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Increasing efficiency of thickener operation in concentrate plant of iron ore mine using coagulation-flocculation

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Original Article

Abstract

Thickener is a main and fundamental step in modern mining separation processes. In this research, the effect of flocculant consumption rate and feed solid concentration of settling rate of layers was studied with different concentrations in iron ore mine of Jalalabad, Zarand, Kerman, Iran. The experiments were performed in two 1000 ml graduated cylinders (61 and 62 mm diagonal and heights of 339 and 349 mm) while the average of feed solid concentration was 12 percent. Additional tests were performed with feed solid concentration of 8, 10, 12, 14, and 16 percent solid weight and dosage rate of flocculant was 10, 14, 18, 22, and 26 g/t respectively. Results depicted that with increasing the flocculant dosage to 22 g/ton, settling rate increased from 0.3 to 0.9 cm/s reaching maximum, and with increasing from 22 to 26 g/ton, settling rate was decrease slowly and reached from 0.9 to 0.7 cm/s.

KEYWORDS: Settling Rate, Thickener, Tailings, Coagulation-Flocculation

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Introduction

Iron ore mine of Jalalabad-Zarand is one of the great reservations in Iran, located in Kerman province and situated 35 kilometers northwest of Zarand. According to mine design, 136 million tons of iron ore with the average grade of 40% with harvesting 450 million ton of waste (tailing) is obtainable. Thickeners are one of the most important tools for recovering the water utilized in comminution and flotation processes. Water is a scarce resource in the main part of the Kerman. Therefore, recovery of most of the water after the sedimentation process creates great interest in design and control of the operation of continuous sedimentation in thickener unit.[1]

Most of methods used in mineral concentration are wet methods, i.e. 80 to 90 percent of minerals are processed using water. In general, 2 to 3 tons of water is consumed to produce one ton of ore. Therefore, the concentrate minerals and their waste contain a lot of water. Water in concentrate should be reduced to the extent to be handled easier and be ready for the next process. When the density variations between liquid and solid are high, settling methods are most efficient in comparison with other methods. Gravitational settling method is one of the most widely used methods in mineral processing in the world. High capacity and low relative cost are favorable features of this method. Hence, it can be conducted to recover thickener water. Conventional thickener, high capacity, high density, cone-depth, multi-part and lamella are examples of thickeners being used.[2-4]

Improvements in thickener process performance typically include efforts directed at improving the feed system, from upstream of the thickener through to the feedwell. How far this upstream takes place will depend on the plant itself, taking into account the effect

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of feed properties, combined streams and elevation changes. Any components not optimized will affect the efficiency of the settling in the thickener and therefore its capacity and performance. However, one of the main ways to create high efficiency thickener to increase settling rate of solid particles is flocculation. In recent years, extensive research has been carried out on the utilization of flocculant in isolated operations such as liquid wax paper industry, mineral industry, industrial water treatment and purification processes.[5] Industrial water usually contains many impurities in the form of dissolved and suspended particles. The suspended particles are different in size, composition, charge, shape, density, etc. There are some methods to purify surface water from these types of impurities, like coagulation and flocculation processes, filtration, disinfection and so on. These methods are used for the separation of suspended solid particles from the water.

Tailings are the waste minerals slurry produced from mineral processing operations for valuable minerals. More than 10 billion tons of tailings are estimated to be produced globally in the mineral processing industry every year.[6] The tailing stream is significantly larger than the mineral concentration stream and contains more than 90 wt.% recyclable water. The modern continuous gravity thickener normally consists of a cylindrical tank with a top-drive rotating rake. Conventional gravity thickeners generally produce underflow solids ranging from 40 to 55 wt.% for clay-rich tailings due to a significant amount of water being trapped between and within the aggregates.

Flocculant polymers were commonly added and mixed with the mineral tailings in the thickener to bridge or bind dispersed small particles into larger aggregates. After the flocculation process, the flocculated aggregates are settled at the bottom section of the gravity thickener. The rake was thought to primarily assist transportation of the sediment out of the gravity thickener.[7-10] Kim et al. showed that higher agitation intensities during flocculation resulted in lower bed densities through measurements of the steady-state bed density profile. They suggested that the rake action, not bed compression, dominated dewatering.[11]

Particles sedimentation ratio of thickener depended to physical chemistry parameters such as the particles size, distribution of solids percentage, pH content, ionic strength of the solution and molecular weight.[12-14]

Chen et al. studied the influence of coagulants on the sedimentation rate.[5] Besra et al. studied the effect of coagulant attractions on the sedimentation rate in the aqueous solution of kaolin that performed on polyvinyl alcohol, polyethylene amine as a coagulant to rate up the settling of suspended solids.[2] In addition, anionic and cationic polyacryl with a molecular weight range of 7-15 × 10^6 g/mol was used widely for the deposition of inorganic particles in the thickener. In this study, the effect of different concentrations of polyacrylamide coagulant was studied on pulp sedimentation rate and other constant parameters. Optimum concentration of coagulant was obtained, which can be used as a basis for designing industrial thickener.[10,15,16] Nowadays, flocculant is referred to a water-soluble polymer with high molecular weight from polyacrylamide.[16,17] In this study, the effect of different concentrations of polyacrylamide coagulant was studied on pulp sedimentation rate and other constant parameters. Optimum concentration of coagulant was obtained, which can be used as a basis for designing industrial thickener.

Coagulation and flocculation are often necessary steps in dehydration, particularly for pulp with very fine particles (less than 5 microns). In most of the systems, flocculation efficiency determines performance of dewatering drainage system efficiency. Flocculation efficiency is not limited to the chemical dosage but it depends on how to use the chemicals.

The whole process consists of three main steps:

(1) Destabilizing suspended particles: removing any repulsion among particles due to electric charges

(2) Flocs formation and their growth: the floc development through particle-particle, particle-floc, and floc-floc collisions

(3) Destruction of flocs: destruction of floc due to shear and mixing the pulp

Most of the particles in the slurry are created with surface charge accumulation and floc resistance. Electrical charge can increase with decomposed species or active membranes adsorbed on the surfaces of the particles. Instability of these particles can be achieved by eliminating the time and cover charge. For this purpose, there could be more toxic ions and other chemicals such as lime and aluminum sulfate.

Polyelectrolyte polymer materials are highly effective especially for unstable slurry of fine particles. Polymers with high molecular weights (molecular weight greater than 10^6) are usually not suitable for destabilizing. They can play an important role in the development of flocs, so they are often used as flocculant.[15] A summary of desirable characteristics for specific applications of flocs is illustrated in table 1.

Various factors such as mixing rate, sedimentation velocity, the volume of material settled, the rate of filtration, and the distribution of flocs are used to assess the performance (velocity and grade).[18]

In general, the characteristics of the flocculation factors can be divided into four categories, as follows:

(1) The nature of the solid material (surface chemistry, particle size, size distribution, shape, density, etc.)

(2) The nature of the fluid (viscosity, dielectric constant, etc.)

(3) The nature of the slurry (solids surface charge, pH, ionic strength, temperature, etc.)

(4) Flocculant nature (flocculant main chemical nature of the side chains, molecular weight, molecular weight distribution, surface load, load density, etc.) However, it is not always possible toproduce floc even when we control all main factors.[12] Flocculation is harmful for long time mixing without addition of polyacrylamide which can be due irreversible forms of flocs. As a result, a floc in a constant concentration produces additive peak with increasing blending time and then reduces it from peak point.

Network model

Another mechanism presenting the flocculation is network model (Figure 1). Polymers such as polyethylene oxide consist of a network of polymer chains cross-ring form. Polymer chains can bind ions or polymers through electrostatic interactions or hydrogen bonds. There is still not much information about the structure of flocs that formed with this mechanism. However, this information can be applied as a basis for designing industrial thickener.

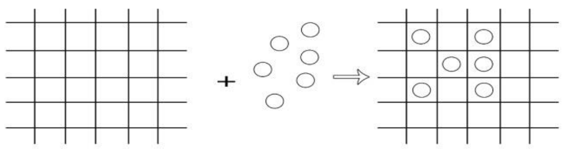

Figure 1. Schematic picture of a network flocculation mechanism[10]

Materials and Methods

For determining the best dosage of flocculant, several experiments were carried out by settling solids feed to thickener (8, 12, 14, and 16%) and flocculant 10, 14, 18, 22, and 26 mg/ton. First, single-factor method was used in order to prove that the first dose was

Table 1 Characteristics of flocs used in various applications[14]

Application	considered Flocculation characteristics
Filtration	Strong, porous, permeable
Sedimentation	Strong, high density, large, regular shapes (usually spherical)
Centrifuge	Strong, high density, large
Flocculation	Low density, strong, the limited size distribution

considered suitable for best solids (18 ppm). After determining the optimal dose of flocculant, flocculant types were investigated.

The final sample was taken for the plant's current tailings (for an hour and with 15 min time gap). The samples were used to measure the density of solids, which were transferred to the laboratory. In the laboratory, the samples were measured using a weighed digital scale. After pulp density measurement, the samples were filtered and then dried to obtain solid weight. Solid percentage can be calculated using density and solid weight of pulp. Samples were collected in form of a homogeneous mixture in several days.

Settling tests were performed in graduated 1000 ml cylinders with diameters of 61 mm and 62 mm and height of 339 mm and 349 mm. For this purpose, the pulps were prepared based on the described method; thickener were transported to the laboratory in order to feed solids and the solid-density quantified. Based on the average size of the solid content (12%), the coagulant was added into the cylinder that contained water.

In settling tests, flocculant solution was provided with a concentration of 1 g/l in one hour. Based on the ISO 10.86, flocculant was just used in 24 hours and after this time new flocculant was prepared.[16] Before addition of flocculant to the cylinder, the cylinder contents were mixed so that pulp were completely become homogeneous. Coagulant solution was added to the pulp and then the cylinder was gently inverted five times to mix the pulp and solution disruption. On the other hand, inversion of excessive floc structure eliminates the adverse effects of settling velocity, and the liquid can be clear. According to the most scholars' belief, the best results will include five returning cylinder.

Results and Discussion

Determining the optimal solids inlet into thickener

Variations of thickener solids feed in a period of three months after the sampling showed that the solids feed concentration was between 8 and 17 percent. Settling velocity of the particles was directly related to the solids feed.[15] The sharp fluctuation in the performance of thickener was due to the large variations of solids feed. Therefore, it is necessary to improve the efficiency of thickener that minimizes the volatility of the feed solids. To determine to optimization of flocculant dosage and solid percent, tests were performed with feed solid concentrations of 8, 10, 12, 14, and 16 percent solid weight and rate of dosage of flocculant was 10, 14, 18, 22, and 26 g/t, respectively.

It has been known that the size and structure of the flocs depend on the concentration of solids at which they are formed. At high solids concentration (above 10% solids volume fraction), flocs form a wide network structure which in turn decreases settling velocity.[18]

As it was indicated in the above charts, the amount of solids settling rate was the highest by 8%. By reducing the feed solids, particles went apart and settling happened more quickly, that is why 8% of feed solids were quickly settled into their allocation (Figure 2a, f).

Consumption rate of flocculant

Consumption rate of coagulant on the base of primary design of plant was 18 ppm. So, the variations in the amount of k80 particles were expected with increase or decrease in the amount of flocculant, and increase in particle settling rate. The gradation curve is presented in figure 3, k80 equals to 71 microns.

Agglomeration of solid particles occurred using flocculant and sticking of solid particles to long-chain molecules. Flocculant acts as a bridge among the solid particles. Agglomeration degree increases with increasing flocculant amount in pulp and also excessive flocculant can break down long molecules. To obtain the best rate of flocculant consumption in kind of A26, it was added from 10 g/ton until adding flocculant reduced the settling rate. As it is indicated in figures 4a and 4f, the best flocculant value is 22 ppm.

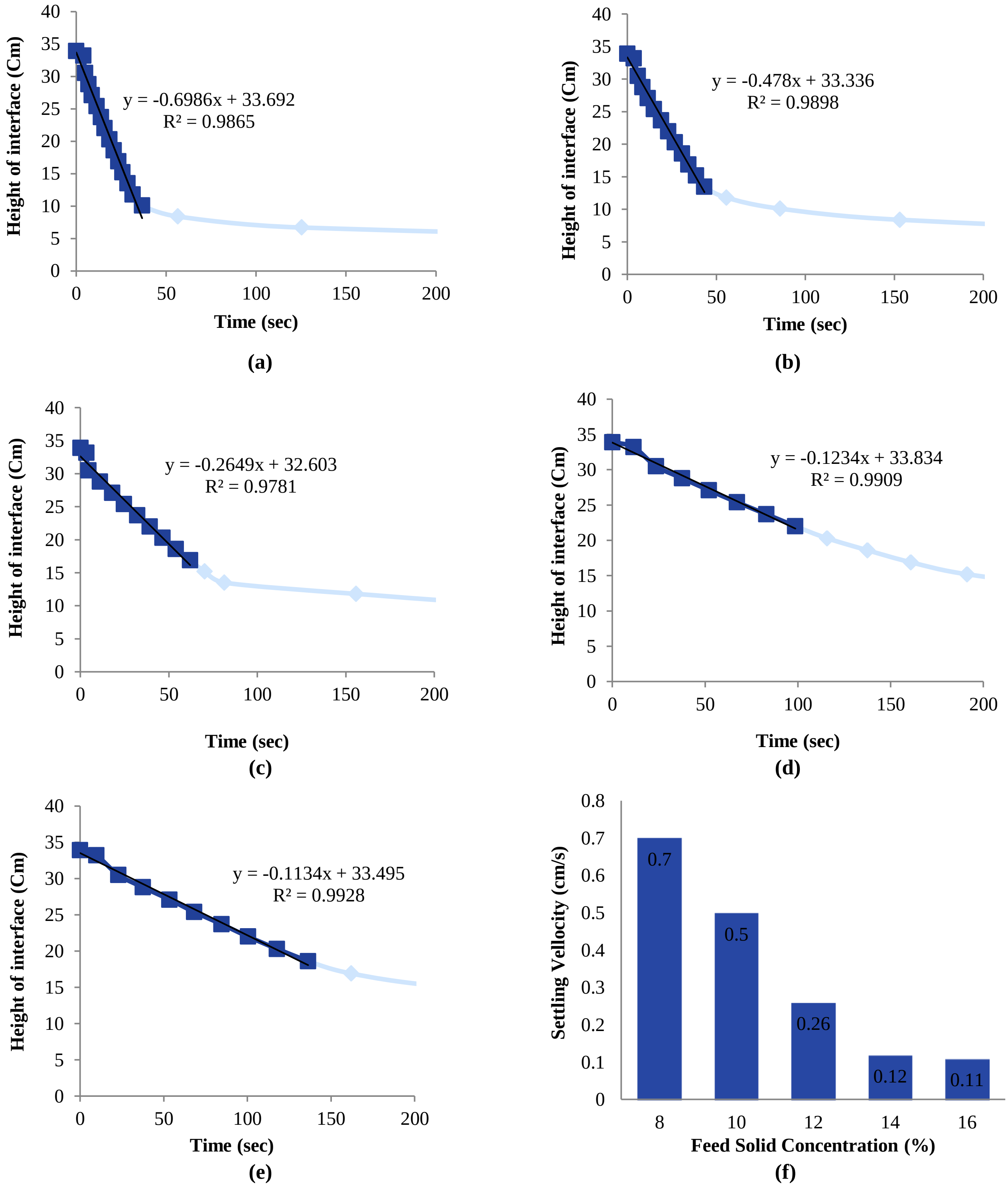

Figure 2. The variation of the height of the goal and the settling rate of pulp solids in flocculant content (a to f)

(a). The variation of the height of the goal and settling rate of 8% pulp solids in content of 18 ppm flocculant; (b). The variation of the height of the goal and the settling rate of 10% pulp solids in content of 18 ppm flocculant; (c). The variation of the height of the goal and settling rate of 12% pulp solids in content of 18 ppm flocculant; (d). The variation of the height of the goal and the settling rate of 14% pulp solids in content of 18 ppm flocculant; (e). The variation of the height of the flowers and the settling rate of 14% pulp solids in content of 18 ppm flocculant; (f). Influence of the flocculant A26 (22 grams per ton) of pulp solids with settling rate of 8%

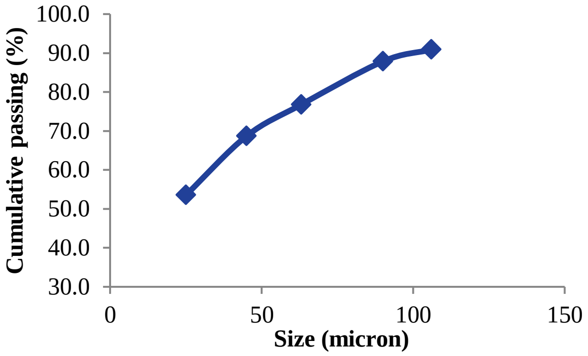

Figure 3. Influence of the flocculant A26 (22 grams per ton) of pulp solids settling rate of 8%

The pulp of low-density, detached thrombus deposition, and settling rate can be higher. But at higher pulp density, blood flocs may form a lattice structure which has a low settling rate.[10] Meanwhile, flocculant concentration influences the rate of overflow water clarity. Water clarity in the sample was prepared with the higher flocculant dose.[16]

From practical aspects, it is possible to achieve the maximum thickener performance using selection of the optimum amount of the flocculant dosage and feed flow rate in mineral processing plants.[19]

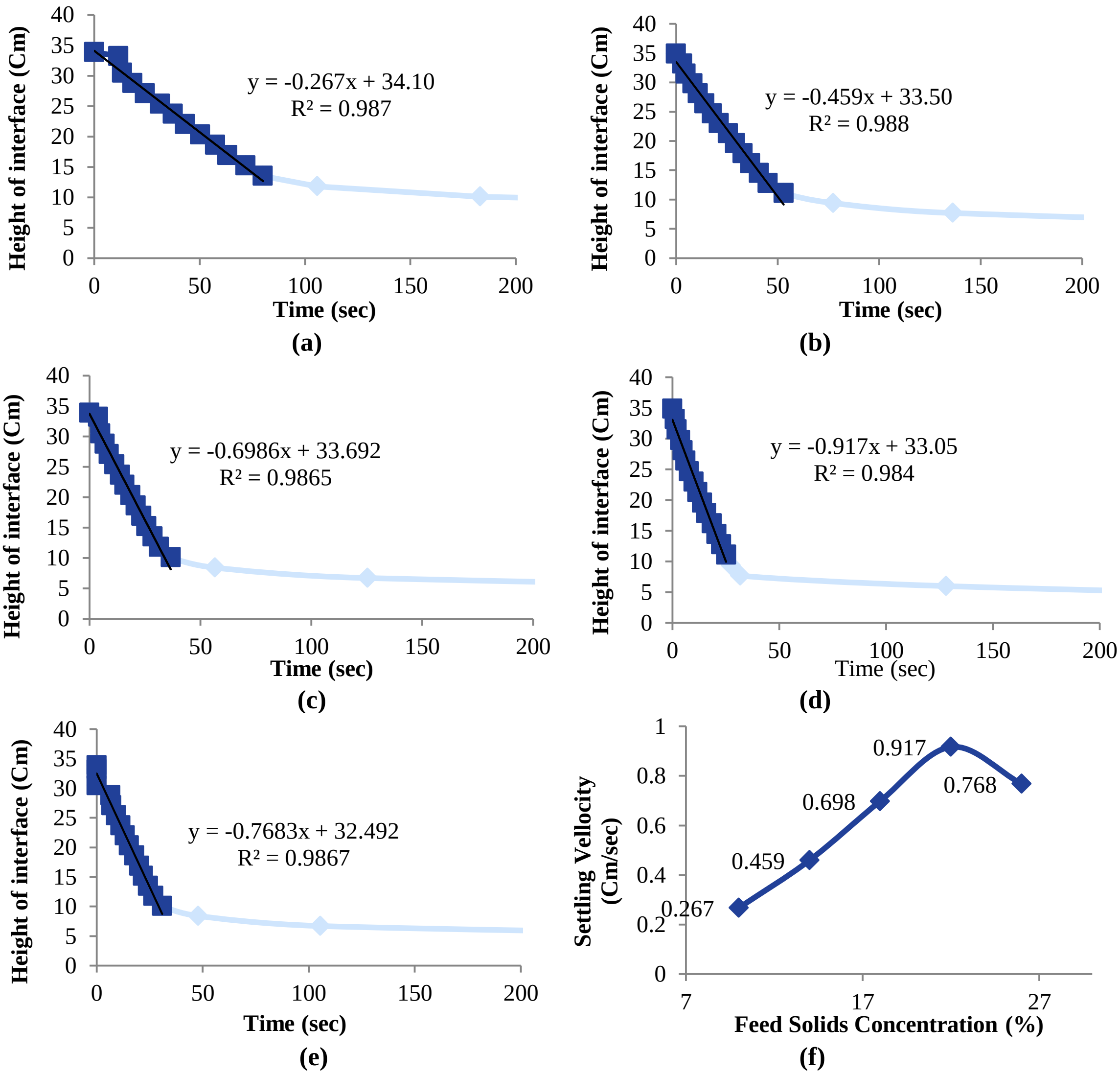

Figure 4. The variation of the height of goal and the settling rate of pulp solids in content Flocculant (a to f)
(a). The variation of the height of the goal and settling rate of 8% pulp solids in content of 10 ppm flocculant; (b). The variation of the height of the goal and settling rate of 8% pulp solids in content of 14 ppm flocculant; (c). The variation of the height of the goal and the settling rate of 8% pulp solids in content of 18 ppm flocculant; (d). The variation of the height of the goal and settling rate of 8% pulp solids in content of 22 ppm flocculant; (e). The variation of the height of the goal and the settling rate of 8% pulp solids in content of 26 ppm flocculant; (f). Influence of the flocculant A26 (22 grams per ton) of pulp solids settling rate of 8%

Initial solids feed pulp has an important impact on the final solids. The reason seems to be a different force in precipitation that varies by size. To investigate the effect of solids on the deposition rate, the percent solids samples that were made in different laboratories using different doses of flocculant, A26, and the deposition rates were compared with each other (Figure 5).

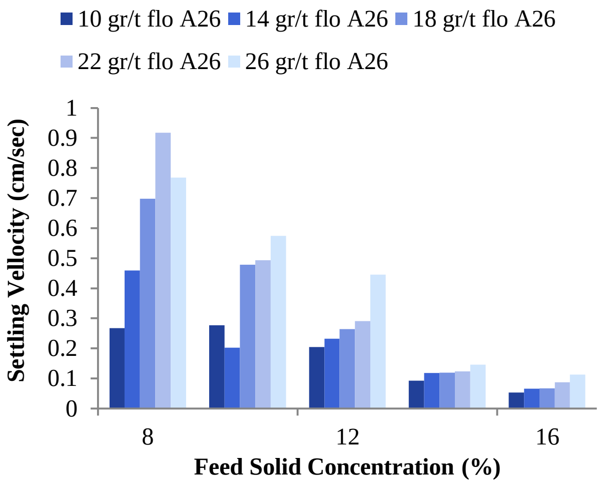

Figure 5. Variation in percentage of solids deposition rate of feed at different levels of flocculant

It can also display the highest rates of deposition of solids on the bottom of the feeding well. It can be due to low influence of flocculants in solid particles. The percentage of solids in the bottom of the deposition conditions is better than others.

The trial evaluated the spillway, water transparency where 26 (gr/t) is less than flocculants with lower dose. The reason seems to be larger clots resulting in deposition rate over the clots, that is a sufficient time to absorb tiny particles suspended in the sector which is not transparent. However, the lower doses used in sample due to clots are formed by a deposition rate of suspended particulate matter. Therefore, sufficient time to collect the water comes more transparent.[15]

Effect of flocculants

Flocculants molecular structure impact on the pulp and adding them can cause a chain flocculants with long molecules. It is not important where the greatest confusion is focused. Because its structure is fragile and may be in the area of discrete time and which may cause losing their effectiveness. Overall, flocculants must quickly be mixed with the pulp because it is a surface phenomenon.[17] Solids weight for testing discontinuous deposition was 8%, 84.39 mg, respectively. Precipitation speeds with the samples A26 and Praestol 2540 TR A26 were 0.9176 and 0.5695 cm/s, respectively. The results of the flocculants are presented in figures 6.

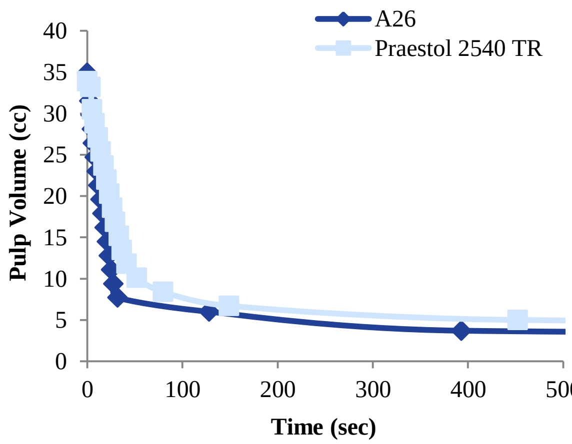

Figure 6. Settling rate of Praestol 2540 and TR A26

Resulted solids were poured in 1000 ml of water with hot flocculants mixer or hand-held devices (for an hour) and then certain amount of flocculants were added for preparation in each experiment. Graduated cylinder after 5 reverse orders was placed on a flat surface due to the low density. The height of the interface is transparent to pulp (flower bottom line is for every 50 ml) that was record settling time. The main characteristic of these curves is that each of them begins with a straight line, then it becomes a curve parallel to the time axis. Tangent drawn at any point on the curves, which present the rate of the solid-liquid, interfaces deposition of solids in the vicinity of the yielded point. Thus, high and uniform deposition rate initially becomes less and less frequently in next steps. Reduction of deposition rates is due to the changes in the deposition conditions that occur over time. In these experiments, the transition of deposition zone occurs at the point that precipitation pulp density is reached about 50 in final concentration. It is also a change from straight line curve in each graph that represents the deposition.[16] Effect of the deposition rate was assessed for two exemplary flocculants which included flocculants such as the A26 (a model that currently in Zarand Iranian steel industry is concentrated) and Praestol 2540 TR (sample is used in concentrate factory of Choghart Bafg Yazd). In accordance to the presented curves and tables, flocculant A26 rate was at the highest deposition.

Conclusion

In this study, we illustrated flocculant A26 as the solid-liquid separation process that was the favorable clotting. High rate of the feed solids settling was seen at the lowest percentage. The feed that is diluted to a solid flocculant have better impact on the performance of thickener. Therefore, feed dilution water can be recovered from thickener. Thickener feed solids concentration of 8% is appropriate. Feed ratio at 8% solids increased flocculant to 22 ppm in settling rate. In all experiments, the transition from the individual to the regional deposition occurred where the final concentration was about 50% of the pulp level. Meanwhile, flocculant concentration influenced on the rate of overflow water clarity. Water clarity in the sample was prepared with the higher flocculant dose. In some cases, where lower doses were utilized, the flocs were formed as a result of low settling rate of suspended particle.

Conflict of Interests

Authors have no conflict of interests.

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