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THE ROLE OF ORE PROPERTIES IN THICKENING PROCESS

Majid UNESI[*], **Mohammad NOAPARAST**[**],
Seiyd Ziaedin SHAFAEI[**], **Esmaeil JORJANI**[*]

[*] Department of Mining Engineering, Science and Research branch, Islamic Azad University, Tehran, Iran
[**] University of Tehran, Tehran, Iran
[*] Corresponding author. E-mail address: noparast@ut.ac.ir

Abstract: The role of ore properties (density, particle size, and mineralogy) in thickening process was studied in this research. The shaking table was used to prepare the sample for the tests. The tailings were continuously fed on the table by gravity to separate the tailings in three products as slime, middling and coarse particles. The solid density and particle size of the samples were different. To study the effect of mineralogical properties, the sedimentation behavior of the feed and middling samples were tested. The results showed that the free settling velocity of the feed (2–6 mm/s) was less than that of the middling sample (18–23 mm/s), and the compressibility of middling (density: 0.63–0.86 Mg/m^3) was more than that of feed (density: 0.33–0.47 Mg/m^3). This was due to the amount of clay reduction in the middling sample. The sedimentation behavior of the slime and the coarse samples were also compared in order to study the effect of particle size and density. The settling velocity of the slime and the coarse particles was obtained as 0.1-0.4 and 26 mm/s, respectively, and the maximum underflow density were obtained as 0.35 and 1.57 Mg/m^3, respectively. Therefore, the particle size and density reduction reduced the thickener performance. In order to study the effect of particle size, the sedimentation behavior of the slime and coarse samples were compared, and it was obtained that the settling velocity and underflow density increased with the increasing in the particle size.

Keywords: *density, particle size, mineralogy, settling flux, underflow density, thickening*

Introduction

Mineral processing techniques are performed in environments which contain a significant amount of water, and in many cases, the most of water is removed with tailings. Therefore, it is necessary to use dewatering equipments such as thickeners in order to avoid environment contamination and water recycling (Burger et al. 1999).

There are many models and experiments which have been presented by researchers to understand the thickening process and to predict the relationship between process

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parameters. A sedimentation relationship was first proposed by Coe and Clevenger in 1916 which was not practical for flocculated suspensions. Kynch provided a breakthrough in suspension dewatering theory in 1952 which shows that the relationship between concentration and height can be used when the slurry is treated with a flocculating agent. Although the Kynch theory is not suitable for all mineral slurries, it is still used for thickener design calculations. Talmage and Fitch (1955) applied the mathematical approach of Kynch for thickener design and thereafter Yoshioka et al. (1957) obtained the thickener area by using a settling flux. Moreover, Oltmann (1975) suggested a simple empirical approach to the critical flux determination, and hence thickener area. The approximate depth of the thickened sludge layer was readily determined by the method outlined by Osborne in 1977, and the Wilhelm-Naide model (1981) used the underflow concentration to define the unit area which is still used for thickeners design. Also Dahlstrom and Fitch (1985) and Yalcin (1988) proposed a relationship between settling flux and unit area. A graphical method was presented by Kelly and Spottiswood (1989) to determine the settling flux (Buscall et al. 1987). Furthermore, several models have been developed to simulate dewatering behavior by chemical engineers (Bustos et al. 1999, Concha et al. 1996, Deventer et al. 2011). A 1-D model of dewatering was developed by Buscall and White (1987) which quantify the solids volume fraction, the compressive yield stress, and the hindered settling function (Garrido et al. 2003a). In addition, Landman and White (1994) used a phenomenon model which was a combination of empirical and theoretical models, and they described the solid flux function and effective solid stress. They also determined the forces acting on particles in the sedimentation and consolidation process (Garrido et al. 2003b). The BW theory, which was developed by Green (1997), properly modeled the comprehensive yield stress $P_y(\varphi)$ and hindered settling function $R(\varphi)$ in the suspension bed, but not sedimentation above the bed (Gladman et al. 2010). The Kynch theory, developed by Garrido et al. (2003), modeled the sedimentation-consolidation process (Green 1997). Garrido et al. (2003) developed a software for design and simulation of batch and continuous thickening. Thereafter, further studies were conducted by other researchers. An algorithm has been developed by Usher et al. (2005) to account for the underflow concentration and sediment bed from fundamental suspension properties (Landman et al. 1988). The suspension dewatering equations were proposed by Usher et al. (2009) based on the aggregate densification where by aggregate compact and become smaller when subjected to forces in thickening process. They presented the liquid flow velocity around and through aggregates (Lester et al. 2010). The validation of the Usher algorithm was studied by Gladman et al. (2010). They stated that this model was most accurate at the shortest residence times and lowest bed heights, and became poorer for longer residence time and higher beds. This was due to changes in dewatering properties of flocculated aggregates over time which is not adequately considered in the Usher algorithm. Lester et al. (2011) developed the 2-dimensional model of BW. They used the continuity, separation, and transport equations in the modeling. Since solving this model by computational methods was difficult, they used the CFD method for modeling (Mcfarlane et al. 2005). Van Deventer et al. (2011) developed the Kynch theory which based on aggregate densification behavior. Additionally, the aggregate densification theory was used to predict the final equilibrium bed height by densification rate and bed compression. Also, the relationship between aggregate size and thickening time was obtained (Usher and Scales 2005).

As mentioned above, the role of ore properties has not been studied by researchers, and most of them have focused on the effect of suspension properties in dewatering process. Therefore, the aim of this study was to study the influence of ore properties such as solid density, particle size, and mineralogy on the thickening process in order to better understand the dewatering behavior in these thickeners.

Materials and methods

The tailings obtained from the Sarcheshmeh copper flotation plants in Iran were used for all experiments. As the shaking table could separate the different particles based on their density and size, the tailings samples were initially continuously fed on the table by gravity to separate the tailings in three products as a slime “c”, middling “b”, and coarse “a”. The particle size analysis, XRD and mineralogical studies were carried out to understand the sample properties. The laboratory screens and cylosizer were used for particle size analysis, and the results are shown in Table 1 and Fig. 1. The five Warman cyclosizers were used to analysis the particle size less than 44 μm (i.e. +44, +33, +23, +15, +11, and –11 μm). This cyclosizer worked at 2130 N/m^2 pressure for 20 min. The solid density was determined by a pycnometer (100 cm^3) and the results are presented in Table 2 along with the XRD analysis shown in Fig. 2. The microscopic mineralogical analysis was carried out to find out the metallic minerals in the samples (Table 3). In order to study the effect of the ore properties on the thickening process, the experiments were carried out on the plant conditions. The samples were taken as a suspension from the shaking table and prepared by tailings waste water, hence the thickening behavior can only be attributed to the ore properties. The sample suspension density was measured by Marcy scale and prepared to required density based on experimental conditions. The pH of the sample was kept as 11 which was the pH in the plant.

A high molecular weight of anionic polyacrylamide (NF43U from SNF) was used to flocculate the suspension and prepared at 0.25 g/dm^3 which were the industrial dosage. A 500 cm^3 of cylinder was used to study the thickening behavior and a chronometer was used to record the mud lines at different times.

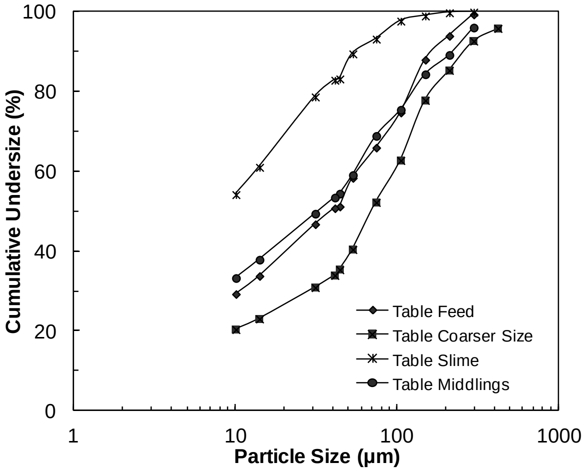

Fig. 1. Particle size distribution of feed, slime, middling, and coarse samples

Table 1. Particle size analysis of the samples

	Feed	Slime	Middling	Coarse
d_{80} (μm)	120	32	120	160
d_{75} (μm)	105	28	105	140
d_{50} (μm)	40	8.5	35	70
d_{25} (μm)	8	2	6	20

Table 2. XRD analysis and solid density of the samples

Minerals	Feed	Slime	Middling	Coarse
aluminum silicate (clinochlore, illite, chamosite, anorthite) (%)	75.6	84.2	43	–
quartz: SiO_2 (%)	22	15.6	53.6	15.6
pyrite: FeS_2 (%)	2.3	-	2.4	84.2
solid density (g/cm^3)	2.8	2.7	2.8	4.7

Table 3. Mineralogical analysis of the samples

Sample	Chalcopyrite	Pyrite	Sphalerite	Hematite	Non-metallic Minerals
Table Feed (%)	0.26	11.621	0	0.302	87.8
Table Slime (%)	0.087	12.244	0	0.392	87.243
Table Middling (%)	0.166	12.352	0.088	0.276	87.066
Table Coarser (%)	1.646	55.256	0.118	0.736	42.243

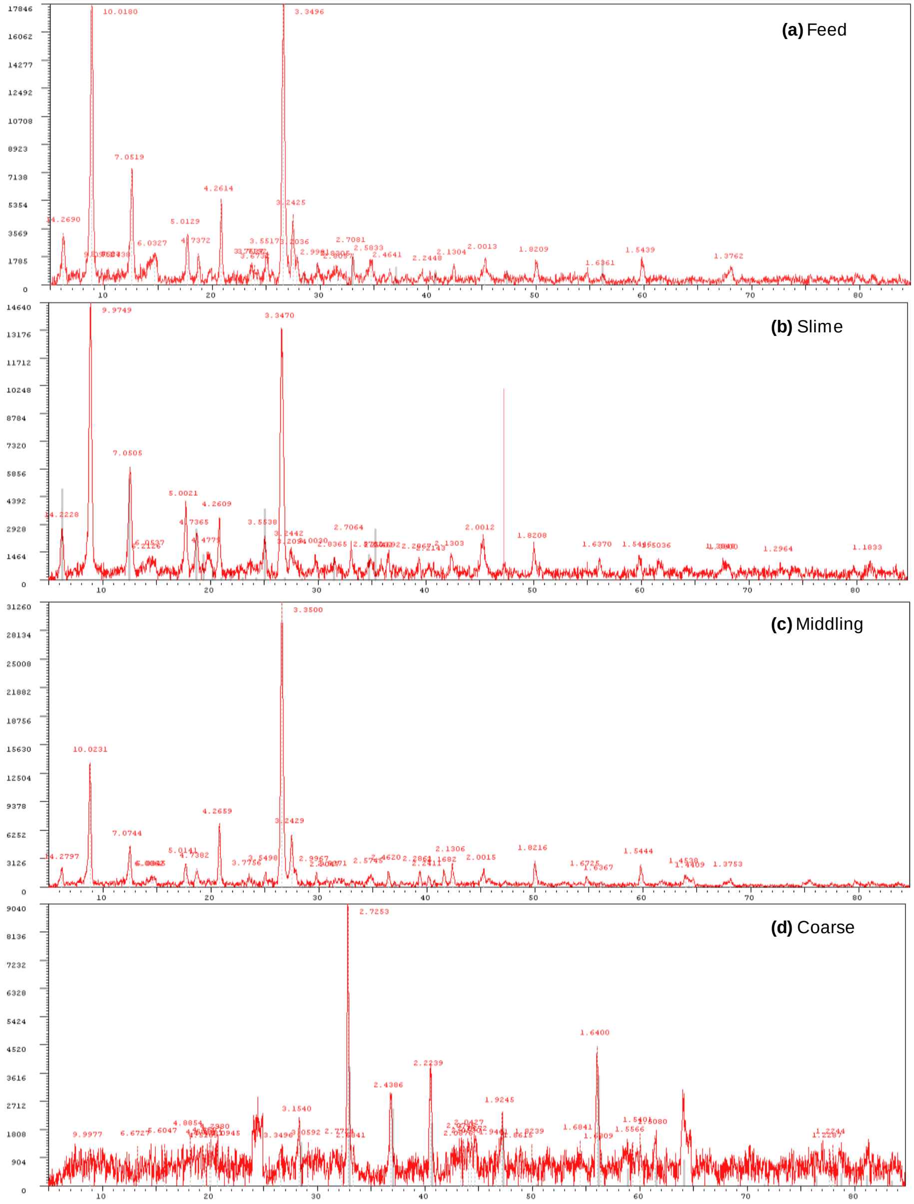

Fig. 2. XRD patterns of (a) feed (b) slime (c) middling (d) coarse samples

Results and discussions

Since the amount of flocculant consumption for the thickening process is usually between 20 and 40 g/Mg, the tests were carried out with a wider range of dosage between 15 and 60 g/Mg. The sedimentation curves for the samples are shown in Figs.

3 to 6. As presented in Tables 2 and 3, the most of the feed is composed of clay minerals and quartz, and the most amount of the slime is composed of clay minerals, but the content of clay minerals in the middle part of the shaking table is significantly lower than the content of them in the feed. In addition, clay minerals were not observed in the coarse sample, and much of them (about 55%) consist of pyrite. The sedimentation tests were performed on the feed and middling in order to investigate the tailings sedimentation behavior in mineralogical view because these two samples have the same solid density as 2.8 g/cm^3 and their d_{80} particle size are similar. In this study, the term "clay" is used as a mineralogical term, i.e. any of a diverse group of fine-grained minerals, not a size fraction.

The negative surface charge (OH^- in alkali solution), swelling characteristics, and small particle size of clay minerals negatively affect the settling behavior of the slimes fraction within the thickening. These factors also affect the rheology of the slurry as it influences the solids concentration and the manner in which the particles stack during settling. As can be seen in Figs. 3 and 5, at different amounts of flocculant, the free settling velocity for the feed sample (2 to 6 mm/s) is much less than that for the middle part sample (18 to 23 mm/s) and in the compaction zone, the compressibility for the middling sample (in concentration range of 0.63 to 0.86 Mg/m^3) is more than that for the feed sample (in concentration range of 0.33 to 0.47 Mg/m^3), which this stems from the reduction of clay content in the middling sample. Also, in Fig. 3, it is observed that by the increasing the flocculant dosage to 30 g/Mg, a good compressibility was obtained in the compaction zone. However, an excessive amount of the flocculant caused the reduction of bed compressibility for the feed sample, and accordingly the final height value in the settling curve increased to 64 mm (for 20 g/Mg) and 68 mm (for 60 g/Mg). The cotton-mode was formed in this zone due to the increasing in the size of the flocks, the networked water was remained inside of the flocks, and therefore the underflow concentration of paste thickeners was reduced. This case was not observed in the middling sample (Fig. 5), and with the increasing of the flocculant dosage, the compressibility increased as well as the free settling velocity and the value of the final height in the settling curve decreased from 43 mm (for 20 g/Mg) to 33 mm (for 60 g/Mg), which could be caused by the interactions between coarse and fine particles in the feed sample, and interaction between the coarse particles in the middling sample.

The packing of the particles on top of each other during settling influences rheology and density of the thickened underflow. The most familiar packing types are referred to as “edge-face” also referred to as “houses of cards” and “face-face” also known as a “band structure” packing relationship (McFarlane et al. 2005). Clays typically stacks into honeycomb structure. The honeycomb packing retains large amounts of water which fills the voids formed by this type of arrangement.

Great effort and highly effective dewatering systems are required to remove the interstitial water therefore the thickener performance will decrease by increasing the clay content in the ore. Since the coarse and high density particles have higher settling velocity than ones that were fine and lower density, thus they could be divided into two parts in view of settling behavior. Solid density of coarse particles (a) and fine particles (c) were 2.7 and 4.7 g/cm^3, respectively, and this difference at the density values was caused by the existence of clay minerals (aluminosilicates) in part (c) and metallic minerals (such as chalcopyrite and pyrite) in part (a). Since there was much difference between them in terms of size and density, there was also much difference between their settling velocities (Fig. 7).

There is a direct relation between the solid density and amount of metallic minerals. Therefore, the effect of metallic minerals in the settling behavior is defined as higher solid density. In addition, the surface charge on the particles (as mineralogical effects) plays an important role in the flocculation performance. This effect is not significant for the metallic minerals because the higher solid density is much more effective than the surface charge. Therefore, the metallic minerals (as ore properties) are more significant in the settling behavior than the flocculant dosage (operating parameter) because the changes in the flocculant dosage showed no significant effect on the thickening behavior of the sample part (a). In the case of this sample, the little amount of flocculant is needed to improve the clarity of the thickener overflow. It was postulated that the dominant minerals (such as clay and metallic minerals) in the samples would cause affecting the thickener performance. Additionally, part (c) and feed can be compared in a view of the particle size. Although their density was close together, they had different particle size distribution. The effect of this particle size differences was visible in their settling velocities. The smaller size would cause the lower settling velocity, hence that settling velocity for the slime sample was obtained between 0.1 and 0.4 mm/s but that was achieved between 2 and 6 mm/s for the feed (Fig. 7).

Meanwhile, the bed compressibility, which was one of the basic parameters in thickeners, was studied for these two samples. As can be seen in Figs. 4 and 6, the final height for sample (a) was about 19 mm, and for sample (c) was about 85 mm. In other words, the compressibility for sample (a) was very high and for sample (c) was very low, which is due to the parameters such as particle size, density, and mineralogy. With the increasing in the flocculant dosage, the compressibility in part (c) increased (Fig.4) and the final height increased from 92 mm (for flocculant dosage of 15 g/Mg) to 85 mm (for flocculant dosage of 60 g/Mg). The significant increase in the compressibility was observed with the increasing in the flocculant concentration from 15 g/Mg to 35 g/Mg, and from 40 g/Mg to 60 g/Mg. This change was also visible in the free settling zone, and there was no significant effect on the settling velocity, and the compressibility by the increasing in the amount of 5 g/Mg flocculant. The behavior of cotton accumulation of flocks (which was shown in Fig. 3 for feed) was considered minimal in this sample. The increasing in the flocculant dosage showed no effect on its compressibility for the sample part (a) because a high density and large particle sizes of this sample led to little need for the flocculant (Fig. 6).

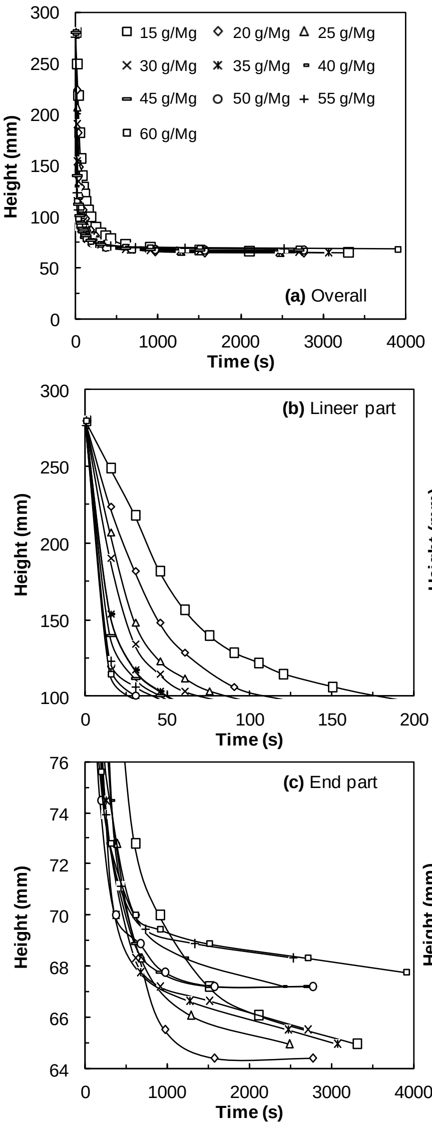

Fig. 3. Feed sedimentation curves
(a) overall (b) linear part (c) end part

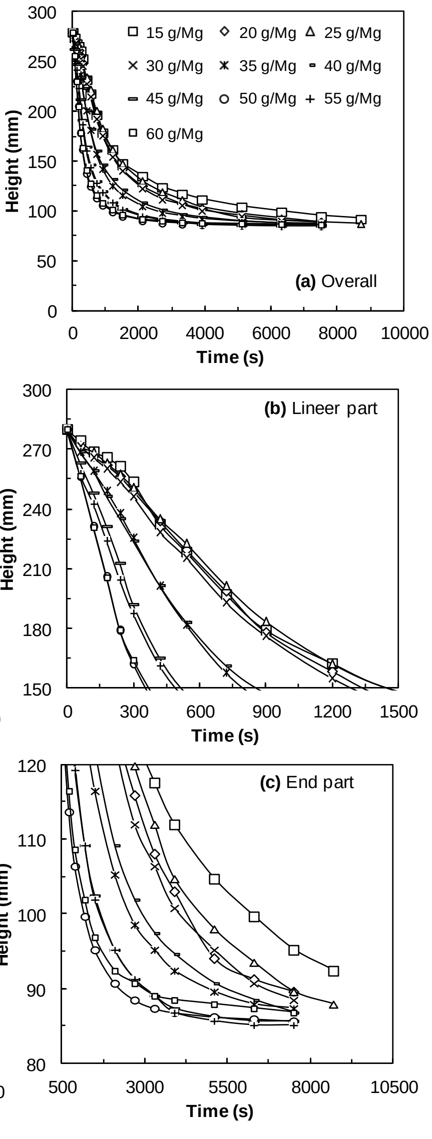

Fig. 4. Slime sedimentation curves
(a) overall (b) linear part (c) end part

Comparing Figs. 3 to 6 indicated that the cotton-mode in the compaction zone, observed only in the feed, can be removed by using this classification because this causes water trapping among the flocks and reduction of underflow concentration in the thickeners and reduces water recovery. Furthermore, with the separation of coarse and high density particles, the consumption of the flocculant for this fraction can be reduced or eliminated.

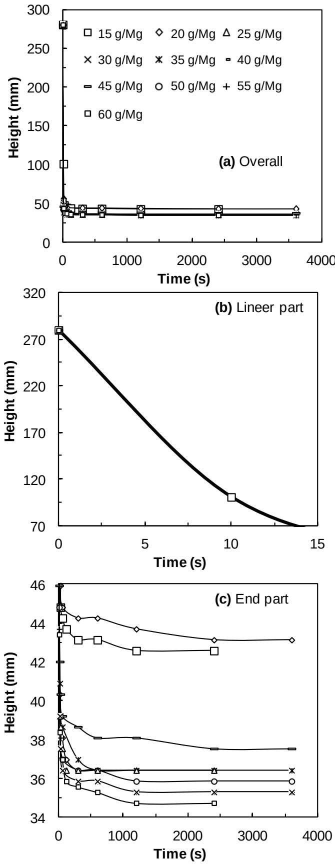

Fig. 5.Middling sedimentation curves (a) overall (b) linear part (c) end part

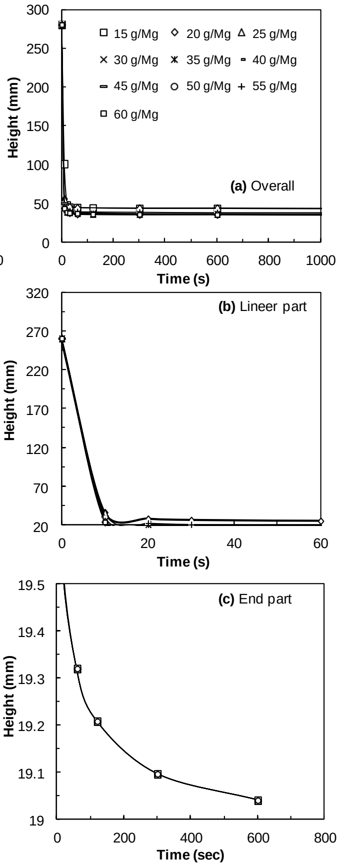

Fig. 6. Coarse sample sedimentation curves (a) overall (b) linear part (c) end part

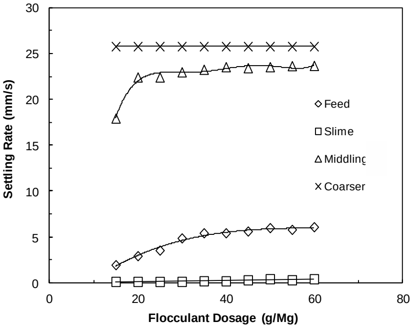

Fig. 7. Free settling curves of the samples

The Wilhelm-Naide model was used in order to compare the settling flux, and the results were shown in Fig. 8. As seen from Fig. 8, the maximum settling flux for the coarse, middling, feed and fine particles were obtained as 120, 55, 9, and 0.25

Mg/m^2/h, respectively. Also, the maximum concentrations in the underflow were obtained as 1.57, 0.87, 0.45, and 0.35 Mg/m^3, respectively. In other words, the maximum settling flux and concentration in underflow zone for the coarse and the middling parts were more than these amounts in the feed, and for the slime part were less than these amounts in the feed. This is due to changes in the ore properties which were illustrated before. The increasing in the flocculant consumption showed no effect on the settling flux for the coarse particle; it was due to the high density and coarse size of metallic minerals in this part. As can be shown from Fig. 8, the initial flux values of the slime sample changed due to the changes in the settling rate. It means that the flocculant cannot prevail on the initial turbulence which was created because of the low settling velocity of the slimes. Also, this behavior was observed in the feed sample with a low concentration of flocculant (15 g/Mg). Therefore, the minimum amount of required flocculant can be obtained by studying the competition between initial turbulence and settling velocity which can be achieved in the settling flux curve.

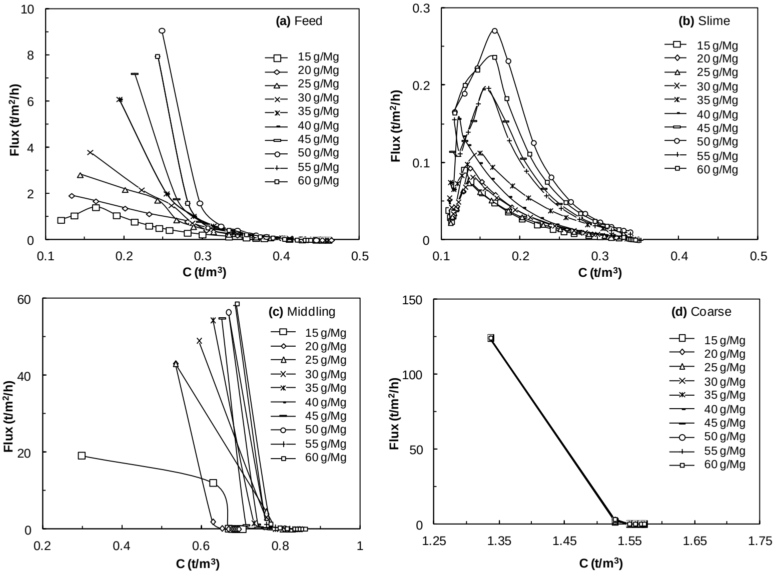

Fig. 8. The settling flux in different underflow density
(a) feed (b) slime (c) middling (d) coarse samples

According to the measurements and calculations, the weight of solid in the slime, middling, and coarse particle size parts were 46%, 50%, and 4% of the feed, respectively. Thus, half of the feed was transferred to the middling part but it could be understood from Figs. 7 and 8 that a major and effective factor in particles settling was the amount of slime in the feed.

Conclusions

The role of ore properties (density, particle size, mineralogy) in thickening process (settling velocity, bed compressibility, settling flux) were studied in this work using a Sarcheshmeh tailing sample. Initially a shaking table was employed and sample was applied to achieve three different slime, middling, and coarse products. As a result, the free settling velocity of feed (2–6 mm/s) was less than middling sample (18–23 mm/s), and the compressibility of middling (density: 0.63–0.86 Mg/m^3) was more than feed sample (density: 0.33–0.47 Mg/m^3). This was due to the amount of clay reduction in middling sample. Also, it was observed that an excessive amount of flocculant caused reduction of bed compressibility for the feed sample, and the final height value in the settling curve increased to 64 mm (for 20 g/Mg) and 68mm (for 60 g/Mg). The cotton-mode was formed in this zone due to the increasing in the size of the flocks, hence the networked water was remained inside of the flocks, and hence the underflow concentration of the paste thickeners reduced. Therefore, it caused remaining the networked water inside of the flocks and the underflow concentration of the paste thickeners would decrease. This case was not observed for the middling sample, and the compressibility increased with the increasing of flocculant dosage as well as free settling velocity. The value of the final height in the settling curve decreased from 43 mm (for 20 g/Mg) to 33mm (for 60 g/Mg), which could be caused by the interactions between coarse and fine particles in the feed sample, and interaction between the coarse particles in the middling sample.

Also, it was concluded that the clay minerals (aluminosilicates) and metallic minerals (pyrite, chalcopyrite) caused to reduce and to increase the settling velocity, settling flux, and underflow density, respectively, hence the settling velocity of the slime and the coarse particles were obtained as 0.1–0.4 and 26 mm/s, respectively. The maximum flux of the slime and the coarse particles were obtained as 0.25 and 120 $Mg/m^2/h$, respectively, and the maximum underflow density of slime and coarse particles were obtained 0.35 and 1.57 Mg/m^3. Therefore, the lower particle size and density would reduce the thickener performance. The cotton-mode in the compaction zone, which was observed only for the feed, could be removed by using this classification. Furthermore, with the separation of coarse and high density particles, the consumption of the flocculant for this fraction would be reduced or eliminated. In addition, the effective and major parameter in the sedimentation was the clay content of the feed.

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