Research into Filtration Washing Kinetics of Sludge Pulp Bottom Settlings

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Abstract. The research presents the results of the study of filtration washing kinetics of sludge pulps containing various substances. The kinetics of the process of washing the valuable solution from mother waters when applying the scrubber solution (water) with the fully engaged surface of the bottom setplings is analysed. Key stages of the washing process are interpreted in the research, as well as the impact of the basic parameters of washing (expendable modulus, washing circulation cycle time, bottom setplings thickness, scrubber solution temperature in the mother waters, etc.) on the performance of washing the valuable solute from interstices of bottom setplings is identified. It is shown that the filtration washing process is influenced by the conditions of appearing the bottom setplings on the filtering element. The research gives an insight into the process of washing the bottom setplings from the flaking and preliminarily concentrated pulps. Analytical expressions for the effectiveness of filtration washing of different stages, which are based on bottom settling specific loads dependent on the dissolved substance and expendable modulus, are provided.

1. Introduction

The filtration washing of bottom setplings is widely employed in different manufacturing sectors: mining-metallurgical, mining-chemical and chemical industries [1,2,3,4,5,6]. The filtration washing is a more complicated process in comparison to the preliminary process of filtering. The process of the filtration washing has been given consideration in numerous research works. For the first time the phenomena within the process were theoretically interpreted by E.Alliot [7], F.H. Rhodes [8]. The ideas went further when taking filtration washing as a complicated process in the research by O.L. Bruke [9], A.A. Golovin [10], F.Rhodeso [11], I. K. Skobeev [12], A.A. Komarovsky [13], etc. A number of researchers described the washing process through the hydrodynamic theory, while others (M.T. Kio [14], R. Rigamotti [15] followed the concept of filtration washing as being a diffusion process. However, the filtration washing procedures are governed by both hydrodynamic and diffusion effects running concurrently [12,13,16,17,18,19,20].

The relevance of studying filtration washing kinetics of sludge pulps is determined by the complex relationship of the structural characteristics of the bottom setplings of detrital material surface behaviour, physical-chemical properties of the liquid-phase and operating conditions for the filtration process, which make it difficult to analyse the process of extracting dissolved solids from the porous medium of the bottom setplings.
2. Experimental technique
The filtration washing process of bottom settlings of sludge pulps was studied through using the laboratory filtration equipment, which consists of several units: the unit with a vacuum-air pump, receiver tank, vacuum regulator component and pressure gauge; the unit with a system of measuring burettes and filter press containers; the thermostat control unit with a thermostatic regulator, thermostatic nest and heating jacket. Before the experiment the filter base was put into the heating jacket with fibre rock to provide thermal insulation. The thermostatic nest connected with the thermostatic regulator was located on the filter body. Laboratory models of nutsche filters, leaf vacuum filters, as well as a vacuum filter cartridge were tailored to filter sludge pulps. As a part of the study, sludge pulps of various material compositions (red and belite sludge, pulps of primary and secondary cryolite, sulphide and non-sulphide gold bearing pulps) went through the filtration process. After forming the bottom settlings, they were washed by the scrubber liquid which covered all the surface of the bottom settlings. While washing, the time of appearing the filtered material in the burettes was measured. Sampling the filtered material to identify the dissolved substance content was parallel to measuring the periods of its appearing. The methods of neutralization (sodium hydroxide) and iodimetry (sodium thiosulfate), as well as rhodanometric method (potassium rhodanate) were employed to measure the content of the washed stuff.

3. Research results
The filtration washing process can be evaluated through a number of parameters. The change in the solute content in the mother waters of the bottom settlings can be shown through its concentration in the leachate. And the washing process performance can be presented as follows:

\[ E = 1 - \frac{g_i}{g_0}, \]  

(1)

where \( g_0 \) is the initial specific load for the solute; \( g_i \) is the current specific load.

The experimental study of the filtration washing of the bottom settlings allows pointing out its three stages (Figures 1-3).

![Figure 1. The impact of expendable modulus \( d \) on the effectiveness of washing \( E \) bottom settlings formed from flaggy pulps.](image)
Figure 2. The impact of expendable modulus $d$ on the effectiveness of washing $E$ bottom settlings formed from concentrated pulps.

Figure 3. The impact of expendable modulus $d$ on the amount of alkali $c$ in the leachate (the bottom settlings are formed from concentrated pulps 1-$c=100$ g/l; 2-$c=50$ g/l; 3-$c=40$ g/l).

During the first stage (frontal drive) the mother waters are driven without being mixed with the washing liquid. The period of releasing the leachate, which concentration is $c_0$, is as long as its moving through the major capillaries. On the average, the volume of the washing liquid is from 0.2 to 1.5 m$^3$ per 1 m$^3$ of locked water content and depends on the way the bottom settlings are formed. In other words, it depends on the structure of the bottom settlings. The first period is characterized by linear relations between the effectiveness of the washing process and its duration or expendable modulus. Within the period the extraction of the solute is equal to 60-70% and the volume is dependent on the type of the structure of the bottom settlings formed.

The second period (hydraulic mechanical drive) involves a high-speed decrease of the solute concentration when it drives from pin holes of the bottom settlings in the leachate from the initial value $c_0$ to $c_i$. The duration of the washing process to obtain the concentration of the solute $c_i$ corresponds to the duration of driving mother waters from the smallest capillaries. Within this working
time interval the collection of the solute per unit volume of the washing liquid goes through a number of stages: mixing with the mother water coming out of the transversal pin holes of the bottom settlings; mixing with loosely bound film moisture; molecular diffusion of the solute from strongly bound moisture; molecular diffusion from stagnant pin holes and zones of low permeability. The flow rate of the washing liquid during this period increases in 3-4 times per 1 m$^3$ of the mother waters compared to the first period.

To make the washing process more effective during the second period there are following empirical dependences obtained:

$$E = a_1 + b_1t + c_1t^2; E = a_2 + b_2d + c_2d^2,$$

(2)

where $a$, $b$, $c$ – experimental coefficients, the value of which depends on the thickness of the bottom settlings, as well as on the concentration of the solute in the mother waters.

The current specific load of the bottom settlings is equal to:

$$g_i = g_0 [1 - a_2 - b_2d - c_2d^2].$$

(3)

During the second period, the highest rate of growth of the contact surface is observed. By the beginning of the third period, the rate of change of the contact surface is minimal, while its value approaches the specific surface of the bottom settlings.

The third period of the washing process is characterized by a slow decrease of the solute concentration in the leachate. Whereas the accumulation of the solute in the washing liquid occurs as a result of molecular transfer from the film moisture of stagnant pin holes and low permeable zones. During this period, the volume of the washing liquid used increases in 10-25 times compared to the first period. The effectiveness of the washing process reduces significantly.

Studying the process of washing the bottom settlings formed from thickened and flaggy pulps shows that the structure of thickened pulps remains the same when its depth increases. The fact demonstrates that there are capillaries of equal size in all separate layers. As for the bottom settlings of flaggy pulps, the structure of all separate layers is different (the model to form bottom settlings from heterogeneous parts).

The study of the filtration process of washing sludge bottom settlings showed that the thicker the bottom settlings are, the bigger the stagnation zones are. The amount of the solute extracted from the pin holes of the bottom settlings in the second period increases. Reducing the size of stagnation zones of sludge bottom settlings is possible within the period when sludge pulps are processed with flocculation agents. For making the process of washing more intensive, some flocculation agents such as polyacrylamide, pyridinium salt polymer, flour were tested.

When using these flocculation agents within the first period of processing red sludge pulps before filtering them, there are optimum doses established. As for hydrolyzed polyacrylamide, the highest filtration rate captured is for the dosage of flocculant 18 g per a ton of sludge. For flour the ratio is 600 g of the flocculation agent to a ton of sludge.

When processing sludge bottom settlings with flocculation agents, it makes the first stage (releasing mother waters) shorter. Forming floccules contributes to forming larger radius capillaries in comparison to the unprocessed bottom settlings. Whereas the pin holes for waters to come off become larger, an increase in washing the solute by the beginning of the second stage is provided. The increase in washing efficiency is also due to reducing the size of pin holes in the stagnation zones. Therefore, for flour $E$ value by the beginning of the third period is 0.67; for pyridinium salt polymer that is equal to 0.59; whereas for polyacrylamide, it is 0.53; and without processing with flocculants the value is equal to 0.48.

Washing bottom settlings with flocculants allows increasing the volume of effective waters removed by reducing the total amount of stagnant liquid substance and increasing the volume of pin holes containing free waters.
4. Conclusion
Thus, in the process of the filtration washing of the bottom settlings of sludge pulps (frontal drive, hydraulic mechanical drive, diffusion), characterized by parallel hydro-dynamic and physical-chemical effects, the key stages of the filtration washing were studied.

The first stage features in releasing mother waters when the expendable modulus is no more than one unit. The second stage is for the mother waters (film and capillary ones) to come off, while the expendable modulus increases threefold or fourfold. During the third diffusion period the most resistible film waters are washed, while there is a slow decrease of the solute and significant growth of washing solution consumption.

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