Optimization of role of physical parameters in the filtration processing with focus on the fluid flow from pore

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ARTICLE INFO

Keywords:
Dewatering
Filtration
Specific cake resistance
Tailing management
Water recovery

ABSTRACT

Tailings management and water recovery from mineral processing tailings which contain high amount of fine and clay materials are very important and this matter presents considerable challenge. Any improvement in disposal and tailings filtration methods requires understanding of fluid flow in the cake pores and filter media, which are affected by various parameters. In this study, the effects of physical parameters on the specific cake resistance (α), cake formation rate, moisture content, and filter cloth resistance in the filtration of iron processing plant tailings have been examined by vacuum Top-Feed Leaf method. The main parameters which investigated in this work were cloth type, solid content, pressure drop, and thickness of cake. Experiments results showed that the polypropylene type B (PP-B) cloth was suitable for filtration process, because it had the least resistance to fluid flow. Increasing solid amount from 30 percent to 60 percent, increased specific cake resistance from $96 \times 10^{10}$ to $230 \times 10^{10}$ kg/m and cake formation rate was also increased from 0.18 to 0.46 mm/min and awas between $10^{11}$ and $10^{12}$. Results also showed that the iron tailings had a moderate filtration capability, and based on the compressibility factor result ($n$: 0.56), the filter cake was compressible. This study clearly determined the action of physical parameters on dewatering mechanism and the fluid flow through the cake and cloth pores, and demonstrated the possibility of enhancing the water recycling in the industrial plant by choosing appropriate level for each parameters.

1. Introduction

Nowadays, the most challenging issue in the iron ore mining industry is tailings management and water recovery. Due to a number of problems such as water scarcity for processing, space limitation for tailings disposal and the environment problems, dewatering of tailings in the iron beneficiation plant is an important issue (Gomes et al., 2016).

In the tailings dewatering, although water recycling from tailings is essential; it is also necessary to produce filtered tailings which can be transportable by truck or conveyor belts. Separation of solids from liquids are usually performed by gravity sedimentation in thickeners, and mechanical pressure in filters. Each of these methods strongly depends on chemical and physical properties of process. Mechanical or physical filtrations are used to separate solids from liquids using a medium where only the fluid can pass (Fernando Concha, 2014; Tarleton and Wakeman, 2006).

In recent years, considerable attentions have been given to reducing cake moisture content by changing physical and chemical parameters, that many studies focused on the impact of chemical parameters (keeping physical parameters constant) (Amarante, 2002; Besra, 1998, 1996; Dias, 2003). The literature indicates that filtration rate, the specific cake resistance, and the residual filter cake moisture content can be enhanced using suitable dewatering filter aids such as surfactant (Patra et al., 2016) flocculant (Dash et al., 2011) and coagulant (Niu et al., 2013), which allow the formation and growth of aggregates (flocs) and destabilizing the fine particle suspensions (Stechemesser and Dobiáš, 2005; Qi et al., 2011). Published experimental results indicate that aggregation/ dispersion conditions, solid surface wettability and surface tension of the liquid, all play an important role in filtration performance. Adsorption of surfactant species on solids from solution is important in controlling a variety of interfacial processes (Patra et al., 2016; Stroh and Stahl, 1990). In addition, chemical conditioning of sludge prior to mechanical dewatering is often necessary to enhance the operating efficiency of dewatering device Zhang et al. (2014).

Although, the effects of physical parameters on filtration process are documented (Bourcier et al., 2016; Zhang, 2014), but very little knowledge has been obtained about the mode of action of physical parameters on the fluid flow through the cake (specific cake resistance) and cloth pores (resistance to filter cloth), cake formation rate, and...
moisture content, despite their successful application worldwide.

Literature shows that the filtration process parameters such as cake formation rate, resistivity cake and cake moisture, are strongly influenced by some physical parameters. Furthermore, the cake structure directly impacts on the specific cake resistance (Yim and Song, 2008). Typically, filtration process takes place in two stages: constant pressure filtration and constant volume filtration. During constant pressure filtration, the level of pressure drop is sustained and the filtrate rate slowly decreases over time as filter cake builds. In the constant pressure filtration, the filtration rate ($Q$) can be calculated by following Eq. (1), in which starting equation is usually derived from Poiseuille's equation (Patra et al., 2016).

$$Q = \frac{dV}{dt} = \frac{A\Delta P}{\mu R}$$  \hspace{1cm} (1)

where $V$ is the cumulative volume of filtrate ($m^3$), $t$ is filtration time (s), $A$ is filtration area ($m^2$), $\Delta P$ is applied pressure drop (Pa), $\mu$ is filtrate Viscosity (Pas) and $R$ is resistance to filtration (1/m).

The total resistive force, $R$ based on fluid flow through capillaries, is given by sum of the medium resistive forces, $R_m$ and sum of the cake resistive forces, $R_c$ as shown by Eq. (2).

$$R = R_m + \alpha c \frac{V}{A}$$  \hspace{1cm} (2)

where $R_m$ is the resistance to filter cloth (1/m), $\alpha$ the average specific cake resistance (m/kg), $c$ the slurry solids concentration in terms of mass solids per volume of filtrate (kg/m$^3$).

Specific cake resistance is a constant (at constant pressure and viscosity) which is a measure of the cake resistance to filtrate flow. It is a useful property that allows different filter cake or filtration aids to be compared. To determine specific cake resistance, Eq. (1) must be integrated and inverted, than Eq. (2) must be substituted into to form Eq. (3).

$$\frac{t}{V/A} = \frac{\mu c}{2\Delta P} \left( \frac{V}{A} \right) + \frac{\mu R_m}{\Delta P} \Rightarrow a + mx$$  \hspace{1cm} (3)

Noting Eq. (3) and Plotting $t/V$ vs. $V$ should give a straight line with a slope equal to $\frac{\mu c}{2\Delta P}$ and intercept equal to $\frac{\mu R_m}{\Delta P}$, from which the specific cake resistance and the medium resistance can be determined, if the viscosity of the filtrate, pressure across the filter, and slurry solid concentration is held constant.

The mass solids per volume of filtrate (is called effective feed concentration ($c$)) in Eq. (2) needs to be calculated. Depending on the level of data recorded, three methods can be used by the following Eq. (4) (Tarleton and Wakeman, 2006).

$$c \approx \frac{(M_k)_j}{V_d} \text{ or } c \approx \frac{\rho_l S}{1-m_{w0}S} \text{ or } c \approx \frac{C_l}{1-S}$$  \hspace{1cm} (4)

where $(M_k)_j$ is the mass of dry cake, $V_d$ the total volume of liquid filtered during the experiment, $m_{w0}$ the ratio of mass wet/dry cake, $S$ the solid concentration, $C_l$ the mass of solid per volume of feed liquid.

Typically, forms of the $t/V$ vs. $V$ plot obtening from experiments of where non-linearity can be observed. Hence the equations for $c$ need to be modified when $t/V$ vs. $V$ plot as a sharp deviation at longer filtration times. Further both $m_{w0}$ and $V_d$ need to be adjusted in order to calculate correct values for specific cake resistance and the resistance to filter cake.

The volume of filtrate and mass of wet/dry cake at the transition from cake formation is denoted as $V_u$ and the ratio of mass wet/dry cake at the transition, is calculated by the following Eq. (5).

$$c \approx \frac{(M_k)_u}{V_u} \text{ or } c = \frac{\rho_l S}{1-(m_{w0})_u S}$$  \hspace{1cm} (5)

where $(m_{w0})_u$, the ratio of mass wet/dry cake at the transition, is calculated by the following Eq. (6).

$$m_{w0} = \frac{(M_k)_u + (M_k)_o + \rho_l (V_u - V_o)}{(M_k)_o}$$  \hspace{1cm} (6)

Based on obtained results, that curvature of the $t/V$ vs. $V$ plot can occur for a number of reasons and may appear over regions other than the end period of filtration. Curve can be observed to differing extents at both first and end filtration times, and choosing the limit of the linear portion on the Characteristic Plot in order to apply Eqs. (5) and (6) must be done with care. If the technique is applied without some feeling for the consequences (and the reasons for plot curvature), then false answers may ensue.

Also, based on the dewatering studies, if $\alpha < 10^{11}$, the filter cake has good filtration capability; $10^{11} \leq \alpha \leq 10^{13}$, the filter cake has moderate filtration capability; $\alpha \geq 10^{13}$, the filtration process is difficult (Dash et al., 2011). Specific cake resistance can be used to determine if filter cakes tend to be soft and compressed under high differential pressure during filtration, which is called cake compressibility. Compression usually decreases porosity and permeability of the cake (Niu et al., 2013). Relationship between $\alpha$ and $\Delta P$ can be expressed using Eq. (7).

$$\alpha = \alpha_0 (\Delta P)^n$$  \hspace{1cm} (7)

where $\alpha_0$ is the specific cake resistance at unit pressure, $n$ the compressibility coefficient of filter cake. For convenience Eq. (7) may be written the following Eq. (8).

$$\lg \alpha = n \lg \Delta P + \lg \alpha_0$$  \hspace{1cm} (8)

Plotting log $\alpha$ versus log $\Delta P$ should give a straight line with a gradient equal to $n$, that $n$ ranges from 0 to 1 for different kinds of filter cakes. Table 1 shows type of filter cake based on compressibility coefficient ($n$) (Dash et al., 2011).

The volume of filtrate collected per time unit ($dV/dt$) expresses filtration rate. The physical factors which are influencing filtration processing are the filter medium, solid percent, pressure drop, and thickness of cake.

Filtration performance could be enhanced by selection suitable filter media (cloth), that significantly decreases the operating cost. Therefore, correct selection of filter media is important part for improving filtration performance. The most important factor in filter cloth choosing is fluid flow through the cloth pores. In the previous studies, this parameter was measured based on air flow rate through filter cloth. This method is incorrect, and misleading results were obtained in the filtration process, because the diffusion mechanism of air and liquid flow is quite different (Tarleton and Wakeman, 2006).

There are very few studies investigating the effect physical parameters on the filtration behavior and cake formation rate of iron ore tailings. This study is a new concept which investigated effects physical parameters on the fluid flow through the cake and cloth pores.

Therefore, the objectives of the present work are to (1) investigate the effect of cloth type on the resistance to fluid flow, cake formation rate, and moisture content of cake, (2) evaluate the respective influence of pressure drop, solid percent, and thickness on the dewatering performance, especially in the ability of the cake to let water go through during the filtration stage, (3) characterizes the filter cakes tend to compressibility under the high differential pressures, and (4) the possibility of enhancing the industrial performance of dewatering process.

<table>
<thead>
<tr>
<th>Value of n</th>
<th>Type of filter cake</th>
</tr>
</thead>
<tbody>
<tr>
<td>$n = 0$</td>
<td>Incompressible</td>
</tr>
<tr>
<td>$n &lt; 0.3$</td>
<td>Low compressible</td>
</tr>
<tr>
<td>$0.3 \leq n \leq 0.5$</td>
<td>Middle compressible</td>
</tr>
<tr>
<td>$0.5 \leq n \leq 1.0$</td>
<td>High compressible</td>
</tr>
</tbody>
</table>

Table 1: The classification type of filter cake based on compressibility coefficient.
by using physical conditioners was investigated.

In this present work, the action of physical parameters in the filtration of iron tailings were studied. The optimum amounts of parameters were maximum cake formation rate, minimum of specific cake resistance, and minimum moisture content.

2. Material and methods

2.1. Sample

The slurry sample of tailings was taken from Shahrak plant which is located Bijar, Iran. The sample for the experiments was prepared by decanting excessive process water from the slurry to increase the solid percent, pressure drop, and thickness of cake, were investigated. The concentrated slurry was stored in a 20 L container in an ambient environment away from direct sunlight. The filtration test was carried out with different concentrate slurry, pressure drop, cloth type, and cake thickness with process water obtained from Shahrak plant. All the experiments were carried out without adding chemicals agent.

2.2. Sample characterization study

The iron tailings sample was characterized by X-ray diffraction (XRD) to define the main and the trace minerals. The XRD result is presented in Table 2. According to the Table 2, the sample contained quartz, goethite and sheets mineral (muscovite and mica), which caused problem in filtration process. The reason for this is the moisture absorption by goethite. It is impossible to remove water from sheet minerals such as muscovite, they also prevent the fluid flow (Stechemesser and Dobiáš, 2005). The result of XRF can be seen in Table 3 which expressed that major components were Fe$_2$O$_3$ and SiO$_2$.

2.3. Experiments

Filtration experiments were performed using laboratory bench-scale vacuum filtration equipment (Buchner funnel), that applied Vacuum Top-Feed Leaf method. In the filtration studies, a known quantity of the slurry was conditioned, and subjected to filtration. During all experiments, no chemical regent was used. At the end of each test, cake was weighted and then dried with oven for 24 h at 75 °C. The collected filtrate volume was monitoring at 10 s intervals, then specific cake resistance and filtration rate were calculated.

The physical effective parameters on the filtration process identified and optimized, that including cloth type, solid percent, pressure drop, and thickness (changing one parameter and keeping constant other parameters at the same time). Finally, response values for evaluation of specific cake resistance, cake formation rate, moisture content, and resistance of filter cloth carefully checked.

Fig. 1 shows sample particle size distribution curves which was obtained by Fraunhofer Hydro 2000S (A). It can be seen in Fig. 1, the $D_{80}$ of the sample was 41 µm.

2.4. Physical parameters

In this paper the effects of physical parameters including filter cloth, solid percent, pressure drop, and thickness of cake, were investigated. In the filtration process, selecting suitable filter cloth not only increases operations efficiency, but could also provides economic savings (Qi et al., 2011). Therefore, it is economically imperative to determine the best cloth type which produce filter cake with low moisture content, low resistance to water flow, and clear filtrate to be returned to the process Table 4 shows various cloth types that were used in this study and microscopic images of these clothes are shown in Fig. 2.

3. Result and discussion

3.1. The effect of cloth type

Cloth type is very important in filtration process because it is one of the main parameters on the resistance to the fluid flow. The effect of cloth type on the filtration process was studied using seven different types of cloth and results illustrated in the Figs. 3 and 4. Some cloth types, demonstrate high resistance to fluid flow which reduces cake formation rate Mattsson et al. (2012). These results are attributed to differences in weave, material, and yarn of cloth. According to Fig. 3, lower resistance to filter cloth obtained for cloth with Satin weave and

**Table 2**

<table>
<thead>
<tr>
<th>Mineral</th>
<th>Formula (K, Na) (Mg, Fe, Al)$_3$ (Si$_3$O$_8$) (OH)$_2$</th>
<th>Wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Quartz</td>
<td>SiO$_2$</td>
<td>6.2</td>
</tr>
<tr>
<td>Muscovite</td>
<td>(K, Na) (Mg, Fe, Al)$_3$ (Si$_3$O$_8$) (OH)$_2$ (Si, Cr)$<em>2$ O$</em>{10}$ (OH)$_8$</td>
<td>10.6</td>
</tr>
<tr>
<td>Calcite</td>
<td>CaCO$_3$</td>
<td>13.7</td>
</tr>
<tr>
<td>Goethite</td>
<td>FeO(OH)</td>
<td>19.6</td>
</tr>
<tr>
<td>Hematite</td>
<td>Fe$_2$O$_3$</td>
<td>6.8</td>
</tr>
<tr>
<td>Dolomite</td>
<td>CaMg(CO$_3$)$_2$</td>
<td>13.1</td>
</tr>
<tr>
<td>Talc</td>
<td>MgSi$_4$O$_10$(OH)$_2$</td>
<td>8</td>
</tr>
<tr>
<td>Clinochlore</td>
<td>(Mg, Fe, Al)$_3$ (Si$_3$O$_10$ (OH)$_8$</td>
<td>21.9</td>
</tr>
</tbody>
</table>

**Table 3**

<table>
<thead>
<tr>
<th>Component</th>
<th>Wt.%</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fe$_2$O$_3$</td>
<td>42.55</td>
</tr>
<tr>
<td>SiO$_2$</td>
<td>21.30</td>
</tr>
<tr>
<td>Al$_2$O$_3$</td>
<td>6.2</td>
</tr>
<tr>
<td>CaO</td>
<td>5.69</td>
</tr>
<tr>
<td>MgO</td>
<td>5.11</td>
</tr>
<tr>
<td>SO$_3$</td>
<td>4.09</td>
</tr>
<tr>
<td>L.O.I</td>
<td>14.20</td>
</tr>
<tr>
<td>K$_2$O</td>
<td>0.58</td>
</tr>
<tr>
<td>P$_2$O$_5$</td>
<td>0.29</td>
</tr>
</tbody>
</table>

**Table 4**

<table>
<thead>
<tr>
<th>Cloth Type</th>
<th>d(10%): $1.520$ µm</th>
<th>d(50%): $9.796$ µm</th>
<th>d(80%): $41.974$ µm</th>
<th>d(90%): $86.778$ µm</th>
</tr>
</thead>
</table>

![Fig. 1. Particle size distribution of the sample.](image-url)
Polypropylene material (Code: PP-B, PP-C, PE-601). This is due to higher permeability and flexibility in contrast fluid passing of this type of cloth. Further, cloth type also affects on the cake formation rate as it can be observed that maximum cake formation rate is for lower resistance filter cloth.

Specific cake resistance for all the cloth type were obtained nearly identical (about $1.36 \times 10^{12}$). Because cloth type does not significantly impact on cakes resistance. Considering abeetwen $10^{11}$ and $10^{13}$, the filter cake has moderate filtration ability.

Based on the obtained results, the PP-B cloth was suitable for iron tailings filtration process, because it had minimum resistance to fluid flow and its cake formation rate, cake density, and rate of moisture redaction was maximum Fig. 4.

3.2. The effect of solid percent

Time and rate of filtration are highly influenced by slurry solid content. Increasing solid percent increases both specific cake resistance and rate of cake formation and decreases solid content decreases process throughput Stickland (2016). Fig. 5 shows the results of specific cake resistance and cake formation rate in various solid percent. By increasing solid percent from 40% to 60% (W/W) a sharp increase in the cake formation and specific cake resistance occurred, But at the solid percent 45–60%, the specific cake resistance increased relatively

<table>
<thead>
<tr>
<th>No</th>
<th>Code</th>
<th>Fiber type</th>
<th>Thickness (mm)</th>
<th>Weight (gr/m²)</th>
<th>Air Perm (Lit/dm²/min)</th>
<th>Weave</th>
<th>Yarn type</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>PP-A</td>
<td>Polypropylene</td>
<td>1.2 ± 0.05</td>
<td>480 ± 10</td>
<td>15 ± 5</td>
<td>Plain</td>
<td>Multifilament</td>
</tr>
<tr>
<td>2</td>
<td>PP-B</td>
<td>Polypropylene</td>
<td>1.75 ± 0.05</td>
<td>1050 ± 10</td>
<td>30 ± 5</td>
<td>satin</td>
<td>Multifilament</td>
</tr>
<tr>
<td>3</td>
<td>PP-C</td>
<td>Polypropylene</td>
<td>1.1 ± 0.05</td>
<td>550 ± 10</td>
<td>20 ± 5</td>
<td>satin</td>
<td>Multifilament (double layer)</td>
</tr>
<tr>
<td>4</td>
<td>PE-601</td>
<td>Polyester</td>
<td>1.15 ± 0.05</td>
<td>520 ± 10</td>
<td>140 ± 15</td>
<td>satin</td>
<td>Multifilament &amp; staple spun</td>
</tr>
<tr>
<td>5</td>
<td>PE-76</td>
<td>Polyester</td>
<td>0.95 ± 0.05</td>
<td>510 ± 10</td>
<td>80 ± 10</td>
<td>twill</td>
<td>Staple spun</td>
</tr>
<tr>
<td>6</td>
<td>PES-500</td>
<td>Polyester</td>
<td>2.3 ± 0.05</td>
<td>650 ± 10</td>
<td>90 ± 10</td>
<td>Needle felts (nonwoven)</td>
<td>Staple spun</td>
</tr>
<tr>
<td>7</td>
<td>PP-D</td>
<td>Polypropylene</td>
<td>0.60 ± 0.05</td>
<td>320 ± 10</td>
<td>15 ± 5</td>
<td>satin</td>
<td>Monofilament</td>
</tr>
</tbody>
</table>

Fig. 2. The microscopic images of the cloth applied.
intensely. This is because of preventing the passage of fluids through the filter cloth pores. By increasing the solid percent of 30–60%, the specific resistance and formation rate of the cake increased from $96 \times 10^{10}$ kg/m to $230 \times 10^{10}$ kg/m and from 0.18 mm/min to 0.46 mm/min, respectively (Raynaud, 2010; Vyas et al., 2000). Further, the recovery of water for each solid percent was also calculated in which results are presented in Fig. 6. As it can be seen in the Fig. 6, the maximum water recovery was obtained for at 45% solid percent.

Because in this solid percent, increasing filtration rate overcome the specific cake resistance. By increasing solid content from 30% to 60%, the specific cake resistance and possibility of blocking cloth pores increased, which had
negative effect on water recovery. On the other hand, the rate of cake formation increased which increased filtration rate and increase water recovery. Therefore, in solid content over 45%, the effects of specific cake resistance and blocking cloth pores overcame the rate of cake formation which reduced water recovery.

### 3.3. The effect of pressure drop

Fluid flow from the filter is performed by pressure difference on either side of it. By increasing pressure drop in filtration cycle, some kinds of materials tend to produce compressible cakes (Stroh and Stahl, 1990) that reduces porosity and permeability and changes structure of the cake (Zhang et al., 2014). Pressure drop experiments were conducted in the Pressure range of 40–80 kPa and the results are shown in Figs. 7 and 8 (Raynaud, 2010). Fig. 7 shows plot of time/filtrate volume vs filtration volume for experiments results and these results could be used to calculate $\alpha$. As shown in Fig. 8, the specific resistance of filter cake increased considerably by increasing pressure drop, which decreases thickness of cake.

In order to determine the compressibility of filter cake, log $\alpha$ vs. log $\Delta P$ graph was plotted Fig. 9). According to Eq. (8) and Fig. 9, compressibility factor of filter cake is 0.56 ($n = 0.56$). Because the value of $n$ is more than 0.5, based on Table 1, the sample had high compression properties. Therefore, an increase of pressure drop up to a certain value could improve filtration efficiency, and beyond a certain limit (70–80 kPa), any changes in pressure drop, did not produce better results.

As it is shown in Fig. 10, when the pressure drop increased, filter cloth resistance tend to decrease up to 60 kPa; and then for pressure drop over than 60 kPa, resistance of filter cloth increased. This high pressure is an indication of the capture of fine particles in the pores of filter cloth. As shown in the Fig. 10, the minimum moisture value for filter cake was obtained at 70 kPa pressure drop. Further, as it can be seen in Fig. 11, the maximum filtrate volume was gained at 70 kPa pressure drop too, and these results confirm each other. This may be due to the compression of the filter cake and the release of water from cake structure.

### 3.4. The effect of cake thickness

Increasing the thickness of cake usually increases plant capacity and throughput, but it changes specific cake resistance, moisture, and filtration rate. Therefore, in each filtration process, it is necessary to identify optimal cake thickness. As shown in the cake thickness results in Fig. 12, an increase in the thickness of the cake increased the resistance to filtration flow, and decreased rate of cake formation gradually. This is due to fact that, as the filtration proceeded, solid particle accumulated on the filter media and formed a packed bed of solids Mattsson et al. (2012).

### 4. Conclusion

The aims of this research was to investigate the effects of physical parameters on filtration of iron tailings, with focus on the specific cake resistance ($\alpha$), cake formation rate, moisture content, and resistance to filter cloth using vacuum Top-Feed Leaf method. Mineralogical studies
showed that the sample contained goethite and sheets minerals that make filtration process difficult due to moisture absorption by goethite, and prevention of fluid flow by sheet minerals (muscovite and mica). Experiments results showed that, the PP-B cloth was suitable for filtration process, because it had the minimum resistance to fluid flow. According to obtained results for compressibility index \( n = 0.56 \) and specific cake resistance \( \alpha \approx 10^{12} \), the filter cake is compressible and had moderate filtration ability.

References


