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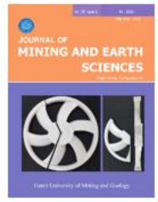

Research on the factors affecting the product filtration efficiency in mineral processing plants

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ABSTRACT

Filtration is a long-standing process but the technology has changed slowly, mainly based on the increase in filtration pressure and changes in the characteristics of filter media. The problem is high moisture remains product, requiring more expensive technologies (thermal drying) and long processing times. In the mineral processing industry, not only concentrates but also tailings need to be dewatered. The test samples were Cam Duong apatite concentrated and tailing ore, Ta Phoi copper concentrated and Sin Quyen tailing ore, Cua Ong fine coal, and Dak Nong red mud. All samples' properties have been defined by sieving analyses, SEM method, and gravitational density measurement. Then, samples were experimented with using the Nutsche high-pressure filtration in the variable operational parameters. While the sludge concentration affected the specific resistance, the filter cake height and filtration pressure did not affect as much. At the suitable condition (homogeneous filter cake, 1 bar pressure difference, and 50 grams solid weight), the specific resistance and residual moisture content of the filter cake are around $2.5x10^{-12}÷1.5x10^{-13}$ m^{-2}, 15÷25%, respectively. Through the test results, some recommendations are mentioned in order to perfect the process and scale up for industrial production.

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1. Introduction

Filtration is a long-standing process with the same principle. Applications of filtration are divided into two types. The first is to remove solids or contaminated components from the useful liquid stream. This application is often encountered in the process of water treatment, air filtration, fuel filtration, and environmental pollution factors treatment at processing facilities. The second application of filtration is to recover useful solids, removing excess components from the suspension mixture (Rushton et al., 1996; Svarovsky, 2001). This application is common in mineral processing plants, chemical, pharmaceutical, metallurgical, and recycling fields (Sparks & Chase, 2015; Townsend, 2003).

The filtration process plays an indispensable role in many areas of life and industry. This role is becoming more and more important as the quality of life needs to be improved, while the environment (due to industrialization) becomes more polluted. The necessity of filtration in industrial facilities, especially mineral processing, metallurgy, and recycling plants, is increasingly emphasized (especially the role of dewatering). A good filtration process leads to the following advantages: (1) Easy transportation and storage of products; (2) Production costs are reduced because most liquids and chemicals are recovered and reused; (3) The environment is improved; (4) The value of processed products is increased, satisfying customers' moisture needs and other technical requirements (Peuker, 2018; Sparks & Chase, 2015).

However, the filtration process is facing many difficulties due to one of the factors being the product particle size. The filter material has increasingly finer particles, even down to a few micrometers, with a wide range of particle size distribution. Filtration technology has changed slowly, mainly based on the increase in filtration pressure and changes in the characteristics of filter media. The result is that product moisture remains high, requiring more expensive technologies (thermal drying stages) and long processing times. In the mineral processing industry, not only concentrates but also tailings need to be dewatered. The solution to building reservoirs is still being debated and it poses a lot of potential risks to the environment and ecosystem (Peuker, 2018). There are not many studies on filtration in Vietnam, especially on filtering fine and ultra-fine products of mineral processing. Filtration resistance and moisture content of the material are basic criteria in research. However, there are still no studies to determine these parameters. In addition, studies on the influence of technological parameters on the above indicators have not yet been mentioned. The scope of the article presents preliminary research to clarify the above problems as well as contribute important advances in the field of material dewatering in general and mineral processing products in particular in Vietnam.

2. Literature Review

The filtration process is divided into two main types: deep filtration and cake filtration. The cake filtration process is commonly used in the mineral processing industry for dewatering (Anlauf, 2019).

Pham and Peuker (2021) have researched the application of Nutsche high-pressure steam filtration to dewater fine-grained materials. Accordingly, limestone material with a size of less than 12 μm is dewatered with a moisture content of 17%. This result is 20% lower than conventional filtration. Another study by Pham (2022) has shown the prospect of applying high-pressure Nutsche filtration to dewater fine-grained materials as well as determining the specific resistance of the filter cake. The materials studied are clean limestone with median particle sizes of 2.46 and 20.68 μm, respectively. Coarse-grained materials are relatively easy to filter, whereas fine-grained materials are severely affected by sedimentation due to long filtration times. Research results are limited to clean materials on the experimental scale (Pham & Peuker, 2020). Barua et al. (2010) in their research on crack formation in filter cakes used Nutsche to determine the water permeability and gas permeability of filtering materials. The experimental equipment is a clear plastic tube connected to a compressed air flow meter, air pressure regulator, and high-pressure nitrogen gas source. At the bottom of the clear plastic tube is the filter water recovery part. Notes related to material granularity, filter cloth pore size, and filter cake pore size when determining filter cake resistance and filter cloth resistance are also presented (Barua et al., 2010).

Löwer et al. (2020) used a Nutsche-type device with a much smaller size (Nutsche tube diameter 5 mm) to study the influence of solid phase volume concentration on the structure formation in the filter cake. After being formed, the filter cake is put into the Tomography device to study the structure of the filter cake, the layering and sedimentation of the filter cake during the filter cake formation process, and mechanical displacement. Pham (2022) did research and calculated filtration resistance on clean coal products and limestone materials using Nutsche-type experimental equipment at TU Bergakademie Freiberg. Accordingly, large-sized materials are much easier to filter than small-sized materials. This is shown through output parameters such as residual moisture content and saturation.

The filtration process is widely used in mineral processing to recover water from processed products, provide products that meet consumer requirements, and ensure environmental criteria. The filtration equipment used is mainly based on vacuum filtration and high-pressure filtration processes. For the vacuum filtration process, rotary drums, discs, trays, and conveyor devices are most commonly used. For high-pressure filtration, common devices are plate press filters, chamber filters, and booster filters. In fine and ultra-fine particle dewatering, centrifugal filtration devices (vertical filtration centrifuges unload by vibrating mechanism, vertical type unloads inertial load, vertical type unloads with torsion blades, horizontal type horizontal unloading by vibrating mechanism) and centrifugal settling are used (Pham et al., 2022; Wakeman & Tarleton, 1999; Wills & Napier-Munn, 2005).

3. Research methodology, samples and test procedure

3.1. Research methodology

Nutsche high-pressure filtration equipment is commonly used on an experimental scale to determine filtration resistance and evaluate the efficiency of filtering coarse-grained materials. The VDI 2762 - 2 guidance standard (VDI, 2010) has specific instructions on how to determine individual filter resistance. Accordingly, the relationship between the ratio of filtration time to filtered water volume and filtration time (t/V and V) is the basis for calculation. Figure 1 introduces how to determine the above parameters.

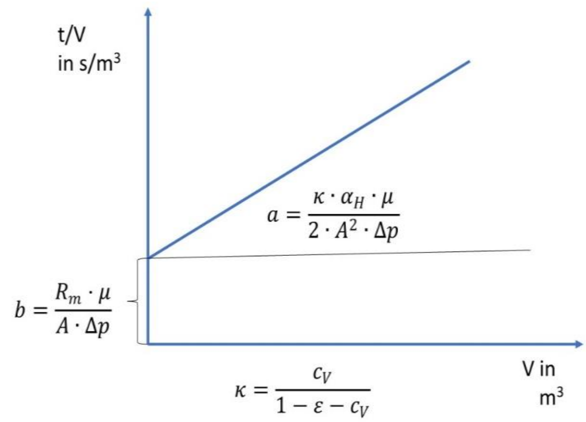

Figure 1. Diagram for the relationship between t/V vs V (VDI 2762, 2010).

According to Figure 1, α_H is the specific resistance cake (m^{-2}), R_m is the resistance of filter cloth (m^2/s), A is the area of Nutsche (m^2), μ is the dynamic viscosity (0.0010016 Pa.s at the standard condition), Δp is the pressure difference (Pa), κ is the concentration coefficiency (c_v) and porosity (ε). The specific resistance filter cake is calculated according to the gradient coefficient of the linear relationship between t/V and V. These values are calculated as Equations (1).

$$\alpha_H = \frac{a \cdot 2 \cdot A^2 \cdot \Delta p}{\kappa \cdot \mu} \tag{1}$$

The theory of the process is presented in research documents (Anlauf, 1994; Hess, 1991; Gasper, 1990; Zogg, 1987; Müller, 1983) and is summarized in the main ideas: the specific resistance filter cake is an average value. In fact, in different parts of the filter cake, the porosity and permeability are different. The liquid flow velocity referred to is the relative velocity between the liquid and the solid parts. The solid displacement due to compression effects in some cases of compressible filter cakes can be neglected (Wakeman, 1976; Xue et al., 2020).

3.2. Samples

In order to comprehensively evaluate the filtration effectiveness and characteristics of mineral processing products, the research samples selected are Cua Ong fine coal, Ta Phoi copper concentrate, Sin Quyen copper tailing, concentrate and tailing Cam Duong apatite, Dak Nong aluminum red mud. Research samples are taken from product storage and tailling ponds (depending on the types of samples). Samples are taken according to standards, ensuring volume and representativeness. After drying and lightly ground, the sample was mixed well and split according to the diagram in Figure 2.

3.2.1. Particle size distribution

The method defining the particle size distribution used is the sieving analysis. The sieves used are 2; 1; 0.5; 0.2; 0.074; 0.045; 0.02 mm. The research results are presented in Figure 3.

It can be seen that most of the samples had fine and ultra-fine particles. The amount of particles passing 0.02 mm of copper concentrate, apatite concentrate, coal, and red mud are all greater than 50 %. Copper tailings and apatite tailings are dominated by coarser sizes. The amount of these two types of samples is relatively uniform at all levels. Samples with the predominance of ultrafine particles will pose a challenge for filtration, due to the small capillary, requiring high entry pressure.

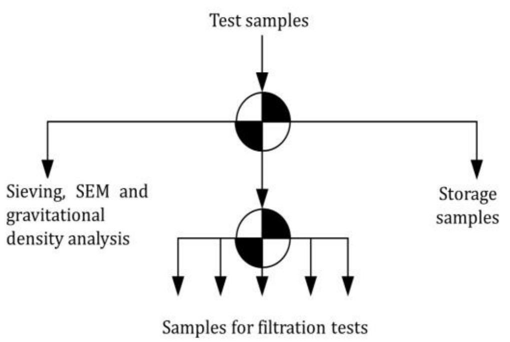

Figure 2. Diagram for samples splitting.

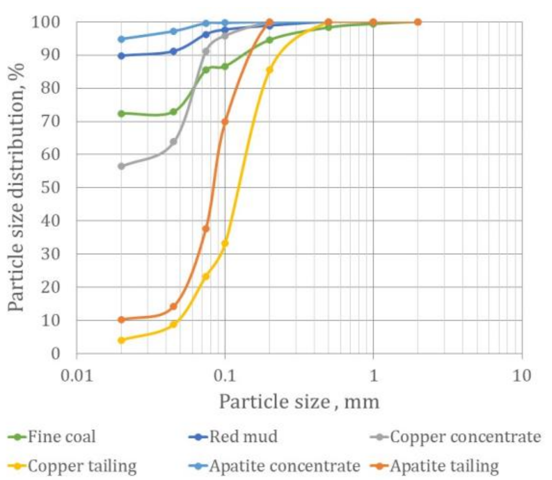

Figure 3. The particle size distribution of samples.

3.2.2. SEM images

Particle size, particle shape, and surface properties of mineral particles play an important role in filtration experiments, related to filter cake formation, stratification, and the homogeneity of the filter cake. Therefore, the samples were sent for image analysis using a scanning electron microscope (SEM). The results are given in Figure 4.

It can be seen that the particles of the apatite concentrate, the red mud, and the fine coal samples were fine and ultra-fine. The amount of small particles predominate (with the representative particle size range of 10÷200 mm). In addition, they have a flat shape and contain a lot of clay. This is predicted to make filtration difficult. The particle shape of the samples of copper and apatite (both concentrates and tailings) are pretty uniform with cubic grains. Those characteristics are favorable during the filtration, especially the cake formation stage. The particles of tailings products are coarser (with the representative particle size range of 100÷500 mm) than those of concentrates. Therefore, the concentrate ore is predicted getting the high filtration efficiency and low moisture content.

3.2.3. Specific gravity

Specific gravity is also an important parameter for the filtration process. It determines the ability of particles to settle and stratify during the filter cake formation stage. During filtration, the homogeneity of the filter cake depends on its density. In addition, this parameter is also the basis for calculating sludge concentration by volume when investigating its influence on filtration efficiency and filter cake resistance. The pycnometer method is used to determine the density of fine sludge (< 3 mm), according to the Equation (2):

$$\delta = \frac{m_2 - m_1}{(m_4 - m_3) + (m_2 - m_1)} \qquad (2)$$

Where m_1 is the mass of the beaker, m_2 is the mass of the beaker + sample, m_3 is the mass of the beaker + sample + water; m_4 is the mass of the beaker and water (full). The result is shown in Table 1.

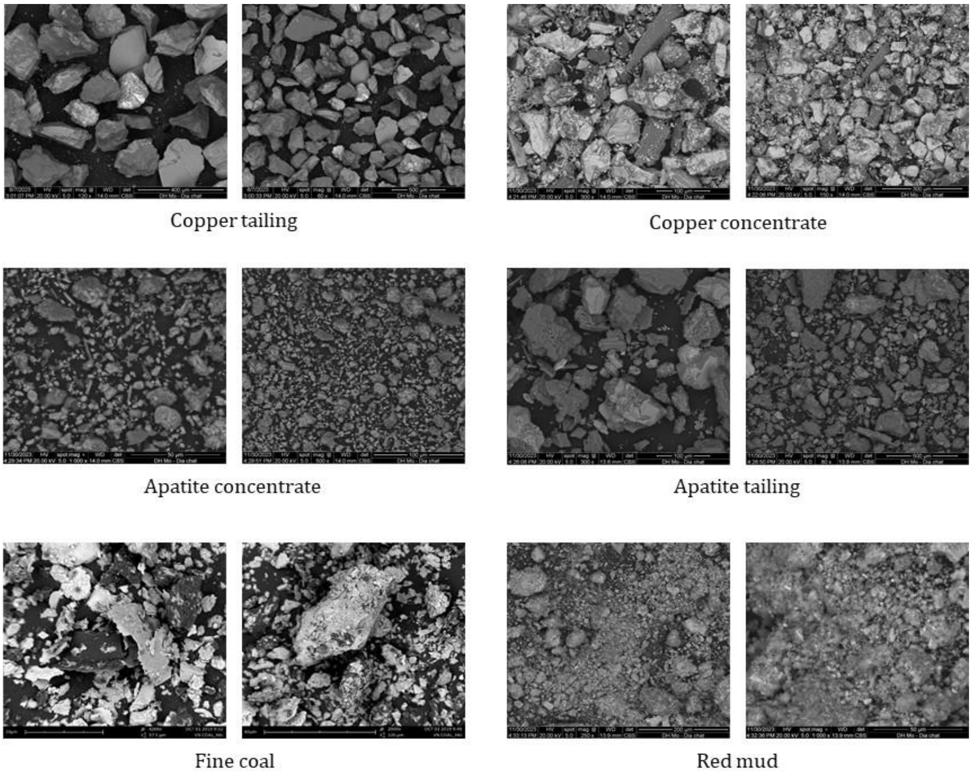

Figure 4. SEM images for samples.

Table 1. Specific gravity of samples.

No	Samples	Average specific gravity	Standard deviation
1	Apatite concentrate	2.22	0.11
2	Apatite tailing	2.78	0.08
3	Copper concentrate	3.19	0.06
4	Copper tailing	3.04	0.04
5	Red mud	2.79	0.13
6	Fine coal	1.50	0.05

The specific gravity is pretty different compared to the actual data of the mineral processing plants. The result may caused by the change of porosity inside the particles. This issue may be a new investigation point that needs to be researched more and mentioned in another article.

3.3. Test procedure

The experimental equipment is a Nutsche tubular high-pressure filter, the device's structure is shown in Figure 5. The filter cloth used in the experiments is the type used for disc filtration, woven from polypropylene fibers with a pore size of 1 µm (Figure 6).

The initial suspension was re-mixed by stirring the solid with distilled water at room temperature (~25^{0}C) for 5 minutes to achieve the best dispersion. The amount of water to make the suspension depends on the amount of solids as well as the solid volume fraction of the sludge in each experiment. The sludge is then fed into the Nutsche and the lid is closed. Compressed air is used into the Nutsche to push the water in the filter cake out. The experiment was conducted until no water flowed out of the Nutsche tube. During the filter cake formation process, the water mass is recorded over time. This is the basic data for drawing the curve (t/V vs V) to determine the specific resistance filter cake according to Figure 1. The filter cake's height and mass (in wet) are determined immediately before being put into the drying oven. The drying temperature is 50^{0}C (±5^{0}C). Determining the output parameters of the filter cake helps to specifically calculate the residual moisture content according to Equation 3 (where m is the mass of the filter cake in different states):

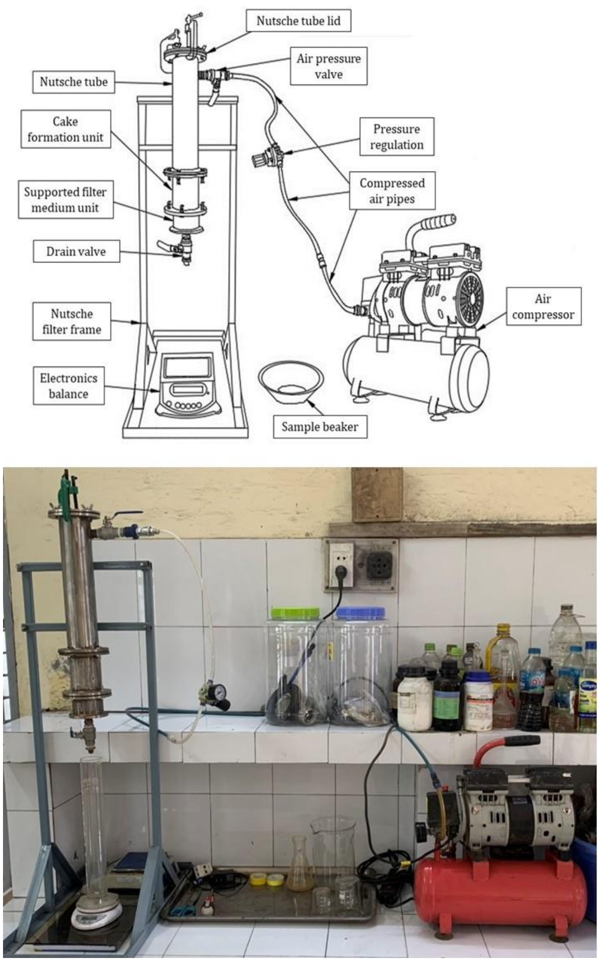

Figure 5. Experimental equipment.

$$M = \frac{m_{wet} - m_{dry}}{m_{wet}} \cdot 100\% \qquad (3)$$

4. Results and Discussions

4.1. The effect of solid volume fraction of suspension

Tests were conducted with different solid volume concentrations of suspension (the solid weight is fixed at 50 grams). Test procedures with the specific parameters of different samples are presented in Table 2. Experimental results are shown in Figure 7 and Figure 8.

In general, when increasing sludge concentration from 5÷40%, the moisture content and specific resistance of the filter cake tend to decrease; The filter resistance value is in the range of 10^{13}÷3.10^{13} m^{-2}.

Figure 6. Filter cloth and supporting unit used in filtration test.

The specific resistance has uncontrolled rules at very dilute sludge concentrations (5%). This value is exceptionally high (in the case of apatite concentrates), while in most other cases the change is not significant. This phenomenon is explained by the fact that at too low concentration, the particles in the filter cake are strongly stratified, leading to inhomogeneity in the filter cake. The fine particles lie on the top layer of the filter cake and hinder the filtration process. In the case of red mud and coal, the material has a large amount of below 0.02 mm particles, which block the filter cloth pores. There are many flat particles and clay particles that hinder the filtration process and cause the process to become uncontrolled. The specific resistance filter cake value therefore determined is not representative of the entire filter cake.

The moisture content of the filter cakes tends to remain unchanged or change very little from a sludge concentration of 20%. This is explained by the uniformity of the filter cake that was achieved when filtering the sludge at this concentration.

The residual moisture content of the products is generally acceptable, fluctuating between 15% when the filter cake is homogeneous and up to 35% when the filter cake is heterogeneous (in the case of red mud). It should be noted that this

Table 2. The specific input parameters of different samples

Slurry concentration, %			5	10	20	30	40
Apatite concentrate	V_{Solid}	cm^3	22.52				
	V_{Liquid}	ml	427.88	202.68	90.08	52.55	33.78
Apatite tailing	V_{Solid}	cm^3	17.99				
	V_{Liquid}	ml	341.81	161.91	71.96	41.98	26.99
Copper concentrate	V_{Solid}	cm^3	15.67				
	V_{Liquid}	ml	297.73	141.03	62.68	36.56	23.51
Copper tailing	V_{Solid}	cm^3	16.45				
	V_{Liquid}	ml	312.55	148.05	65.80	38.38	24.68
Red mud	V_{Solid}	cm^3	17.92				
	V_{Liquid}	ml	340.48	161.28	71.68	41.81	26.88
Fine coal	V_{Solid}	cm^3	33.33				
	V_{Liquid}	ml	633.27	299.97	133.32	77.77	50.00

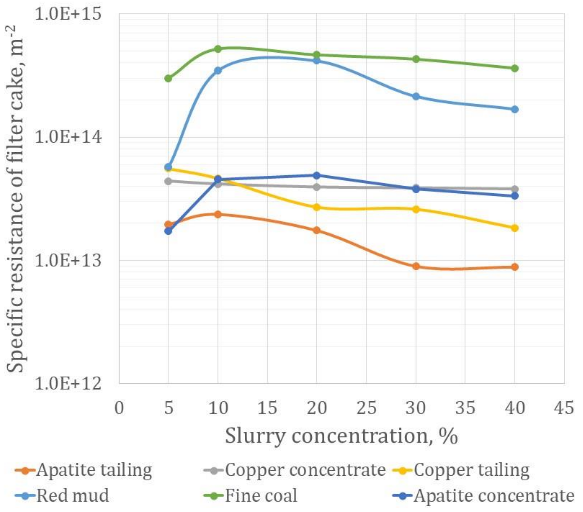

Figure 7. The relationship between solid volume concentration and specific resistance of filter cake.

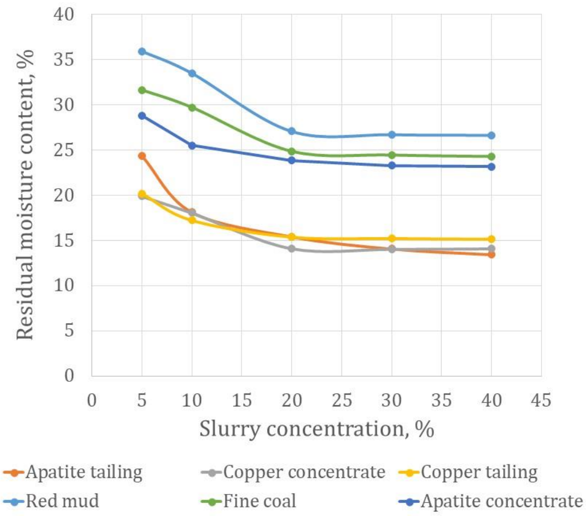

Figure 8. The relationship between solid volume concentration and moisture content of filter cake.

moisture determination only stops at the second phase of the filtration process. When the filtration process of products goes through all three phases, the moisture content may decrease slightly further due to the drying effect. In these surveys, the author chose the optimal sludge concentration of 30% to stabilize the process and increase filtration productivity.

4.2. The effect of filter cake height

Samples were conducted with different solid fraction masses of 10; 30; 50; and 70 grams (corresponding to the variable in the filter cake height). Filter pressure of 1 bar is selected; solid volume concentration is 30%. Detailed experimental results are shown in Figure 9 and Figure 10.

It can be seen that when increasing the filter cake height from about 5 mm to about 40 mm, there was no change in the overall filter cake resistance. This is consistent with previous theories asserting that the specific resistance itself is not affected by the filter cake height. Moisture values are subject to change with the degree of decreasing trend not clearly defined. Material moisture content with easy filtering such as copper concentrate, copper tailing, and apatite tailing, fluctuates around 15% while the remaining materials fluctuate around 25%.

In general, the filter cake height factor does not greatly affect the specific resistance of the filter

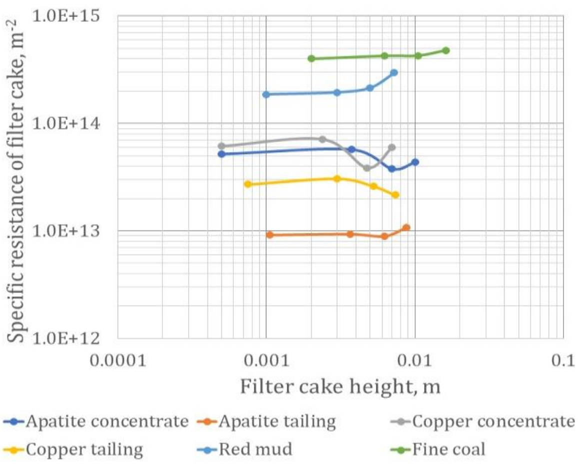

Figure 9. The relationship between the filter cake height and the specific resistance of filter cake.

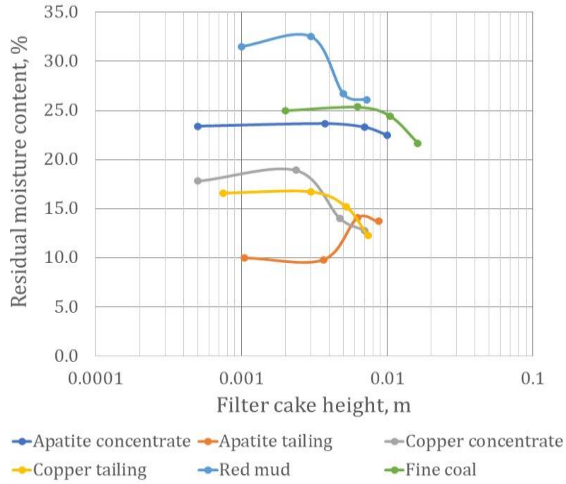

Figure 10. The relationship between filter cake height and moisture content of filter cake.

cake and the moisture content of the material. However, the filter cake resistance is the function of specific resistance and the filter cake height. Therefore, when increasing the height of the filter cake, greater driving forces are required to ensure filtration performance. The height of the filter cake is an important parameter in determining the efficiency of the filtration process. Determining the optimal height filter should be determined taking into account the filtration pressure difference and filtration time.

4.3. The effect of pressure difference

The sample was carried out with varying pressures of 0.5; 1; 2; 3 bars. The parameters kept the same are the sample weight of 50 grams and the solid volume concentration of 30%. The experimental results are shown in Figure 11 and Figure 12.

In general, when increasing filtration pressure, the specific resistance tends to increase slightly in all surveyed samples. This increasing trend is most clearly shown in the copper tailing sample (5.0.1013 m^2). This proves that this tailings sample had a compression phenomenon when filtered at high pressure. However, this increase is not large. Selected samples can still essentially filter at a pressure of 3 bar. Material moisture (when filtered at pressures of 2 and 3 bar) does not change as much (fluctuating at about 10÷15% for materials considered easy to filter and 20÷25% for materials considered harder to filter).

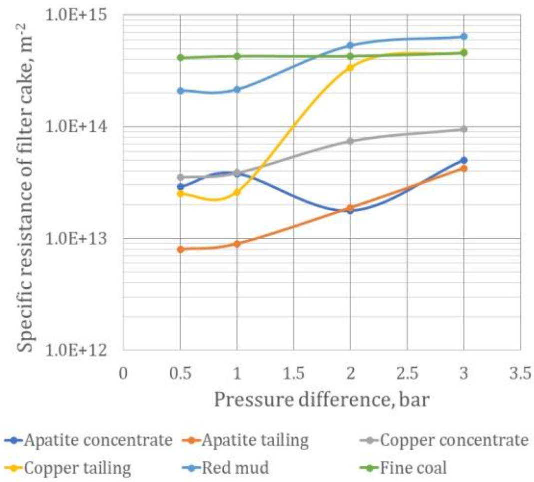

Figure 11. The relationship between pressure difference and specific resistance of filter cake.

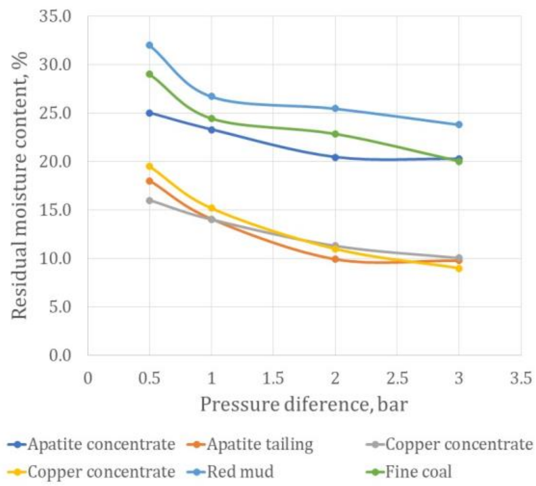

Figure 12. The relationship between pressure difference and moisture content of filter cake.

Filtration pressure does not greatly affect the efficiency of the filtration process, but the following notes are needed: (1) the pressure must be high enough to overcome the bonds of water with ore particles (capillary force is predominant); (2) be careful when choosing too high a filtration pressure (some materials may be compressed, increasing specific resistance and negatively affecting the filtration process). Choosing the optimal filtration pressure depends on the type of material being filtered and the required filtration capacity.

5. Conclusions and Recommendations

5.1. Conclusions

The Nutsche high-pressure filter is a suitable experimental device for determining the specific resistance of filter cakes of fine and ultra-fine sludges.

Samples have been studied for the particle size distribution, specific gravity, and SEM images of samples. The majority of materials are fine and ultra-fine with particle size passing 0.02 mm (accounting for 50÷90%). Several samples have the presence of flat particles, mica flakes, and clay. This characteristic makes the filtering process difficult.

The value of the specific resistance and moisture content of mineral processing products was determined. In general, samples have low specific resistance, except fine coal and red mud.

As the sludge concentration increases, the specific resistance filter cake generally tends to decrease. At sludge concentrations of 20%, the decrease trend is not obvious because the filter cake has been formed homogeneously. The optimal material moisture in this homogeneous region ranges from 15÷25%.

Filter cake height is an important parameter in determining the productivity of filtration equipment. Increasing the filter cake height does not affect the specific resistance of the filter cake. However, the resistance of the filter cake is the function of the specific resistance. This requires investigating the optimal filter cake height to both ensure productivity and ensure dewatering efficiency. Calculation and selection of filter cake height should take into account the appropriate filtration pressure difference and desired capacity.

Filtration pressure does not change the specific resistance of the filter cake, but the selection of this parameter can affect the filtration productivity (specifically, the filter cake formation time). The influence of filtration pressure on material moisture is positive. Specifically, when increasing the filtration pressure from 1÷3 bar, the material moisture content decreases from about 5% moisture. However, it should be noted that the filtration pressure should not be chosen too high because material compression may occur (indicated by a rapid increase in specific resistance). This in turn low filtration efficiency (including dewatering efficiency and washing efficiency). The filtration pressure must also be large enough to overcome the forces between water and mineral particles in the filter cake (capillary forces).

5.2. Recommendation

The research should be implemented to conduct more diverse types of products of the processing industry such as products of the chemical industry, pharmaceuticals, metallurgy, recycling, and wastewater treatment.

Perfecting the high-pressure filtration system in a more convenient way for conducting experiments.

The hypotheses and explanations of the phenomena should be verified using modern methods.

Research and develop this laboratory equipment system into industrial-scale filtration equipment to serve production. Apply information technology and utility software to collect, store and process experimental data.

Experiments on the effects of filter aids should be studied to elucidate their influence on the specific resistance filter cake and filtration efficiency.

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Contributions of authors

Hai Thanh Pham - methodology, setting up lab-scale equipment, conducting experiments, analyzing results, writing, review & editing; Duoc Van Tran, Thuat Tien Phung - building the experimental equipment; Nhung Thi Pham, Chinh Thi Vu and Anh Phuong Ta - conducting the experiments.

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