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ORIGINAL ARTICLE

Introduction of Equivalent shape factors for investigating settling Velocity in thickeners

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ABSTRACT
In this research roles of effective parameters on settling velocity within thickeners were studied with introducing equivalent shape factor. Several samples of thickener feed including copper, lead& zinc and coal were prepared with different densities. Settling tests were carried out on the samples and settling curves were plotted. Utilizing the R statistical software, chein's equation and experimental results, relation between settling parameters and equivalent shape factor were investigated. Results show that equivalent shape factor generally decreases as initial solid concentration increases. Unlike other samples, the equivalent shape factor for coal is not between 0 and 1 due to use of flocculants and formation of network structure in samples with higher initial concentration.
***Key words**: Equivalent shape factor, Flocculation, Mud line, Individual settling, Regional settling.*

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INTRODUCTION

Water plays a vital role in mineral processing and about 2-3 tons of water is used for the treatment of one ton of ore. Because of the scarcity of water resources, recycling plays a major role in the mineral processing industry. If not recycled, harmful minerals in the water can damage the environment. Major part of water recovery is performed in thickeners. Settling capacity for a sedimentation unit is characterized by settling velocity in the free settling zone [1, 2, 3, 4].

Floc structure (size and shape) plays an important role in settling velocity for particles [5]. This structure depends on the nature of many factors including solids (surface chemistry, size, size distribution, shape, density), the liquid (viscosity, dielectric constant), the suspension (solids loading, pH, ionic strength, temperature), and the flocculant (chemical nature of backbone and side chains, molecular weight, molecular weight distribution, charge, charge density). Studying effects of all mentioned parameters on settling velocity of particles is very complicated. Even when all major factors can be controlled under practical conditions, with only a few parameters that are independently variable, the task is still difficult to do [6]. So, previous studies have mostly concentrated on effects of one parameter on settling velocity while others remained constant [7, 8, 9]. Despite of using deferent methods (experimental, analytical and numerical methods) most of them have been suffering over simplification, low number of samples and insufficient number of variables.

The aim of this research is to calculate settling velocity for mineral particles using chein's equation. Also this equation is widely utilized for calculating velocity of non mineral particles [10,11] however it has not be used for mineral particles yet. Because mineral particles does not have specific geometric shape and their shape have been changing during settling process, an equivalent shape factor have been introduced for each sample and have been determined by fitting the chein's equation on experimental settling curves. More over effects of use of floculant in coal samples had investigated.

Determining these equivalent shape factors is an important achievement in mineral processing. Researchers can simply put these factors in chein's equation to calculate settling velocity and design thickener instead of doing time consuming experiments and modeling.

MATERIALS AND METHODS
Experimental details
Materials
In this study, a sample of three different materials was used for the settling experiments.

- Coal refuse (average density: 1.6 g/cm^3) related to thickener inter of Interkarbon coal preparation plant with 80% of particles smaller than 35 μm.
- Copper ore (average density: 2.7 g/cm^3) with 80% of particles smaller than 80 μm.
- Lead & zinc ore (average density: 3.7 g/cm^3) with 80% of particles smaller than 55 μm.

Settling test method
Settling tests were carried out in glass cylinders with a diameter of 10mm and volume of 1000 mL. For each experiment, the cylinder was filled with a certain amount of one of the three materials and water was added to the cylinder until the total volume was reached to 1000 mL. If needed, the required amount of flocculant was added to the cylinder and the content was mixed well using a mixer then mud line height versus time was recorded.

By dissolving solid flocculant in water, a flocculant solution with concentration of 0.05 % was prepared and added to the pulp in each related experiment. The flocculant used in these experiments was Polyacrylamid (A65) which is normally used by Interkarbon coal preparation plant. It should be noted that the flocculant according to ISO 10.86 standard was used just during 24 hours and after this time, the flocculant was constructed again.

Since so much of the pulp is lost by inverting the test cylinder, a punching mixer for liquid displacement and mixing operation was used to reduce the error resulting from the test. Stirring is considered to provide three functions: 1- To break up flocculant bonds that keep the particles apart. 2- To allow the fines to move into voids between coarse particles. 3- To facilitate the escape of liquid from the settling bed of solids [12].

Experimental design
Settling tests were carried out on the samples of coal refuse, copper and lead & zinc ores in order to determine the equivalent shape factor.

For the coal sample, the settling tests were started by changing the initial concentration from 2 to 10% with 2% distance and from 15 to 30% with 5% distance. The flocculant concentrations were 15, 25 and 35 g/t. To determine the error of settling tests, tests with percent solids of 2, 4 and 8% were repeated two or three times and the relative deviation for settling velocity as an index of experimental error was calculated. The average deviation for these experiments was 0.13.

The settling tests for copper, lead & zinc samples without the flocculant were done by changing the initial concentration from 5 to 40 percent with 5% distance. Due to ease of mud line observation, the test was repeated once only.

Research method for determining effects of equivalent shape factor on the settling velocity
All calculation methods of thickener surface area are based on settling velocity in the individual settling zone [13, 14]. To now this velocity has been mostly measured by doing time consuming experiments and results could be used only for test conditions. This means thickener designers should perform new experiments whenever they want to design new thickener which need lots of money and time. So, it will be very useful to have an equation to calculate settling velocity according to settling parameters. Such an equation has been widely in several fields of science and engineering and known as Chein's settling velocity equation [7, 11]:

$$V_p^{\,2} + 4.458\, e^{(5.03\, ¢)} \left(\frac{\mu_e}{d_p\ \rho_f}\right) V_p - 19.45\, e^{(5.03\, ¢)} d_p \left(\frac{\rho_p}{\rho_f} - 1\right) = 0 \qquad (1)$$

V_p: *Settling velocity of the particle*
μ_e : *Effective viscosity of the fluid*
d_p: *Average particle diameter*
ρ_f : *Fluid density*
ρ_p : *Particle density*
¢ : *Shape factor*

To use this equation in the mineral processing area, it should be noticed that mineral particles don't have any specific geometric shape. So we can not assign a constant shape factor to each mineral sample. As a result of changes in the shape of minerals during settling velocity, the shape factor varies from an initial value to a final value. This may cause useless of chein's equation in mineral processing however defining an equivalent shape factor which is an average value, will solve the problem. In this study settling test data were used to plot the settling curves and fitting the chein's equation on curves will determine equivalent shape factors.

Because, the settling tests were done in water, we take:

$$\rho_f = 980\ \frac{Kg}{m^3}$$

$$\mu_e = 0.81\ mpa.s$$

Values of above parameters for each sample had been determined using the results of settling tests, and particle size analysis (see sections 2.1 and 3.1). The slope of the curve which shows mud line height versus time in the individual settling zone was considered as V_p in the chein's equation. For each of the three samples with different initial solid percent, we used the statistical software R to obtain the equivalent shape factor based on the settling velocity values.

RESULTS AND DISCUSSION

Settling test without flocculant

Unlike coal, the mud line for the copper and lead & zinc samples could easily be seen without using the flocculant. The settling velocities for these two samples with different initial concentrations (from 5 to 40%) were obtained. The settling curves for a number of experiments related to the copper, lead & zinc samples are shown in Figures 1 and 2, respectively. A characteristic feature of these graphs is that each starts off with a straight line, then turns into a curve and finally becomes parallel to the time axis. A tangent drawn at any point on these graphs gives the settling rate of the solids in the vicinity of the interface corresponding to that point. As the graphs reveal, the settling rates are high at the beginning, but later become considerably lower. The decrease in the settling rates is due to changes in the settling conditions that take place over the time [12].

Zone and compressive settling regimes are further characterized by the sharp boundary that exists between the settling solids and supernatant liquid. Clarification or particulate settling regimes, on the other hand, do not show a distinct interface (see Figures 3, 4).

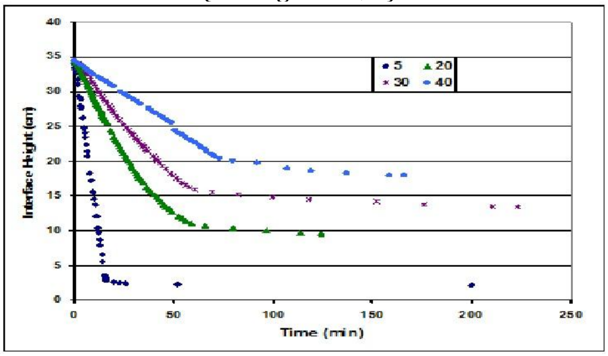

Figure 1. Copper settling rates without flocculant for different initial solid percent.

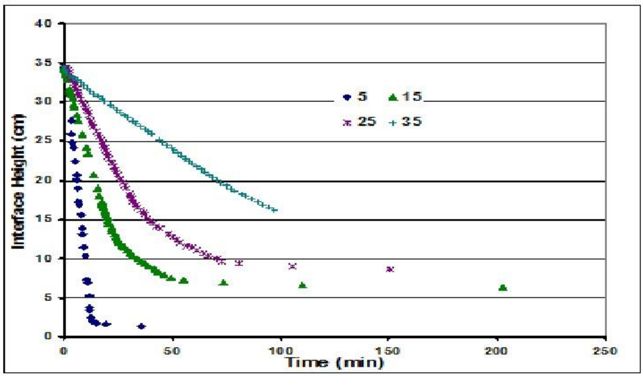

Figure2. Lead & zinc settling rates without flocculant for different initial solid percent

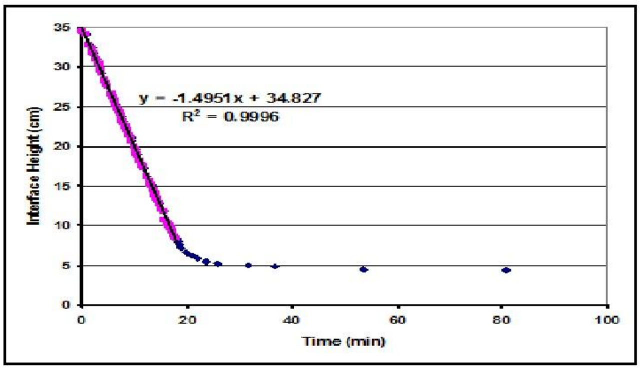

Figure3. Determination of the velocity in particulate setting zone for copper sample with 10 percent of solids in feed without flocculant.

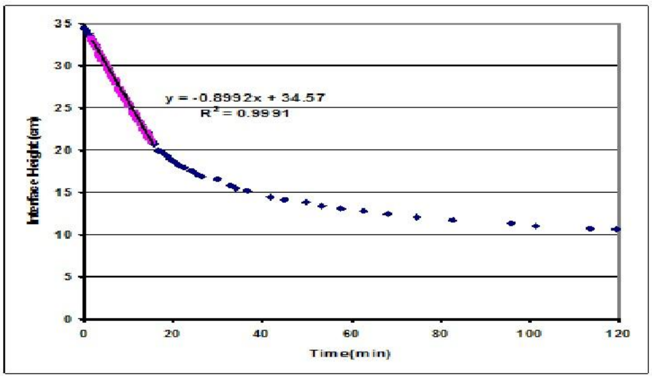

Figure4. Determination of the velocity in particulate setting zone for coal sample with 10 percent of solids in feed and 35 gr/ ton flocculant dosage.

Settling test using flocculant

Due to low settling velocity of coal sample, it was difficult to see the mud line. Therefore, these tests were carried out with flocculant. The settling velocities in this sample were obtained for different initial concentration values (from 2 to 10%). As mentioned above, each experiment was repeated three times and the average velocity of the settling velocities from the three replications was computed.

Figure 5 shows the results obtained from the coal sample. It seems that floc formation makes the settling velocities much higher than the settling without flocculant. But adding flocculant more than its optimal amount, not only does not improve the settling velocity but also it produces looser flocs that reduces the compressibility of solids during compaction and decreases the final pulp densities. However, increasing flocculant dosage reduces the overflow clarification. In the other words, compared to a thick pulp, flocculant that is used in a diluted pulp produces larger flocs. As the amount of feed solid concentration goes up, the settling rate increases by lower amounts of flocculant and higher velocities. Under low-pulp-density conditions, sedimentation of individual flocs is observed and so the settling rate of the suspension becomes higher. At higher pulp densities, however, the flocs form a network structure, retarding the sedimentation rate.

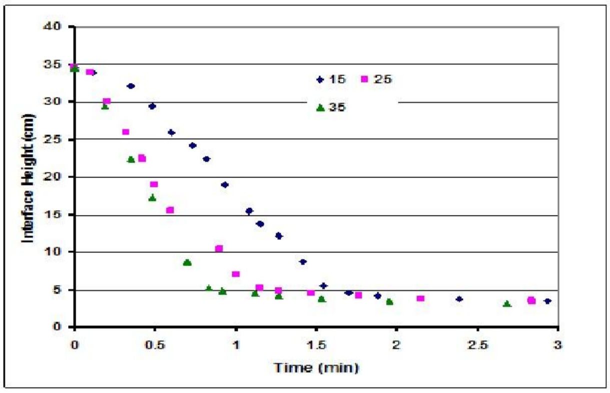

Figure5. Effects of flocculant dosage on settling velocity for the coal sample with 2 feed percent solids.

Relationship between equivalent shape factor and settling velocity

Settling particles have often irregular shapes, especially when flocculant is used to increase the settling velocity [7]. The equivalent shape factor is usually less than 1 [8]. As mentioned before, the Chein's equation was employed to obtain the effect of equivalent shape factor on the settling velocity. Using the statistical software R for all the three samples, the equivalent shape factor was computed for different initial solid concentrations.

As it can be seen from Figure 6, the equivalent shape factor increases as the settling rate rises. This issue was confirmed by the three samples.

Figures 9-11 show the equivalent shape factor changes versus different initial solid concentrations for the coal sample when adding different flocculant dosages.

Figures 7-11 indicate that as the initial solid concentrations increases, due to the increased pressure on the particles the equivalent shape factor (degree of sphericity) decreases and forms larger flocs. In other words, by increasing the initial solid concentrations, more time is needed to obtain underflow desired density in a compressive zone. As Figures 9-11 show, for the coal sample, changes in the equivalent shape factor due to adding flocculant is remarkable. By comparing Figures 7-11, it is understood that unlike the copper and lead & zinc samples, the equivalent shape factor for the coal sample is not necessarily between zero and one, because of using flocculant leading to significant changes occurred in the floc structure. For the coal sample with the high percent of solids, the equivalent shape factor has negative and close to zero values because of increased pressure forces from above layers on solids in the bottom layers that makes a network structure and a significant decrease in the settling velocity.

Unlike the expected decreasing trend, the settling velocity and hence the equivalent shape factor for 25% initial solids in the copper sample and 20% initial solids in the lead & zinc sample increase significantly. This means that the difference in velocity up for withdrawing water from flocs and the settling velocity due to the gravity force is increased. This behavior is often the result of channeling or short - circuit in fluid that occurs at high concentrations and it is likely to be related to the cracks in the structure of solids via the existence of forces between particles.

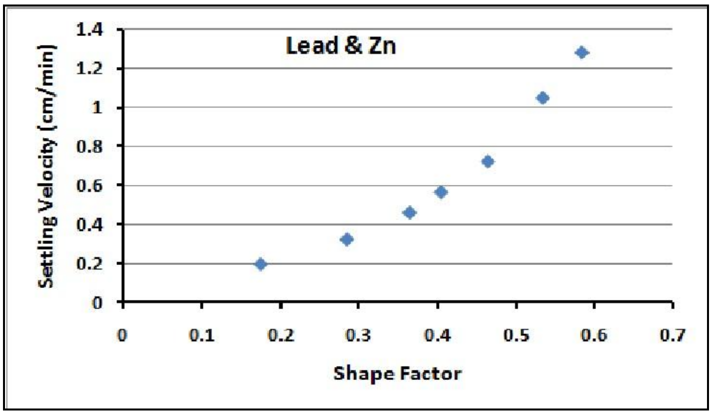

Figure6. Settling velocity changes versus shape factor for the lead & zinc sample.

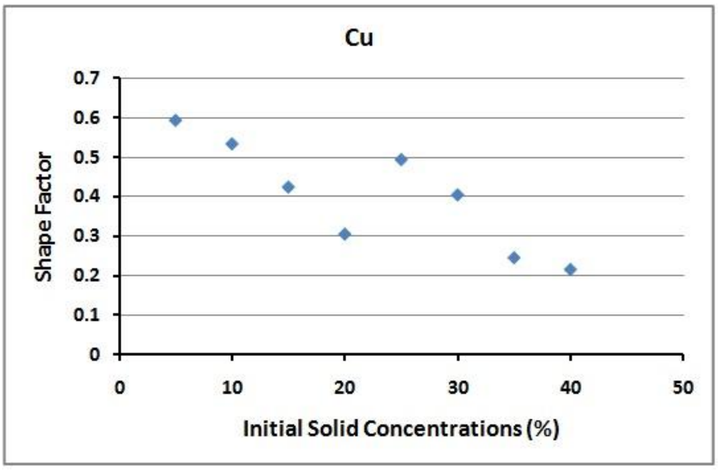

Figure7. Shape factor changes versus different initial solid concentrations for the copper sample.

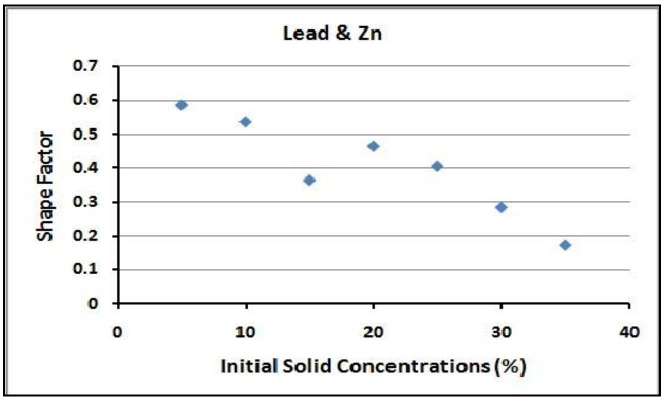

Figure8. Shape factor changes versus different initial solid concentrations for the lead & zinc sample.

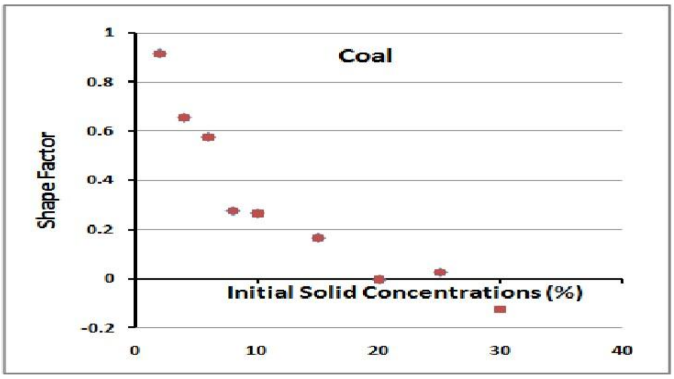

Figure9. Shape factor changes versus different initial solid concentrations for the coal sample with 15 gr/ton flocculant dosage.

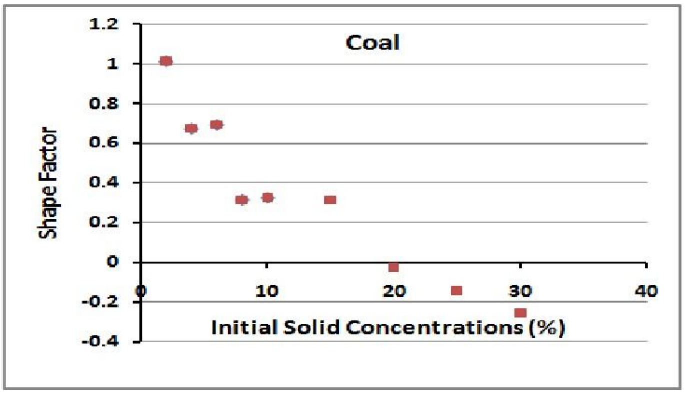

Figure10. Shape factor changes versus different initial solid concentrations for the coal sample with 25 gr/ton flocculant dosage.

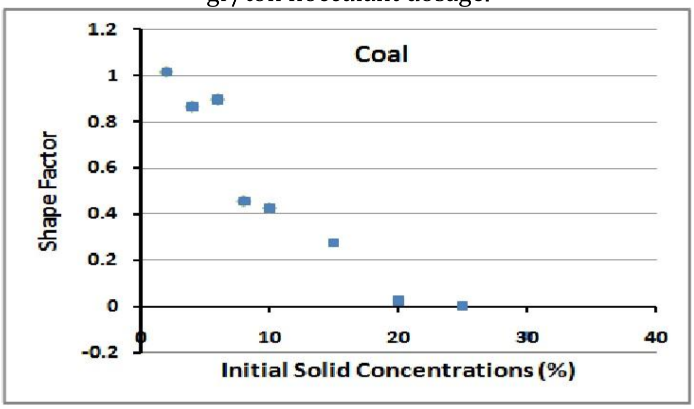

Figure11. Shape factor changes versus different initial solid concentrations for the coal sample with 35 gr/ton flocculant dosage.

CONCLUSIONS

Under low-pulp-density conditions, sedimentation of individual flocs is observed and so the settling rate of the suspension becomes higher.
Equivalent shape factor generally decreases as initial solid concentration increases.
For the coal sample, decreases in settling velocity that lead to an increase in the pressure on particles and formation of larger flocs, reduce the equivalent shape factor.
Unlike other samples, the equivalent shape factor for coal is not between 0 and 1 due to use of flocculants and formation of network structure in samples with higher initial concentration.
Unlike the expected decreasing trend, the equivalent shape factor for 25% initial solids in the copper sample and 20% initial solids in the lead & zinc sample increase significantly. This behavior is often the result of channeling or short - circuit in fluid that occurs at high concentrations and it is likely to be related to the cracks in the structure of solids via the existence of forces between particles.
Determining equivalent shape factors for mineral materials is an important achievement in mineral processing. Researchers can simply put these factors in chein's equation to calculate settling velocity and design thickener instead of doing time consuming experiments and modeling.

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