Mining Science, vol. 31, 2024, 103–118

www.miningscience.pwr.edu.pl

Mining Science

(Previously Prace Naukowe Instytutu Gornictwa Politechniki Wroclawskiej, ISSN 0370-0798)

ISSN 2300-9586 (print)
ISSN 2353-5423 (online)

Received January 11, 2024; Reviewed; Accepted August 27, 2024

THICKENER DESIGN FOR A COPPER CONCENTRATE USING RHEOLOGY, SEDIMENTATION AND COMPRESSION PARAMETERS

Aldo QUIERO-GELMI*, Rubén OLCAY-BARREDA,
Paola MAMANI-APALA

School of Engineering and Architecture, Arturo Prat University, Chile

Abstract: This study was carried out to evaluate the operation of the thickener at mine site, in addition to increasing the geometallurgical information of the mining process. It analyzes the results of the sizing of a thickener that treats copper concentrate ore slurry from the flotation process. For this purpose, discontinuous sedimentation tests were carried out to determine: the effect of the flocculant dosage on the sedimentation velocity, on the sediment in compression, and on the thickener design by Adorjan's method, which uses sedimentation parameters and compression parameters, and is complemented with rheological parameters obtained from the calculation of the effective solid stress and the measurement of the yield stress in slurries without the addition of flocculant. Batch sedimentation tests were performed for flocculant dosage between 0–20 g/TMS and volume fraction concentrations between 0.025–0.130. The results obtained show that the sedimentation velocity tends to constant and maximum values starting at a dose of 4 g/TMS; however, the analysis of the sediment granulometry indicates that the addition of flocculant is not necessary, since there is no significant size segregation for low dosage of flocculant; and finally, the design of the thickener by Adorjan's method indicates that the optimum value would be 20 g/TMS. When evaluating the rheological parameters for the concentrate without the addition of flocculant, it is observed that the behavior of the effective solids stress and yield stress have a marked increase in their values for volumetric fractions of 0.45 (79.60% of solids by mass), which would indicate a change in the fluidity of the concentrate, so it is correct to design the thickener for a discharge volumetric concentration of 0.239, which corresponds to the range used in the industrial operation, and it is expected that the fluidity of the concentrate thickener discharge will have an adequate rheological behavior.

***Keywords*:** *thickener, design, Adorjan, sedimentation, compression, rheology*

* Corresponding author: aquiero@unap.cl (A.I. Quiero)

doi: 10.37190/msc243106

1. INTRODUCTION

The solid-liquid separation operations performed by thickeners are carried out in mineral processing for different purposes: recovery or recirculation of process water, dewatering of pulps containing concentrates, tailings, and slimes, for transport or disposal in dams. Currently, in countries with desert areas in South America, such as Argentina, Brazil, Chile, and Peru, among others, water resources are scarce, a situation that will become even more serious in a short time. For this reason, processes that consider higher water recoveries will be increasingly relevant in the regional and global mining future. In this context, it is relevant to know the operation of the thickener within the process. So, the design of the thickener is carried out, and the operating conditions at the mine site are evaluated, which is consistent with the geometallurgical studies carried out to improve the efficiency of the mining process.

The thickening operation is usually employed in industrial plants that use the sedimentation of solid particles in tanks of different geometries suitable for each type of application. Conventional thickeners are characterized by a circular tank in the center of which the slurry feed is carried out, thus producing two products: a clarified liquid in the overflow and a slurry with a higher concentration of solids (discharge or underflow), as shown in Fig. 1.

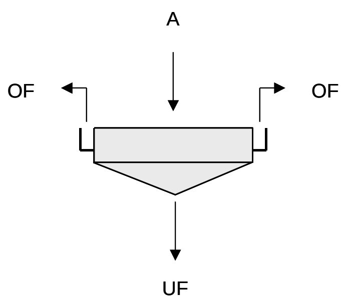

Fig. 1. Representation of a conventional thickener: feed (A), clarified water (OF), and discharge with higher solid concentration (UF) (Author's own elaboration, 2022)

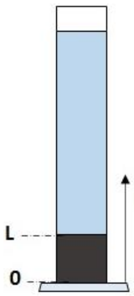

Fig. 2. Reference system used in the sediment in compression of a discontinuous sedimentation test. (Author's own elaboration, 2024)

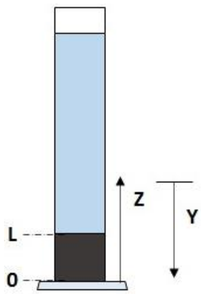

Fig. 3. The final reference system used in the sediment in compression of a discontinuous sedimentation test. (Author's own elaboration, 2024)

In the specific case of copper sulfide ore treatment mines that use flotation as a concentration process, the thickener is the equipment used in the sedimentation and clarification of the slurry coming from this process, either as concentrate or tailings.

The design of conventional thickeners had its first proposals with the Mishler equation and with the method of Coe and Clevenger. Later, Kynch's kinematic theory developed, and several design methods using this theory were presented, such as the methods of Talmage and Fitch and Yoshioka and Hassett; finally, models developed that consider the behavior of flocculated slurries, incorporating the consolidation of dense sediments, with the use of dynamic models, such as the model proposed by Adorjan (Concha and Barrientos 1993).

A critical analysis of these thickener design methods was performed by Concha and Barrientos (1993), and an evaluation of these methods was performed by Quiero (1994) for a flocculated tailing ore slurry, demonstrating that the method that most accurately described the design and subsequent simulation of the thickeners operating in their respective sites was Adorjan's method, showing differences of less than 5% of the operating values.

Adorjan's thickener design (Adorjan 1976) considers the forces existing between the particles that make up the slurry under study; therefore, it establishes that the concentration of solid in the compression zone depends on its pressure, and on the height of the sediment in compression. In this regard, Adorjan studying this phenomenon indicated that: "if a slurry presents significant compressive forces, the dimensions of a thickener cannot be calculated from discontinuous sedimentation test", since compression parameters must be applied for example.

Thus, the area required for a thickener calculated by Adorjan's method given by Eq. (1) shown below:

$$A = \frac{Q_F}{\rho_s v_S}\left(\frac{1}{\phi_F} - \frac{1}{\phi_D}\right), \tag{1}$$

where: Q_F is the feed flow to the thickener, ϕ_F is the volume fraction of solids feed to the thickener, ϕ_D is the volume fraction of solids from the thickener discharge, ρ_s is the density of the solid, ρ_f is the density of the fluid, and v_s is the settling velocity of the feed slurry.

To determine calculate the settling velocity, Eq. (2) developed by Richardson and Zaki (1997), was used:

$$v_S = v_\infty (1-\phi)^n , \tag{2}$$

where v_∞ and n are parameters of the equation, and v_∞ is the terminal velocity of a particle, the settling velocity of a particle in an infinite dilution medium.

The Equation (3) of Michaels and Bolger (Michaels y Bolger 1962), was used to find the critical volume fraction of solids:

$$v_S = v_\infty \left(1 - \frac{\phi}{\phi_m}\right)^{4.65} , \tag{3}$$

where v_∞ and ϕ_m are parameters of the equation.

The dimensions of a thickener are calculated for the chosen design variables, such as feed mass flow rate, feed and discharge concentration. However, these operational variables can change in certain conditions of the production process, generating critical operating conditions, in which the thickener must work without generating problems such as the dragging of solids to the overflow zone, the thickener can become clogged or generate a high torque on the scraper, which prevents its operation. Adorjan defined a factor to control this condition and called it the "load factor", which is defined by Eq. (4):

$$Q = \lambda Q_F \text{ and } 0 < \lambda < 1. \tag{4}$$

The choice of an adequate load factor λ will result in the successful operation of the thickener, since fluctuations do not affect efficient operation, even in critical conditions.

Substituting Eq. (2) and Eq. (4) into Eq. (1), we finally obtain that the area needed for the thickener is show in Eq. (5):

$$A = \frac{Q}{\lambda \rho_s v_\infty} \frac{\left(\frac{1}{\phi_F} - \frac{1}{\phi_D}\right)}{(1-\phi_F)^n}. \tag{5}$$

For the determination of the thickener height, it is necessary to calculate the compression parameters of the slurry to be studied, for which Eq. (6) of Concha and Barrientos (1993), shown below, was used:

$$\sigma_e = a e^{b\phi}, \tag{6}$$

where σ_e effective stress, and a and b are parameters of the Concha and Barrientos equation's,

Using this Eq. (6), Adorjan's method return the following expression:

$$\frac{dh}{d\phi} = \frac{abe^{b\phi}}{\Delta\rho\phi g\left[1 - \frac{QJ^*}{\rho_s A v_\infty (1-\phi)^n}\right]} = f(\phi), \quad \phi > \phi_c, \tag{7}$$

where $J^* = (1/\phi_F - 1/\phi_D)$.

Equation (7) provides a relationship between the solid concentration of sediment in compression and its height.

As all the parameters of equation (7) are separable variables, the fourth order Runge–Kutta method was used, whose values are calculated with a volume fraction increase of solids of $\Delta\phi_c$, obtaining: $k_1 = F(c_j)$, $k_2 = F(c_j + \Delta\phi_c/2)$, $k_3 = F(c_j + 2\Delta\phi_c/3)$, and $k_4 = F(c_j + \Delta\phi_c)$. Therefore, the value of the thickener height is given by Eq. (8):

$$h_{j+1} = h_j + \frac{1}{8}(k_1 + 3k_2 + 3k_3 + k_4). \tag{8}$$

To reach this height, an additional value should be added for the feed, the clear water zone and the conical base that should be in the discharge. A good estimate for the additional height is about 1 meter.

For the determination of the compression parameters, which are given by the parameters a and b in Eq. (6), a relationship must be found between the concentration that the sediment presents at different heights and the effective stress of solids in the zone of the sediment that is in compression, for a process carried out in discontinuous sedimentation. The above relation is returned with the following development:

Considering the reference system shown in Fig. 2, Adorjan developed the force balance equation, finally obtaining Eq. (9) (Adorjan 1976):

$$\frac{d\sigma_e}{dZ} = -\Delta\rho g \left\{ \phi(Z) + \frac{f - q\phi(Z)}{v_\infty [1 - \phi(Z)\}^n]} \right\}. \tag{9}$$

By integrating, we obtain Eq. (10):

$$\sigma_e = -\Delta\rho g \int \left\{ \phi(Z) + \frac{f - q\phi(Z)}{v_\infty [1 - \phi(Z)\}^n]} \right\} dZ\ . \tag{10}$$

To solve the integral of equation (10), Simpson’s Numerical Integration method was used; to apply this method, the following change of variables must be performed:

$$Y = L - Z, \text{ thus } dY = -dZ.$$

Then, the new reference system shown in Fig. 3, the above transformations are performed on Eqs. (10) and (11) is obtained:

$$\sigma_e = \Delta\rho g \int_{Y=0}^{Y=Y} \left\{ \phi(Y) + \frac{f - q\phi(Y)}{v_\infty [1 - \phi(Y)^n]} \right\} dY\ . \tag{11}$$

Replacing the limits of the integral, we finally arrive at Eq. (12):

$$\sigma_e = \Delta\rho g \int_{L}^{L-Y} \left\{ \phi(Y) + \frac{f - q\phi(Y)}{v_\infty [1 - \phi(Y)^n]} \right\} dY\ . \tag{12}$$

Equation (12) is the link between height, volume fraction, and effective solid stress of the sediment in compression, which will allow obtaining a set of data of effective solid stress as a function on volume fraction, and those results are adjusted to the equation of Concha and Barrientos (6) and thus obtain the compression parameters of the slurry.

Regarding the study of the rheological parameters, the transport of slurry through pipes and its subsequent deposition in tailings dams or deposits such as mineral pastes depend on variables such as pressure difference or height that are external to the fluid, and other variables of the transported fluid such as its rheology; which will be analyzed by characterizing the effective stress of solids and the yield stress. The latter is related to the minimum stress that a fluid must be subjected to before it begins to flow.

Concentrated solid-liquid suspensions have different behaviors under stresses of different magnitude. When the fluid is subjected to a low-stress value, the system deforms elastically and does not flow; on the other hand, if a stress higher than a certain value is applied, the system flows as a viscous fluid (Dsuy and Boger 1983). The yield stress can be understood as a property of the solid-liquid system, which marks the transition from "solid behavior" to "liquid behavior" (Saavedra 2019).

The main objectives of the present work are the following: i) analyze the rheological parameters, sedimentation, and compression of a copper concentrate, and to design a thickener using the Adorjan Method; ii) design the necessary unit area and thickener diameter, considering the concentrate without and with the addition of a flocculant; iii) characterization of the physical properties of the copper concentrate ore to be used in the design of the thickener.

2. EXPERIMENTAL PROCEDURE

The sample used in this study was a copper concentrate, with a majority presence of chalcocite and about 30% Cu in grade, from a mining site in northern Chile. To obtain the solid sample, a drying stage of 300 kg of the initial collected sample was carried out in an electric stove, and later, with the use of the riffle cutter and the cone and quartering, respectively, a representative sample of 2 kg was obtained for granulometric analysis and determination of the density of the copper concentrate.

For the granulometric analysis, the Ro-Tap equipment was used, and 0.5 Kg of ore were weighed, where the Tyler meshes were considered: from 14# (1180 μm) to 400# (38 μm). The flocculant solution used for the discontinuous sedimentation tests was SH-913 with a concentration equal to 0.1 g/Lt, which is the flocculant used at the site that produced the copper concentrate used in this study.

For the determination of the optimum flocculant dosage (by sedimentation velocity method and sediment granulometry), discontinuous sedimentation tests were carried out for a volume fraction of 0.0824 (the value used in the industrial operation), in 1 Lt test tubes for flocculant dosages of 0 until 20 g/TMS. To obtain the sediment granulometry, it was decided to consider a height of 5 cm from the bottom as a representative sample of the sediment to be studied; therefore, samples of approximately 5 cm were taken for each batch sedimentation test with the different dosage of flocculant mentioned (0 until 20 g/TMS). These samples were filtered and dried in the electric oven, and subsequently, their granulometry was calculated considering the coarse fraction as +270# (53 μm) and the fine fraction as –325# (45 μm).

For the calculation of the area and height of a thickener by Adorjan's method, it is necessary to determine the parameters of slurry sedimentation and slurry compression. In the case of determining the sedimentation parameters, discontinuous sedimentation tests were carried out for dosage of 0 until 20 g/TMS, for the range of volumetric concentrations of $\phi = 0.025$ until 0.130. The calculated sedimentation parameters correspond to the parameters V_∞ and n of the Richardson and Zaki (1997) and ϕ_c of the Michaels and Bolger (1960) equations, which were calculated for each of the flocculant dosage mentioned.

For the determination of the compression parameters, discontinuous sedimentation tests were carried out, with an initial concentration of $\phi_0 = 0.20$, for flocculant dosage of 0 until 20 g/TMS, which are the same as in the previous case, in a sedimentation column of 10 cm in diameter and 10 Lt of total capacity, which has a series of tubes to make it possible to measure the concentration at different heights in quasi-steady state, as shown in Fig. 4, and thus measure the volume fraction versus sediment height, and with these data, calculate the effective solids stress versus sediment height, and calculate the parameters of the Concha and Barrientos equation.

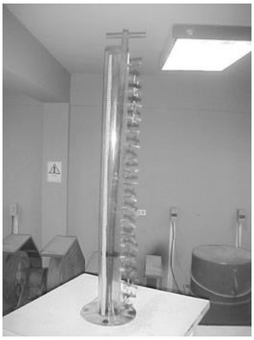

Fig. 4. Sedimentation column used to determine the concentration profile in batch sedimentation tests of copper concentrate. (Author's own elaboration, 2006)

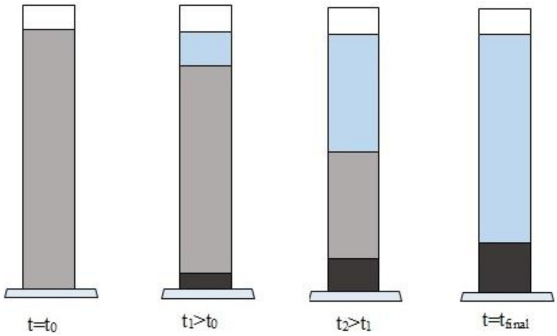

Fig. 5. Sequence of a discontinuous sedimentation test showing the clear water zone (A), solid-liquid interface sedimentation zone (B) and compression zone (C). (Author's own elaboration, 2024)

Fig. 6. Schematic of the Brokfield DV3T Rheometer. Adapted from Brokfield's WEB site

In these tests, samples were taken when the sedimentation velocity had values of approximately 1 mm/min, which was considered a quasi-steady state. Samples of approximately 50 ml of the slurries taken at different compression heights were weighed and dried to determine the percent solids and volume fractions (ϕ) at these different heights of the sediment in the column.

The sedimentation velocity was determined considering the first sedimentation zone where the velocity is constant. The calculation of this sedimentation velocity was performed considering the record of the measurement of the solid-liquid interface as a function of time, in discontinuous sedimentation tests, shown in Fig. 5.

For the measurement of the rheological parameter yield stress, for different mineral slurries and pastes, experimental tests were carried out on the Brokfield digital rheometer model DV3T shown in Fig. 6. The Bingham model was used for the measurement of the yield stress, which lasted approximately 300 seconds per test with a shear rate from 1 to 100 rpm, where the four-vane helical sensor performs the initial rotation slowly varying its speed in the Slurry or paste to determine the final yield stress, for mixtures of 50, 55, 60, 65, 70, 75, and 80% in solids, which is equivalent to volume fractions ϕ between 0.173 and 0.456.

3. RESULTS AND DISCUSSIONS

3.1. DENSITY DETERMINATION AND GRANULOMETRIC ANALYSIS OF THE ORE

To determine the density of the ore, the pycnometer method was used, performing three tests and obtaining an average specific weight value of 4.77 g/cm^3.

The granulometric analysis of the copper concentrate sample was carried out using Tyler meshes and a Ro-Tap as equipment. The results are as follows:

Copper concentrate has a fine particle size, as it has 99.94% passing at 150 μm, 78% passing at approximately 75 μm, and an average size of approximately 52 μm.

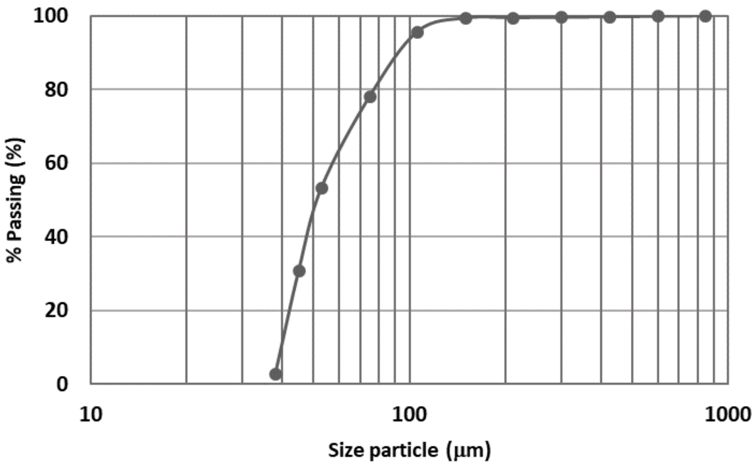

Fig. 7. Granulometric analysis of copper concentrate ore
(Author's own elaboration, 2024)

For further calculations of the Granulometric Ratio (GR), we will use values for %+270# equivalent to 53 μm, of 46.72%, and for %–325# which are equivalent to 44 μm, of 30.78%.

3.2. STUDY OF THE RELATIONSHIP BETWEEN SEDIMENTATION RATE AND FLOCCULANT DOSE

The results of the experimental batch sedimentation tests for a volume fraction of 0.0824, and for flocculant dosage between 0 and 20 g/TMS, according to the procedure already described, are shown in Fig. 8.

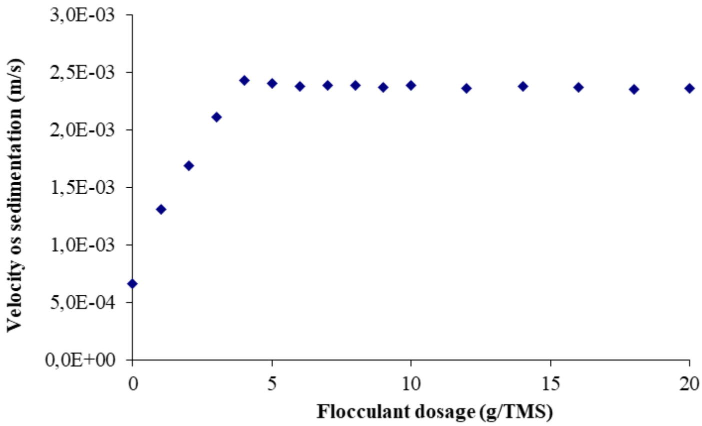

Fig. 8. Velocity of sedimentation against flocculant's dosage, for tests of batch sedimentation in a column of 1 Lt and with ϕ_0 = 0.0824 (Author's own elaboration, 2024)

The analysis of the Fig. 8 shows that for flocculant dosage higher than 4 gr/TMS no significant increase in sedimentation velocity is achieved, so this method indicates that the optimum dose would be 4 g/TMS (Quiero et al. 2022).

3.3. STUDY OF THE RELATIONSHIP BETWEEN SEDIMENT PARTICLE SIZE AND FLOCCULANT DOSE

For the same experimental tests as the previous point, the sediment granulometry was calculated, and a dimensionless number called the "granulometric ratio" defined by Eq. (12) is used:

$$RG\,(accumulated\ o\ reatained) = \frac{\%\ accumulated\ o\ retained\ in\ a\ mesh\ in\ the\ sediment}{\%\ accumulated\ o\ retained\ in\ a\ mesh\ in\ the\ mineral\ sample}. \quad (13)$$

In this case, the RG(+270#) and RG(–325#) were studied and are shown in Fig. 9.

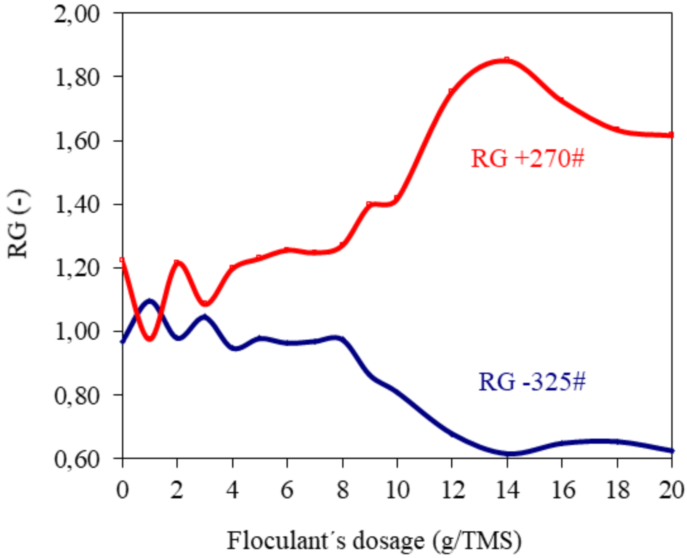

Fig. 9. Granulometric ratio against flocculant's dosage, for tests of batch sedimentation in a column of 1 Lt and with ϕ_0 = 0.0824 (Author's own elaboration, 2022)

According to Fig. 9, can be concluded that if the objective is to avoid size segregation in the sediment as much as possible, the most appropriate dosage is 1 g/TMS. If, operationally, for coarse mineral values (+270#) higher than 20% and fines (–325#) lower than 5% of the feed sample, there is no problem in the thickener discharge, it would be better to work without flocculant, since for flocculant dosage from 2 to 8 g/TMS, segregation conditions notoriously higher than operating without flocculant addition are not achieved (Quiero et al. 2022).

3.4. STUDY OF THE RELATIONSHIP BETWEEN THICKENER DESIGN AND DIFFERENT FLOCCULANT DOSAGE

To use Adorjan's method (Adorjan 1976), it is necessary to determine the sedimentation parameters, so batch sedimentation tests were performed for flocculant dosage of 0 until 20 g/TMS, for ϕ = 0.025 until 0.130; and it is also necessary to determine the compression parameters, for which discontinuous sedimentation tests were carry out with ϕ_0 = 0.20, for flocculant dosage of 0 until 20 g/TMS.

3.4.1. SEDIMENTATION PARAMETERS

The values obtained are shown in Tables 1 and 2.

The parameter V_∞ increases linearly with increasing flocculant dosage, which is proven by performing linear regression. The equation $y = 5.51*10^{-4}x + 1.9515$ is obtained, where "y" is the velocity at infinite dilution and "x" is the flocculant dosage, and the parameter $r^2 = 0.984$. The trend of parameter "n" will be mentioned later in conjunction with the thickener capacity (Quiero et al. 2022).

The critical concentration has the lowest value for sedimentation without flocculant, which is logical since the limiting concentration value between free and hindered sedimentation will increase as flocculant is added, since the addition of the latter increases the sedimentation velocity of the slurry, causing the slurry to sediment in free form at higher concentrations, without interference between particles for slightly higher concentrations; therefore, the critical concentration must increase until reaching a limit value (Quiero et al. 2022), a situation that is not reached in this working range.

Table 1. Sedimentation parameters of the slurry by Richardson and Zaki equation and Michaels and Bolger equation

Sedimentation parameters	Flocculant dosage, g/TMS					
	0	4	7	10	14	20
$V_\infty*10^2$ m/s	1.95	2.16	2.29	2.54	2.80	3.00
n	31.29	28.58	28.20	29.02	30.54	27.46
r^2	0.987	0.996	0.999	0.998	0.999	0.999
ϕ_c	0.051	0.053	0.058	0.061	0.062	0.069
r^2	0.977	0.993	0.999	0.999	0.998	0.998

3.4.2. COMPRESSION PARAMETERS

The values obtained are as follows:

Table 2. Slurry Compression parameters by Concha and Barrientos equation

Compression parameters	Dosis de Floculante, g/TMS					
	0	4	7	10	14	20
a N/m^2	216.074	0.270	21.230	18.690	1.576	1.101
b	4.672	19.604	9.961	10.428	16.947	19.242
r^2	0.99	0.92	0.98	0.98	0.73	0.94

The trend presented by the parameter "a" will be discussed later, as it will be done together with the analysis of the height obtained for the thickener.

3.4.3. RHEOLOGICAL PARAMETERS

For the evaluation of the rheological parameters, a mineral slurry without the addition of flocculant was used, and the effective stress values were obtained by Eq. (12) and yield stress values by measuring them with the rheometer shown in Fig. 5. Both types of stresses are plotted in Fig. 10, showing that both types of stress have the same tendency, and show a change in behavior, due to the strong increase in the values of both stresses for volume fractions of 0.45, which is equivalent to a value of 79.60% in mass percent of solids, which indicates a change in the behavior of the mineral slurry, which visually shows that it has characteristics of mineral paste. It is suggested to deepen this study by evaluating the predominance of states for a solid-liquid mixture (Baker and Hugues Company 2001), the abatement percentage (Hernandez et al. 2005) and the angle of repose (Robinsky 2002) for example, and relate them to variables such as percent solids by mass, pH of the solid-liquid mixture, granulometry, and flocculant dosage (Arenas 2024).

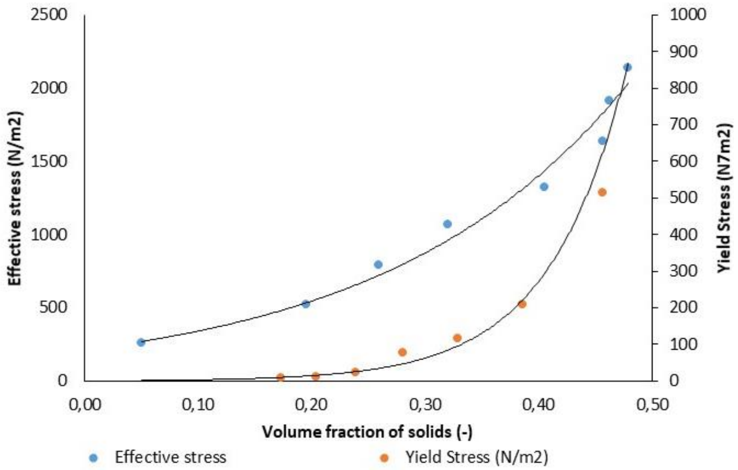

Fig. 10. Effective and Yield stress of the slurry of copper concentrate without flocculant against (Author's own elaboration, 2024)

It is observed that both stresses fit the Concha-Barrientos equation, with values of coefficients a = 216.074, b = 4.672 and r^2 = 0.988 for the effective stress and a = 0.760, b = 14.701 and r^2 = 0.972 for the yield stress.

3.4.4. THICKENER DESIGN

Using as design values, a feed of 2500 TPD, a feed volume fraction ϕ_F of 0.146, a discharge volume fraction ϕ_D of 0.239, an ore density of 4.77 g/cm^3, and a load factor λ of 0.90, the values obtained are as in Table 3.

The trend shown by the sedimentation unit area as a function of the flocculant dose, has an expected behavior for flocculant dosage from 0 to 14 g/TMS, in which a maximum value of designed unit area is shown without the addition of flocculant, which is obvious, in those conditions, the sedimentation will be of lower quality when compared to the sedimentation of a flocculated slurry; for higher dosage the sedimentation unit area values decrease until reaching a minimum value for 7 g/TMS, which increases with the higher addition of flocculant dosage up to a dose of 14 g/TMS, which shows an expected behavior, since in general the thickener design methods present a behavior of this type, with a minimum value and then increase. However, when the flocculant dose is increased to 20 g/TMS, there is a new decrease in the sedimentation unit area, which cancels the dose of 7 g/TMS as a minimum value. The explanation for this behavior is observed by comparing the trend of the parameter "*n*" of the Richardson and Zaki equation together with the sedimentation unit area with respect to the flocculant dose (see Fig. 11), which results exactly the same, so it is concluded that this parameter "n" has great influence on the values of sedimentation unit area. However, we propose to check this behavior with the Kynch and/or Yoshioka–Hassett design methods, and also using a pilot thickener. This information is complemented by a study carried out for tailings ore from this same mining company (Zambra and Olcay 2005), which showed that the behavior of both variables mentioned in Fig. 11 versus flocculant dosage was the same as that obtained in this study.

Table 3. Thickener design results using Adorjan's method

Design Parameters	Dosis de Floculante, g/TMS					
	0	4	7	10	14	20
Height, m	1.77	1.04	1.33	1.32	1.13	1.16
Diameter, m	23.9	16.5	15.3	16.0	18.3	12.3
A.U., m^2/TPD	0.180	0.086	0.074	0.081	0.105	0.048

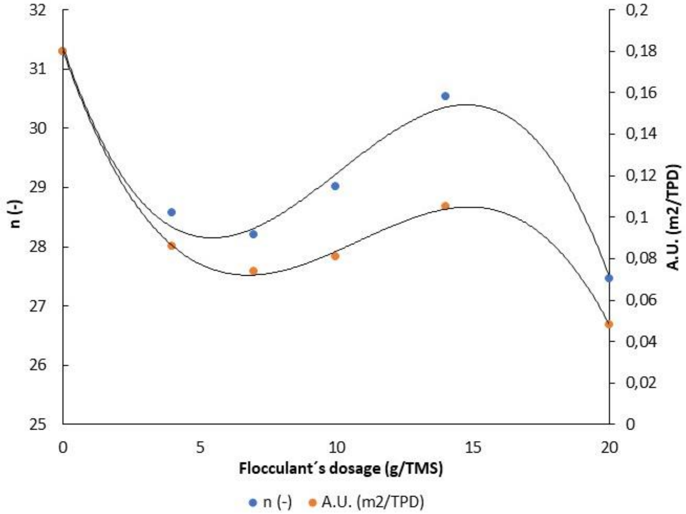

Fig. 11. Thickener unitary area design and parameter "*n*" against flocculant's rate (Author's own elaboration, 2022)

Figure 11 shows that the trend in both curves is the same and corresponds to a polynomial of order 3, where $y = -0.0055x^3 + 0.1683x^2 - 1.342x + 31.363$ and $r^2 = 0.985$ for the coefficient n and $y = -0.0001x^3 + 0.004x^2 - 0.0376x + 0.1801$ and $r^2 = 0.999$ for the unit area of sedimentation.

Concerning the trend shown by the design values of thickener height versus flocculant dosage, it shows a maximum height value necessary for a slurry without flocculant, which is expected because sedimentation occurs in the most adverse conditions studied; reaching a minimum value for a dose of 4 g/TMS and for dosage between 7 and 20 g/TMS the height varies between 15 and 30 cm (discounting the value of an additional meter mentioned in the description of the method), which are values that for equipment design purposes are slight differences that affect the decision to purchase
a thickener, so they can be considered negligible (see Fig. 12) (Quiero 1994; Zambra and Olcay 2005).

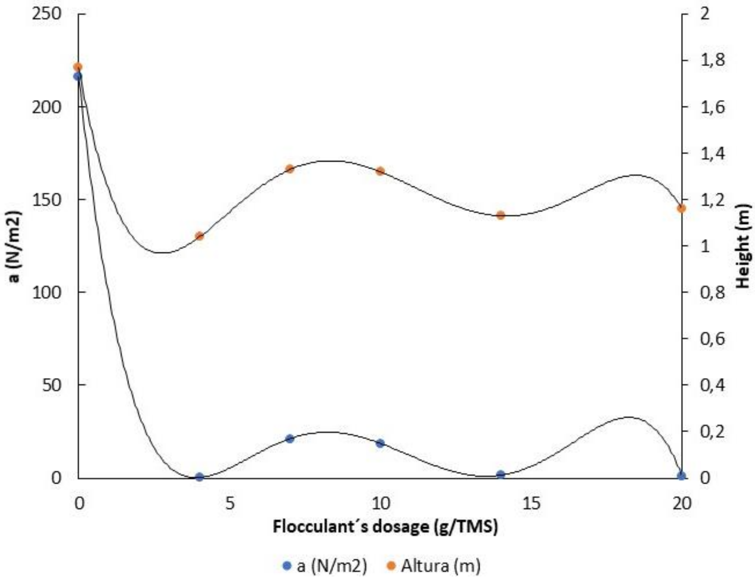

Fig. 12. Thickener height design values and parameter "*a*" of Concha-Barrientos equation against flocculant's rate (Author's own elaboration, 2022)

An analysis from the operational point of view, in which no flocculant is added to the thickener that treats the copper concentrate from flotation, shows that both the value of the diameter and the height of the thickener are those used in normal operation at the mine site, showing approximately 5% error in the simulations of the operation of such equipment. The values cannot be shown due to a lack of authorization from the mine site. However, this shows that the Adorjan Method is reliable in the reproducing the operating conditions of a thickener at a mine site.

Figure 12 shows that the trend in both curves is the same and corresponds to a polynomial of order 5, where $y = -2*10^{-5}x^5 + 0.0013x^4 - 0.0262x^3 + 0.2219x^2 - 0.7296x + 1.77$ and $r^2 = 1.0$ for the height and $y = -0.0039x^5 + 0.2139x^4 - 4.3107x^3 + 39.02x^2 - 153.75x + 216.07$ and $r^2 = 0.999$ for the coefficient a.

4. CONCLUSIONS

- The trend of the thickener unit area regarding the flocculant dose is evaluated by comparing the values of the sedimentation unit area to the parameter "*n*" of the Richardson and Zaki equation, both trends of polynomial type of degree 3, with a direct dependence of the thickener diameter with the mentioned parameter "*n*".
- Regarding the height of the thickener, it exhibits a similar tendency to the parameter "*a*" of the Concha and Barrientos equation, which is a polynomial of order 5, demonstrating a direct correlation between the height and the parameter "*a*". The optimal dose is 4 g/TMS.
- For this type of mineral, the effective stress of solids and yield stress have the same tendency, which is an exponential equation. There is a marked increase in the values of both stresses for volume fractions of 0.45, which is equivalent to a value of 79.60% of solids. This shows that the flow behavior of the mineral slurry has changed.
- For dosages higher than 4 g/TMS, we observed that the sedimentation rate remained constant.
- During the evaluation of the size segregation in the lower zone of the sediment, it was confirmed that there are no significant variations in flocculant dosage ranging from 0 to 8 g/TMS of sediment. Therefore, from an operational standpoint, it is not necessary to employ flocculant in the treatment of copper concentrates to enhance the operating conditions and prevent thickener clogging.

REFERENCES

ADORJAN L.A., 1976, *Determination of thickener dimension from sediment compression and permeability test results*, Trans. Inst. Min. Met., Sec C, 85, pp. 157–163.

ARENAS J.A., 2024, *Analysis of physicochemical and rheological properties affecting the sedimentation of mineral suspensions in cement industry thickeners*, Master Thesis in Engineering-Mineral Resources, Universidad Nacional de Colombia-Sede Medellin.

BAKER and HUGHES COMPANY, 2001, *Deep Paste Thickener System for Tailing Disposal*. III International Seminar of High Density and Paste Tailing, Pilanesberg, South Africa.

CONCHA F. and BARRIENTOS A., 1993, *A critical review of thickener design methods*, Kona, No. 11, pp. 79–104.

CONCHA F., 2001, *Manual de Filtración y Separación*, CETTEM, Universidad de Concepción, pp. 41–229, ISBN 956-291-042-3.

CONCHA F. and BURGER R., 2002, *A century of research in sedimentation and thickening*, Kona (20).

DSUY N. and BOGER D., 1983, *Yield Stress measurement for concentrated suspensions*, Journal of Rheology, Vol. 27, No. 4, pp. 321–349.

HERNANDEZ C.A., ARAUJO A., VALADAO G., and AMARANTE S., 2005, *Pasting Characteristics of Hematite/Quartz System*, Mineral Engineering, Vol. 18, pp. 935–939.

MICHAELS A.S. and BOLGER J., 1962, *Settling rates and sedimentation volumes flocculated kaolin suspensions*, Ind. Eng. Chem. Fund., 1 (1), pp. 24–33.

OLCAY R.E., 2005, *Calculation of the of the sedimentation and compression parameters of a C.M.D.I.C. copper concentrate slurry and design of a thickener for the treatment of this slurry using the Adorjan methods*, Degree Thesis of Civil Metallurgical Engineering, Universidad Arturo Prat, 191 pp.

QUIERO A.I., 1994, *Determination of the sedimentation and compression parameters on a industrial slurry, evaluation of the thickener design and analysis of a new type of thickener*, Degree Thesis of Civil Metallurgical Engineering, Universidad de Concepción, 203 pp.

QUIERO A.I., OLCAY R.E., and TORO N., 2022, *Comparative Study Between Different Mechanisms for Determining the Flocculant Dosage in the Sedimentation of Copper Concentrates*. Proceedings of Fifth International Conference on Inventive Material Science Applications, Advances in Sustainability Science and Technology, Ed. Springer, pp. 33–45, DOI: 10.1007/978-981-19-4304-1.

RICHARDSON J.F. and ZAKI W.N., 1997, *Sedimentation and fluidization*. Part. I, Chem. Eng. Res. Des., 75, pp. 82–100, DOI: 10.1016/S0263-8762(97)80006-8.

ROBINSKY E., 2002, *Planning for Thickened Tailing Disposal (TTD)*, High Density & Paste 2002 Seminar.

SAAVEDRA G., 2019, *Effect of solids concentration, pH and flocculant on yield stress of tailings produced in pellet plant*, Degree Thesis of Civil Metallurgical Engineering, Universidad de Concepción.

ZAMBRA R.M., 2005, *Thickener design for the Adorjan's methods and analysis of the sedimentation and compression parameters of a flocculated slurry*, Degree Thesis of Civil Metallurgical Engineering, Universidad Arturo Prat, 2005, 157 pp.