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

Hassan Mamghaderi, Mahdi Gharabaghi*, Mohammad Noaparast

School of Mining Engineering, College of Engineering, University of Tehran, Iran

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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 αwas between 10^{11} and 10^{13}. 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) flucculant (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

* Corresponding author.
E-mail addresses: gharabaghi@ut.ac.ir, m.gharabaghi@gmail.com (M. Gharabaghi).

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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).

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

where V is the cumulative 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 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, Rm, and sum of the cake resistive forces, Rc as shown by Eq. (2).

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

where R_m is the resistance to filter cloth (1/m), α 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 filtrationaids 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).

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

Noting Eq. (3) and Plotting t/V vs. V should give a straight line with a slope equal to $\frac{\alpha c\mu}{2A^2\Delta p}$ and intercept equal to $\frac{\mu R}{A\Delta p}$, 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).

$$c \approx \frac{(M_s)_e}{V_e},\ c = \frac{\rho_L S}{1 - m_{av}S} \text{ or } c \approx C_L = \frac{\rho_L S}{1 - S} \quad (4)$$

where $(M_s)_e$ is the mass of dry cake, V_e the total volume of liquid filtered during the experiment, m_{av} 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 obtaining 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_{av} and V_e need to be adjusted in order to calculate correct values for specific cake resistance and the resistance to filter cloth. When the volume of filtrate and mass of wet/dry cake at the transition from cake formation is denoted as V_{tr} and $(m_{av})_{tr}$, corrections to Eq. (4) to account for dewatering are Eq. (5).

$$c \approx \frac{(M_s)_e}{V_{tr}},\ c = \frac{\rho_L S}{1 - (m_{av})_{tr}S} \quad (5)$$

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

$$(m_{av})_{tr} = \frac{(M_S)_e + (M_L)_e + \rho_L(V_e - V_{tr})}{(M_S)_e} \quad (6)$$

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. Curvature 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 α and ΔP can be expressed using Eq. (7).

$$\alpha = \alpha_0(\Delta P)^n \quad (7)$$

where α_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).

$$\lg\alpha = n\lg\Delta P + \lg\alpha_0 \quad (8)$$

Plotting log α versus log ΔP 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 physicals 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 1
The classification type of filter cake based on compressibility coefficient.

Value of n	Type of filter cake
$n = 0$	Incompressible
$n < 0.3$	Low compressible
$0.3 \leqslant n < 0.5$	Middle compressible
$0.5 \leqslant n \leqslant 1.0$	High compressible