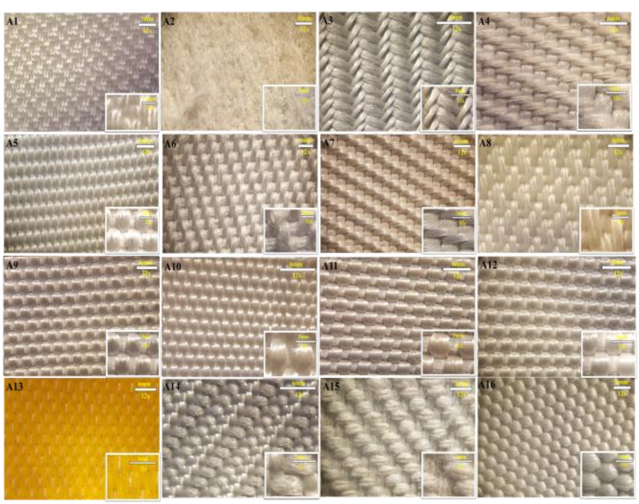

Figure 5. The microscopic images of the 16 different cloths applied.

3. Results and discussion

3.1. The effect of cloth type

Most filtration processes require the usage of a filtration media (filter cloth). The effect of cloth type on the efficiency of the filtration process was investigated using 16 different filter cloth types (Figure 5). Each cloth has certain characteristics (Thermal, chemical, mechanical, etc.) that can be considered as the best choice for specific use [17]. The type of filter cloth is effective on the four parameters of the specific cake resistance, resistance to filter cloth, moisture, and cake formation rate, which their results are presented in Figures 6a and b. According to Figure 6a, the highest specific cake resistance is related to clothes made of cotton or polyester. The cloth with the texture of satin has more muddy and turbid filtrate comparing the clearer filtrate which is obtained by the cloth with the texture of twill and plain.

The range of resistance to filter cloth was observed from 215.59 (1/m×10^{10}) for cloth A2 to 22.68 (1/m×10^{10}) for cloth A3. One of the most important parameters is the cake formation rate that depends on the weave of the filtration cloth itself. According to Figure 6b, the highest cake formation rate is related to the filter cloth A1 with a value of 0.08 (mm/s) and the lowest cake formation rate for the filter cloth A10 with a value of 0.04 (mm/s). Due to the slight variation in the specific cake resistance (from 3.66 kg/m× 10^{12} for cloth A7 to 5.15 kg/m×10^{12} for cloth A15), it can be concluded that the amount of specific cake resistance negligible affects the type of filter cloth and depends on the characteristics of the raw material. According to Figure 6b, the variation range of moisture content is also recorded from 13% for cloth A13 up to 14.5% for cloth A2. Overall and with the priority of parameters such as maximum cake formation rate and minimum resistance to filter cloth and moisture content (simultaneously), the two filter cloths A12 and A7 scored the best with plain and twill weaver, respectively, and were selected for optimization of other parameters.

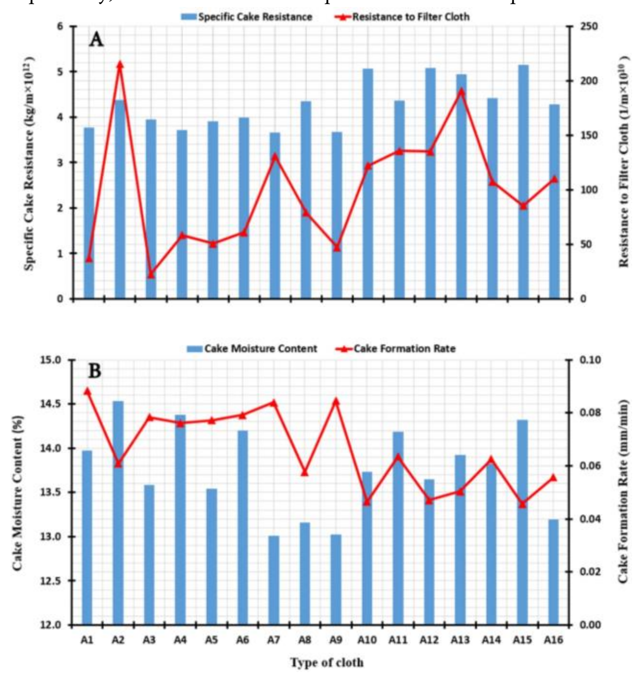

Figure 6. The effect of cloth type on the specific cake resistance and resistance to filter cloth (A) and cake moisture content and cake formation rate (B), (pressure drop: 0.6 bar, cake thickness: 13 mm, solid percent: 60% w/w, time: 10 min).

3.2. Effect of solid content

The time and rate of the filtration process are influenced by the pulp solid content. In general, the increase in solids content increases the specific cake resistance and the cake formation rate while reduces the capacity [31]. In tests, solid percent of pulp was considered in the range of 45-65%. Figure 7a shows the graph of t/v versus v for cloth A7 and Figure 7b shows the graph of t/v versus v for cloth A12, which is used to calculate α. The general equation for the cake formation rate in equation (6). According to equation (6), it is expected that in high solids content, due to the low amount of water (assuming solid dry weight is constant in all tests), the cake formation rate also increases. According to Figure 8a, with increasing the solid content from 45% to 65%, the cake formation rate has increased by about 1.5 times. Increasing the solid content, assuming a constant weight of the substance, means reducing the volume of the pulp water. This reduction in water volume increases the density of pulp particles in the Buchner funnel and by applying vacuum pressure, a thin film will be formed in the filter cloth bed immediately. Over time, the layer becomes thicker and fluid passage becomes more difficult. In other words, an increase in the solid content causes the phenomenon of surface and deep filtration (regardless of the type of filter cloth). This phenomenon, coupled with an increase in the resistance to filter cloth due to creating an obstacle in the fluid path, also increases the specific cake resistance. Figure 8b shows the effect of a solid content increase on the resistance to filter cloth. According to the figure, with increasing the solid content, resistance to filter cloth reached from 26.29 (1/m×10^{10}) to 101.39 (1/m×10^{10}) for cloth A7 and from 25.38 (1/m×10^{10}) to 245.67 (1/m×10^{10}) for cloth A12. In other words, with increasing the solids present from 45% to 65%, the resistance to filter cloths A7 and A12 increase 3.8 and 9.6 times, respectively. On the other hand, according to Figure 8c, with increasing the solids present, the specific cake resistance of clothes A7 and A12 were increased.

The highest specific cake resistance of cloth A7 was in solids 65% (4.46 kg/m×10^{12}) and the lowest in solids 50% (3.04 kg/m×10^{12}). The highest and lowest amount of specific cake resistance of cloth A12 was found in 60% and 50% solids with values of 6.73 (kg/m×10^{12}) and 2.99 (kg/m×10^{12}), respectively. According to the results of solid percent tests and considering the maximum cake formation rate and the minimum resistance to filter cloth, for filter cloth A7, solid content 55 and solid content 50 were selected as an optimal choice for filter cloth A12. On the other hand, working with a lower solid content in the thickener reduces the consumption of chemicals and also reduces the blocking of the thickener underflow.

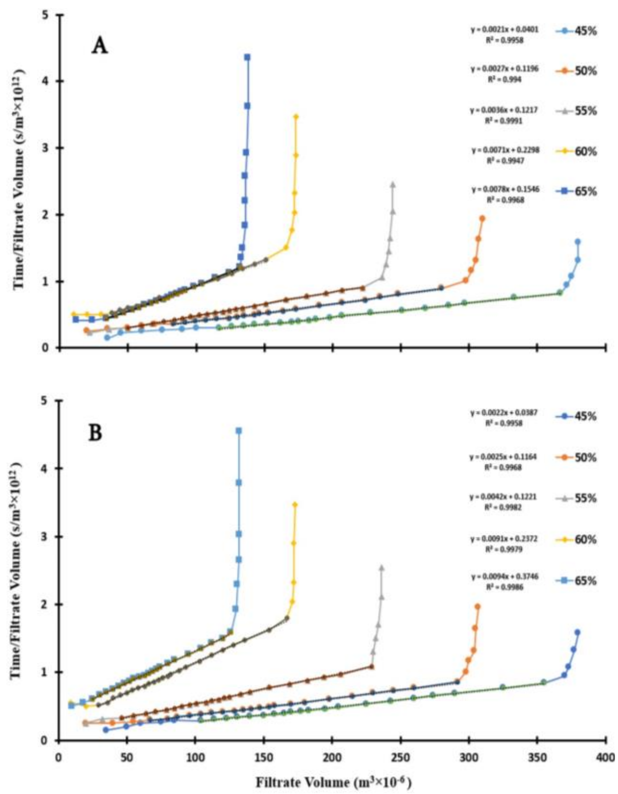

Figure 7. Plot of t/v vs v for solid percent in the range of 45-65% for cloths A7 (A) and A12 (B),
(pressure: 0.6 bar, cake thickness: 13 mm, time: 10 min).

3.3. The effect of pressure drop (ΔP)

The pressure drops across filters using porous media increase rapidly over time, particularly for feeds with high concentrations and/or very fine (sub-micron) particles [32]. The pressure drop tests were carried out at a range of 0.4-0.8 (bar). Before examining the results, it was expected that as the pressure difference increased, the cake formation rate would also increase. According to Figure 9, and with increasing pressure differences, the general trend of changes in the cake formation rate is also an incremental trend, but in a high-pressure difference, this trend is seen to be constant or even diminishing. The reason for this incident can be attributed to pulling fine particles into the warp and woof of cloth. This, in addition to reducing the operational capacity, increases the resistance to filter cloth (Figure 10). According to Figure 10a, b with increasing pressure, resistance to filter cloths A7 and A12 increase from 74.62 (1/m×10^{10}) to 84.42 (1/m×10^{10}) and from 45.17 (1/m×10^{10}) to 84.94 (1/m×10^{10}), respectively. On the other hand, the cake formed on the filter cloth bed is rapidly thickened and compressed. This compression is more tangible in high-pressure difference so that it can even change the diameter of the cake. According to Figure 10, in both tested clothes, with increasing pressure difference, the specific cake resistance has also increased. In the filter cloth A7, the specific cake resistance increased from 3.35 (kg/m×10^{12}) to 5.52 (kg/m×10^{12}) and in the filter cloth A12 this value changed from 2.2 (kg/m×10^{12}) to 4.43 (kg/m×10^{12}). The increase in pressure also has a significant effect on the moisture content of the filter cake. With increasing the pressure drop from 0.4 to 0.8 bar, the moisture content of cake for clothes A7 and A12 decreases by 2.2 and 2.6 percent, respectively (Figure 11).

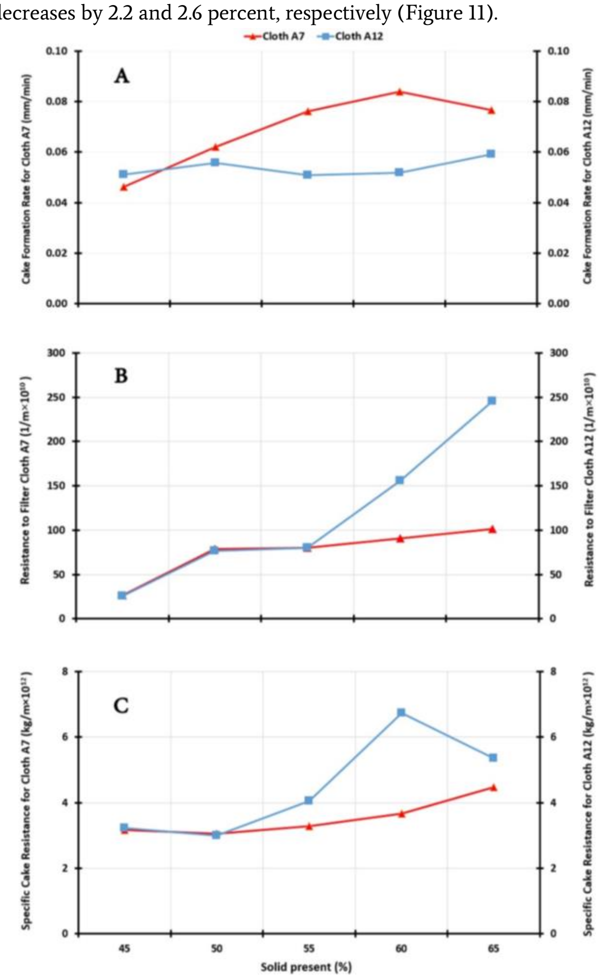

Figure 8. Effect of solid percent on cake formation rate (A), resistance to filter cloth (B) and specific cake resistance (C); (cloths A7 and A12, pressure drop: 0.6 bar, cake thickness: 13 mm, time: 10 min).

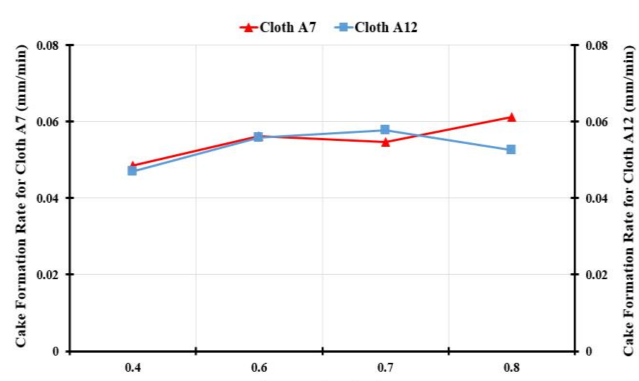

Figure 9. Effect of pressure drop on cake formation rate, (cloths: A7 and A12, solid percent: 55% (A7) and 50% (A12), cake thickness: 13 mm, time: 10 min).

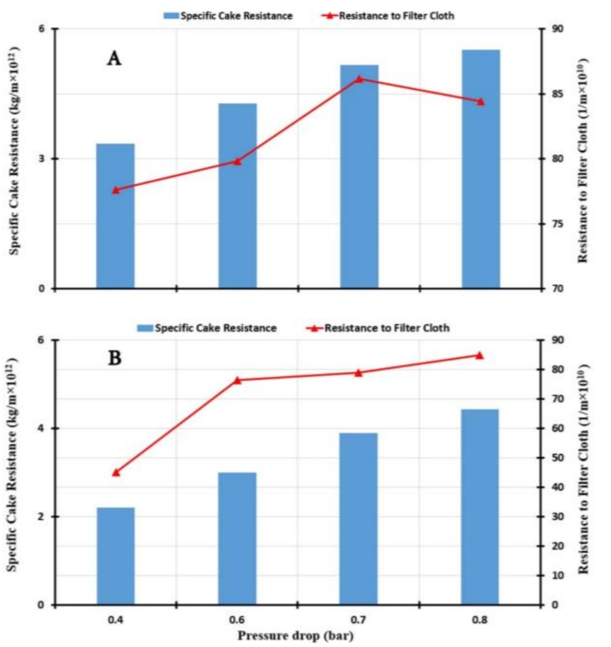

Figure 10. Effect of pressure drop on specific cake resistance and resistance to filter cloth, (cloths: A7 (A) and A12 (B), solid percent: 55% (A7) and 50% (A12), cake thickness: 13 mm, time: 10 min).

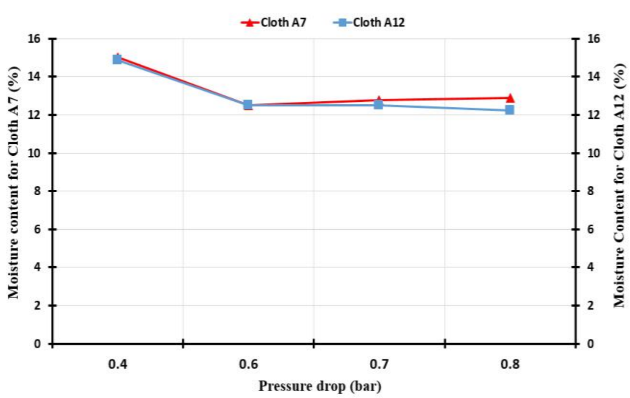

Figure 11. Effect of pressure drop on cake moisture content, (cloths: A7 and A12, solid percent: 55% (A7) and 50% (A12), cake thickness: 13 mm, time: 10 min).

The amount of water recovered during the time of the filtration process with cloths A7 and A12 are presented in Figure 12a, b. Noteworthy, the amount of water recovered was reduced at a pressure drop of 0.8 bar for both clothes. The reason for this phenomenon can be attributed to the early cracking of the cake and the completion of the dewatering process. Considering the high cake formation rate at a pressure drop of 0.7 bar for each filter cloth (0.054 mm/s for cloth A7 and 0.057 mm/s for cloth A12) and the minimum moisture content of the cake at this pressure (12.75% for cloth A7 and 12.48% for cloth A7), the optimal value of the pressure drop was selected as 0.7 bar for both clothes. On the other hand, working with higher pressures can cause serious damage to the weave, the warp, and woof of the filter cloth and can deform the cloth of the filters and reduce their useful operational life.

3.4. Compressibility

The fluid flow from the filter cloth is carried out with a pressure difference on both sides. With increasing pressure in the filtration cycle, some of the materials produce compressed cakes that reduce porosity and permeability and change the structure of the cake [33]. By plotting the specific cake resistance in terms of pressure drop at different pressures in the log-log scale and calculating the slope of the line, the amount of compressibility of filter cake is determined. The specific cake resistance versus the pressure drop for two filter cloths A7 and A12 are illustrated in Figures 13a, b. According to Figure 13, the compressibility factor of the filter cake for each cloth is equal to 0.056 (n=0.056). According to the results and Table 1, the filter cake obtained from the tests has low compression properties (n < 0.3). Due to the small difference in the amount of cake compression coefficient for each filter cloth tested, it can be concluded that the cloth type has a negligible effect on the compressibility of the cakes and the different compression coefficient of each cake depends on the inherent properties of the raw material.

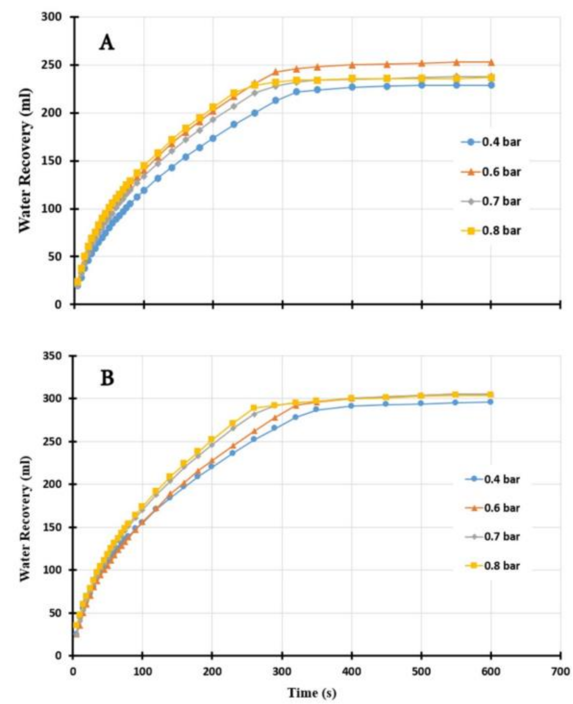

Figure 12. Effect of pressure drop on water recovery versus time, (cloths: A7 (A) and A12 (B), solid percent: 55% (A7) and 50% (A12), cake thickness: 13 mm, time: 10 min).

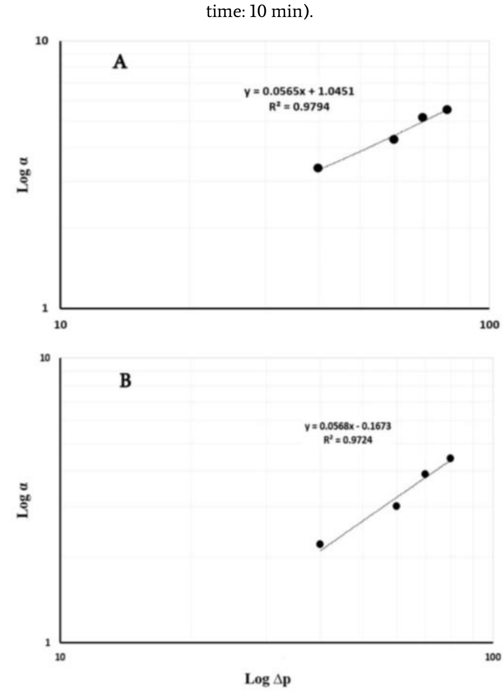

Figure 13. Gradient of logα vs. log Δp plot showing the compressibility of filter cake, (cloths: A7 (A) and A12 (B), solid percent: 55% (A7) and 50% (A12), cake thickness: 13 mm, time: 10 min).

3.5. The effect of pH

The filtration conditions depend on the particles' interaction and the accumulation of particles in the pulp and, on the other hand, the cumulative circumstance depends on the surface charge of the particles and the zero charge point of the minerals. By changing the pH, the particle surface charge can be changed and even set to zero [20]. For testing, the pH of the pulp was adjusted by H_2SO_4 and NaOH in the range of 4.5-9 which their results are shown in Figures 14a, b, c. According to Figure 14a, with increasing the pH of the pulp, the specific cake resistance for each cloth decreases, so that for the cloths A7 and A12, the specific cake resistance was decreased from 6.11 (kg/m×10^{12}) to 4.96 (kg/m×10^{12}) and from 4.61 (kg/m×10^{12}) to 3.91 (kg/m×10^{12}), respectively. This is due to the reduction of the electrostatic force of the particle surface due to the addition of Na^+ ions and the neutralization of the particle surface charge [20]. As shown in Figure 14b, the cake formation rate has also increased with increasing pH and minimizing the repulsive force of the particles in the pulp by the presence of Na^+ ions. The highest and lowest cake formation rates for both cloths A7 and A12 were found at pH=6 and 4.5, respectively. By neutralizing the surface charge, particles tend to settle, so it will be easier to pass fluid through the cake pores. The high cake formation rate at high pHs causes crack formation in the filter cake, which has a negative effect on the moisture content of the filter cake. Because, by the creation of the first cracks in the cake, the process of reducing the moisture content stops. As shown in Figure 14c, the moisture content changes for both filter clothes tested are initially reduced and then incremented. The lowest moisture content for cloth A7 has occurred at pH=6 (12.76%), and for cloth A12 at pH=7.5 (12.35%).

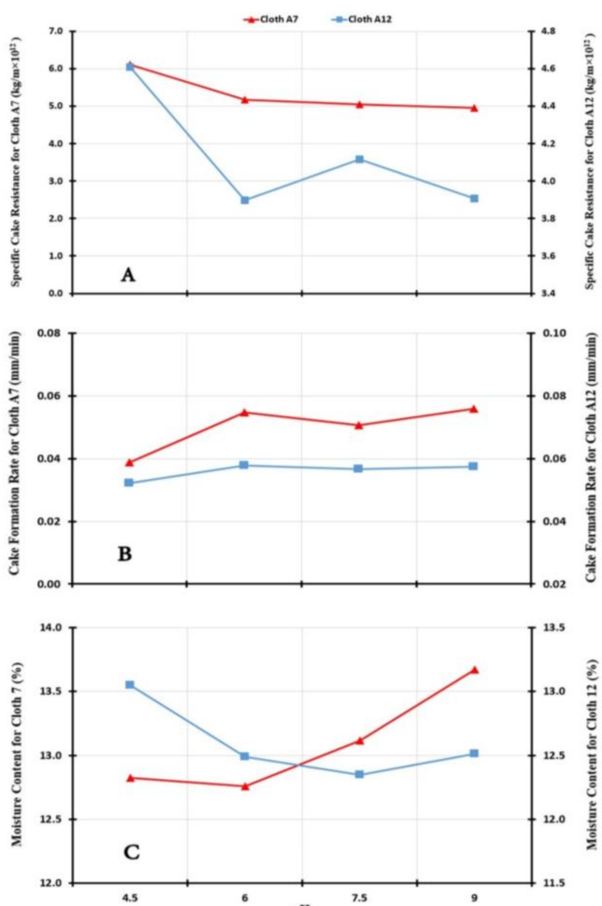

Figure 14. Effect of pH changes on specific cake resistance (A), cake formation rate (B), and cake moisture content (C); (cloths: A7 and A12, pressure drop: 0.6 bar, cake thickness: 13 mm, time: 10 min).

4. Conclusions

This study aimed to investigate the effect of physical parameters of the filtration process on the responses of filter moisture content, water recovery, cake formation rate, specific cake resistance, and resistance to various filter cloths, which was performed using the Vacuum Top-Feed method. By analyzing a variety of filter cloths and considering the minimum resistance to fluid flow and cake moisture content, as well as the maximum cake formation rate and water recovery, cloths A7 (fiber: polyester, weave: twill) and A12 (fiber: polyester, weave: plain) were selected for the filtration process. It was found that the compressibility factor for each cloth was the same and equal to 0.56 (n = 0.56). Therefore, the filter cake obtained from the tests has low compressibility (n= 0.3). Also, given the uniformity of the amount of compaction coefficient for each cloth, it is concluded that the difference in the compaction coefficient of each cake depends on the inherent properties of the raw material. After performing pH tests in the range of 4.5-9, it was found that by increasing the pH value due to the reduction of the electrostatic force of the particle surface due to the addition of Na^+ ions and the neutralization of the particle surface charge, specific cake resistance for each cloth has a downward trend. So that for the cloths A7 and A12, the specific cake resistance was decreased from 6.11 (kg/m×10^{12}) to 4.96 (kg/m× 10^{12}) and from 4.61 (kg/m× 10^{12}) to 3.91 (kg/m× 10^{12}), respectively. Reducing the electrostatic force of the particle surface has increased the cake formation rate. The highest and lowest amounts of cake formation rate for cloth A7 were observed at pH=9 and 4.5, respectively, with values of 0.056 (mm/s) and 0.039 (mm/s). For cloth A12, those values were 0.058 (mm/s) and 0.052 (mm/s).

Acknowledgment

The authors acknowledge with thanks the University of Tehran for financial support. The authors are also thankful to Mr. Ali Rezaei for his technical assistance.

REFERENCES

[1] Gálvez, E.D., Cruz, R., Robles, P.A., Cisternas. L.A. (2014). Optimization of dewatering systems for mineral processing. Minerals Engineering. 63: p.110-117.

[2] Klemes, J.J. (2012). Industrial water recycle/reuse. Current Opinion in Chemical Engineering. 1(3): p. 238-245.

[3] Usher, S.P., and Scales, P.J. (2005). Steady state thickener modelling from the compressive yield stress and hindered settling function. Chemical Engineering Journal. 111(2-3): p. 253-261.

[4] Bürger, R., Concha, F., Karlsen, K.H. (2001). Phenomenological model of filtration processes: 1. Cake formation and expression. Chemical Engineering Science. 56(15): p. 4537-4553.

[5] Chuvaree, R., Otani, Y., Mizukami, Y., Tanaka, T. (2007). Study on the fundamental characteristics of a filter press dryer with a featured model dryer. Advanced Powder Technology. 18(3): p. 273-285.

[6] Wills, B.A., and Napier-Munn, T.J. (2006). An introduction to the practical aspects of ore treatment and mineral recovery. Wills' Mineral Processing Technology. p. 267-352.

[7] Adrian, H., and Meintjes, C. (2005). Dry tailings disposal-increased production and potential water saving. Mwale, AH, Musonge, P., Fraser, DM., p. 915-926.

[8] Stickland, A.D., Skinner, S.J., Cavalida, R.G., Scales, P.J. (2018). Optimization of filter design and operation for wastewater treatment sludge. Separation and Purification Technology. 198: p. 31-37.

[9] Wang, Q., Lin, X., Chen, D.R. (2016). Effect of dust loading rate on

the loading characteristics of high-efficiency filter media. Powder Technology. 287: p.20-28.

[10] Luo, H., Ning, X.A., Liang, X., Feng, Y., Liu, J. (2013). Effects of sawdust-CPAM on textile dyeing sludge dewaterability and filter cake properties. Bioresource Technology. 139: p. 330-336.

[11] Huttunen, M., Nygren, L., Kinnarinen, T., Ekberg, B., Lindh, T., Karvonen, V., Ahola, J., Häkkinen, A. (2019). Real-time monitoring of the moisture content of filter cakes in vacuum filters by a novel soft sensor. Separation and Purification Technology, 223: p. 282-291.

[12] Sparks, T. (2012). Solid-liquid filtration: Understanding filter presses and belt filters. Filtration+ Separation. 49(4): p. 20-24.

[13] Tarleton, S., and Wakeman, R. (2006). Solid/liquid separation: equipment selection and process design. Elsevier.

[14] Gadhave, A.D., Mehdizadeh, S.N., Chase, G.G. (2019). Effect of pore size and wettability of multilayered coalescing filters on water-in-ULSD coalescence. Separation and Purification Technology. 221: p. 236-248.

[15] Chen, F., Ji, Z., Qi, Q. (2018). Effect of pore size and layers on filtration performance of coalescing filters with different wettabilities. Separation and Purification Technology. 201: p. 71-78.

[16] Patra, A.S., Makhija, D., Mukherjee, A.K., Tiwari, R., Sahoo, C.R., Mohanty, B.D. (2016). Improved dewatering of iron ore fines by the use of surfactants. Powder Technology. 287: p. 43-50.

[17] Svarovsky, L. (2000). Solid-liquid separation. Elsevier.

[18] Dash, M., Dwari, R.K., Biswal, S.K., Reddy, P.S.R., Chattopadhyay, P., Mishra, B.K. (2011). Studies on the effect of flocculant adsorption on the dewatering of iron ore tailings. Chemical Engineering Journal. 173(3): p. 318-325.

[19] Niu, M., Zhang, W., Wang, D., Chen, Y., Chen, R. (2013). Correlation of physicochemical properties and sludge dewaterability under chemical conditioning using inorganic coagulants. Bioresource technology. 144: p. 337-343.

[20] Besra, L., Sengupta, D.K., Roy, S.K. (2000). Particle characteristics and their influence on dewatering of kaolin, calcite, and quartz suspensions. International Journal of Mineral Processing. 59(2): p. 89-112.

[21] Townsend, I. (2003). Automatic pressure filtration in mining and metallurgy. Minerals engineering. 162(2): p. 165-173.

[22] Dong, K.J., Zou, R.P., Yang, R.Y., Yu, A.B., Roach, G. (2009). DEM simulation of cake formation in sedimentation and filtration. Minerals Engineering. 22(11): p. 921-930.

[23] Ni, L.A., Yu, A.B., Lu, G.Q., Howes, T. (2006). Simulation of the cake formation and growth in cake filtration. Minerals engineering. 19(10): p. 1084-1097.

[24] Day, A. (2002). Mining Chemicals Handbook. Revised Edition, CYTEC, Horton Printing Company, Meriden, CT.

[25] Mamghaderi, H., Gharabaghi, M., Noaparast, M. (2018). Optimization of the role of physical parameters in the filtration processing with a focus on the fluid flow from the pore. Minerals Engineering. 122: p. 220-226.

[26] Castro, S., and Laskowski, J.S. (2015). Depressing effect of flocculants on molybdenite flotation. Minerals Engineering. 74: p. 13-19.

[27] Fan, Y., Dong, X., Li, H. (2015). Dewatering effect of fine coal slurry and filter cake structure based on particle characteristics. Vacuum. 114: p. 54-57.

[28] Wang, L.F., He, D.Q., Tong, Z.H., Li, W.W., Yu, H.Q. (2014). Characterization of dewatering process of activated sludge assisted by cationic surfactants. Biochemical Engineering Journal. 91: p. 174-178.

[29] Lihong, D.U., Xu, C.H.E.N., Wenping, L.I., Qixin, Z.H.U. (2011). A study on enhancement of filtration process with filter aids diatomaceous earth and wood pulp cellulose. Chinese Journal of Chemical Engineering. 19(5): p. 792-798.

[30] Jabri, W., Vroman, P., Perwuelz, A. (2015). Study of the influence of synthetic filter media compressive behavior on its dust holding capacity. Separation and Purification Technology. 156: p. 92-102.

[31] Stickland, A.D., Irvin, E.H., Skinner, S.J., Scales, P.J., Hawkey, A., Kaswalder, F. (2016). Filter Press Performance for Fast-Filtering Compressible Suspensions. Chemical Engineering & Technology. 39(3): p. 409-416.

[32] Lee, K.M., Jo, Y.M., Lee, J.H., Raper, J.A. (2008). Assessment of surface and depth filters by filter quality. Powder Technology. 182(2): p. 187-194.

[33] Zhang, Y., Gong, G., Wu, G., Wang, Y. (2014). Physical properties and filter cake structure of fine clean coal from flotation. International Journal of Mining Science and Technology. 24(2): p. 281-284.