Some Aspects on the Sedimentation of Aqueous Suspension of Haematite: Determination of the Constant Rate of Sedimentation

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Like all other physical rate – governed processes, the phenomenon of sedimentation is also found to be a combination of constant rate and falling rate period. The constant rate sedimentation of an aqueous slurry of haematite particles has been found to depend on the initial concentration of the slurry – expressed as volume % of solids and the bulk density of the solids. Such dependence can be expressed with a fair degree of accuracy by the relation $-r_c=A(\rho_B)^{a1}$ at constant solids concentration or by $-r_c=B(c)^{b1}$ at constant bulk density. The joint variation of $-r_c$ with the groups ρ_B / ρ_f and c is given by the relationship: $-r_c=472.3285(\rho_B / \rho_f)^{-6.997}.(c)^{-0.368}$, which shows a standard deviation of ±11.23% and a correlation coefficient of 0.954885.

The separation of a particular kind of solid from a mixture of solids of different kinds happens to be an inseparable feature in a chemical industry for which almost invariably the wet classification process is adopted. The presence of gigantic thickeners or classifiers in any industry is a practical application of such wet classification which is based on the principle of settling. The design of such chambers, therefore, rests on the data on settling characteristics of the solids to be separated or concentrated [1,2,3]. Such data are generated on laboratory scale by undertaking a batch settling test by putting a uniform concentration of the slurry in a graduated measuring cylinder [4] and noting the height of the interface at regular intervals. It has been observed that irrespective of the type of solids and the slurry concentration, the height of the interface, H, decreases gradually and attains a constant value after a long interval, which is known as the equilibrium height, H_E [2]. The rate of change of the interfacial height, H, with time, θ, remains constant upto a certain period known as the critical time, θ_c, after which such rate gradually decreases and ultimately vanishes at H_E.

The whole phenomenon is a representative feature of the physical rate governing process – the most common example of which happens to be the process of drying.

The process of sedimentation – like all other physical rate governed processes – is, therefore, a combination of a constant rate period, r_c, and a falling rate period, r_f, (cf. drying, where falling rate period is composed of the first falling rate, followed by a second falling period [2] which is a characteristic feature of the internal diffusion of moisture through the pores of the solids). Since the constant rate is also an indication of the maximum rate, the determination of the same is important (cf. the initial rate for a particular chemical reaction). This can be determined in different ways:

- Drawing tangent at the starting point in the plot of H vs θ (i.e., $H=H_o$ and $\theta=0$).
- By plotting the value of ln (H/H_O) vs θ and noting the break point in the linearity in the plot.
- From the differential plot obtained from the magnified basic plot of H vs θ and by plotting $\Delta H/\Delta H_o$ vs. θ.

The rate of sedimentation is always negative. Since the final value of H is always less then the initial value of the same between any two intervals and since no information is available to predict the constant rate of sedimentation, the present work is undertaken to throw some light on the same for haematite slurry in water.

Experimental

The solid (haematite) has been ground in a prototype ball mill and sieved to five different size fractions of 150/200, 200/240, 240/300, 300/350 and –350 mesh BSS, corresponding to particle size of 0.0089, 0.0069, 0.00585, 0.00485 and 0.0022 cm respectively. The individual size fractions have been washed by a gentle stream of water to make them dirt-free, dried in a compartment drier and finally kept in a $CaCl_2$ dessicator. The bulk densities of the solids have been measured by the conventional method, e.g. putting a definite quantity of solids in a measuring cylinder and noting corresponding volume. The true solid density has been measured by specific gravity bottle which has been found to be 4.00 gm/cc and the bulk densities of the size fractions 150/200, 200/250, 250/300, 300/350 and –350 mesh BSS have been measured to be 2.591, 2.630, 2.680, 2.820 and 2.917 gm/cc respectively. The required quantity of the solids, to make the slurry of a particular consistency (vol/vol), has been calculated from the bulk density data and put inside a 100 ml measuring cylinder, attached to a strip of graph paper to ensure more precise reading, and the volume has been made upto 100 ml. The slurry has been stirred and allowed to settle. The height of the interface, read from the bottom, has been kept on being recorded with time which gives the basic data on H vs θ. The whole thing continues till there is no further change in the reading of H which gives the value of H_E. Water has been used as the suspending liquid whose density has been taken as 1.0 gm/cc.

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Results and Discussions

The basic plot of interfacial height with time, on a rectangular graph paper, indicates the constant rate as well as the position of equilibrium height, H_E. A typical plot has been shown by Fig. 1 for slurry of different size haematite particles, keeping the volumetric concentration of the slurry constant as 2%. The slope of the initial portion of the curve gives the idea of the magnitude of r_c which is expectedly the highest for the coarsest particles, i.e., 150/200 mesh BSS, because of faster settling velocity of the same. The free settling condition is a characteristic feature till the critical condition is reached [4]. Such general trend of variation of H vs θ follows for other slurry concentrations at constant particle size. A typical such plot is shown by Fig. 2 which stands for particle size of 240/300 mesh BSS and for slurry consistency of 1%, 2% and 6%. It is clear from the plot that the curves tend to be more and more flat with the increase of the solids concentration which results in a progressive decrease in the value of r_c. This is due to the hindered settling condition which sets in for higher concentration of solids when the possibility of a particle remaining in the close proximity of others increases. In such case, motion of the particle is impeded by other particles even though they may not be actually colliding [2]. Such conditions significantly affect the hydrodynamic conditions around each particle which markedly reduce the particle settling velocity. The effective slurry viscosity also becomes much higher than that of the suspending fluid and is taken care of by Steinour's correction factor [5]. Such increased effective viscosity of the medium (which increases with the slurry consistency) also impedes the movement of the particle, thereby reducing the settling velocity of the same. The gradual flattening characteristics of the H-θ plot with the increase in slurry consistency agrees with the same for $CaCO_3$ slurry as reported in the literature [3].

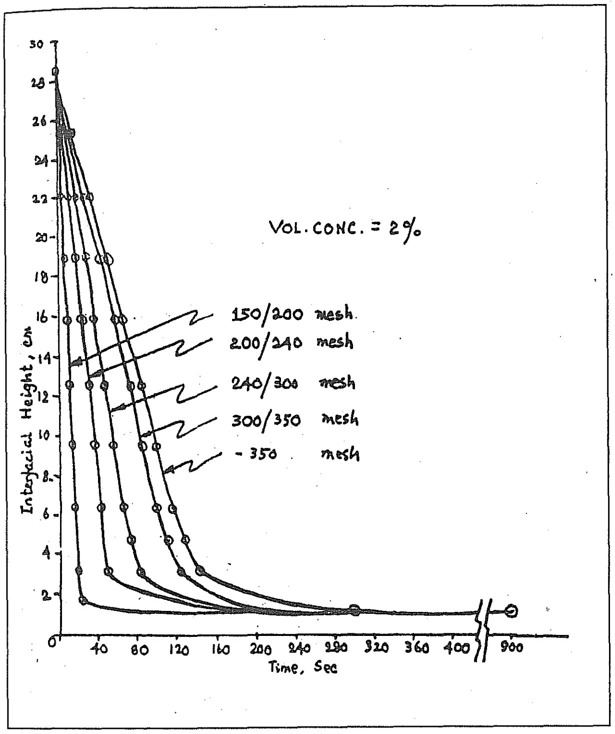

Fig. 1: Variation of Interfacial Height with Time for Different Size Fractions

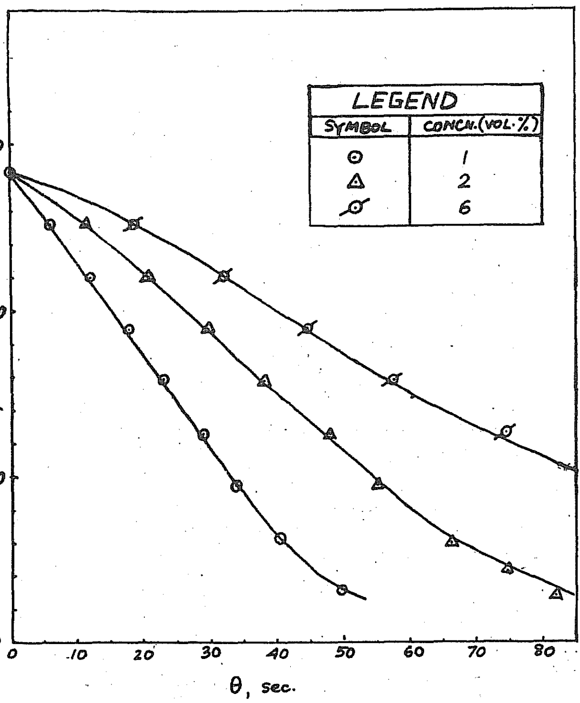

Fig. 2: Variation of the Interfacial Height with Time for Different Solids Concentrations

The values of r_c are, therefore, dependent on both slurry concentration, c, at constant bulk density, ρ_B (or particle size) or on bulk density at constant slurry concentration which is shown by Figs. 3 and 4 respectively. The linearity of both the plots on log – log grid clearly indicates that r_c can be correlated with ρ_B and c as

$$-r_c=A(\rho_B)^{a1} \quad (1)$$

$$-r_c=B(c)^{b1} \quad (2)$$

To take into account the combined effect of ρ_B and c, a joint variation for $-r_c$ with c and ρ_B (expressed as dimensionless number, given by ρ_B / ρ_f) has been tried. Such variation can be expressed as:

$$-r_c=X(\rho_B / \rho_f)^{x1}(c)^{x2} \quad (3)$$

the values of the coefficient X and the exponents x_1, x_2 has been evaluated by multiple linear regression analysis and is given as:

$X=472.3285$, $x_1=-6.996$, $x_2=-0.368$

Putting these values, equation 3 takes the final form as

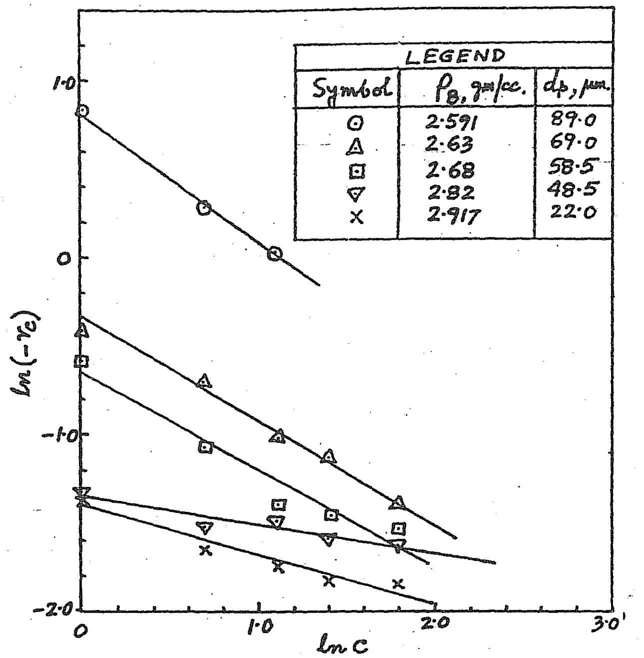

Fig. 3: Variation of Constant Rate of Sedimentation with Slurry Concentration at Different Bulk Density of the Solids

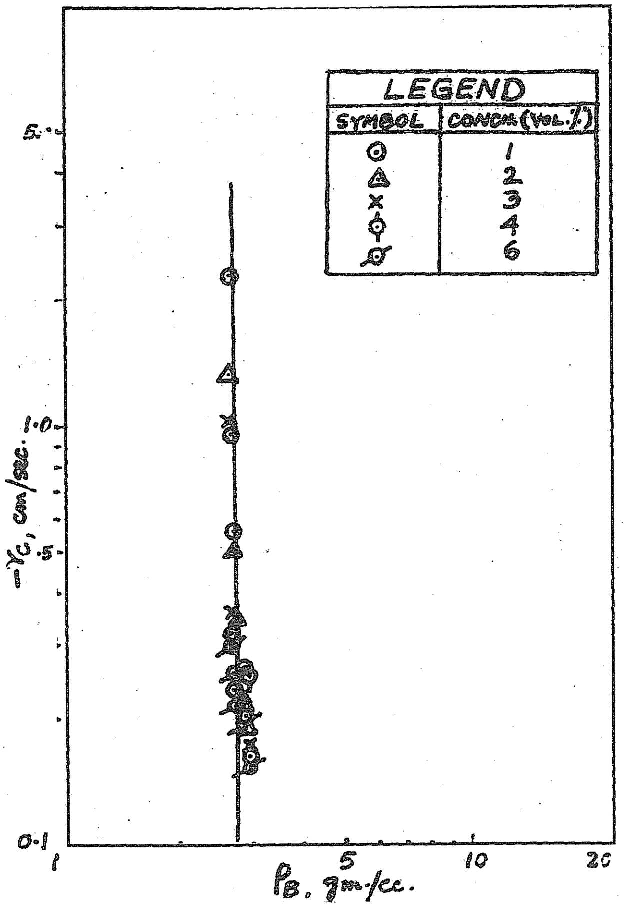

Fig. 4: Variation of Constant Rate of Sedimentation with Bulk Density of the Solids at Different Slurry Consistencies

$$-r_c=472.3285\,(\rho_B/\rho_f)^{-6.997}(c)^{-0.368} \tag{4}$$

The ranges of the parameters are $2.591 \le \rho_B/\rho_f \le 2.917$ (for d_p range of 0.0022 cm $\le d_p \le 0.0089$ cm.) and $1.0 \le c \le 6.0$.

Since equation (3) is a dimensional one, the coefficient X has the same unit as that of $-r_c$ which is expressed as cm/sec. The correlation plot, i.e., the variation of ln $(-r_c)$ with ln $[(\rho_B/\rho_f)^{-6.997}(c)^{-0.368}]$ is shown by Fig. 5. The standard deviation for equation (4) and the correlation coefficient of the same have been calculated as ± 11.23% 0.954845 respectively. The scanning of % errors is depicted by the histogram Fig. 6 which shows that 76.5% of the values of $-r_c$, calculated by equation (4), shows an error which is within ±15% of the experimental values of $-r_c$. A comparison between the calculated and experimental values of $-r_c$ has been shown by Fig. 7 which shows a fair agreement between these two.

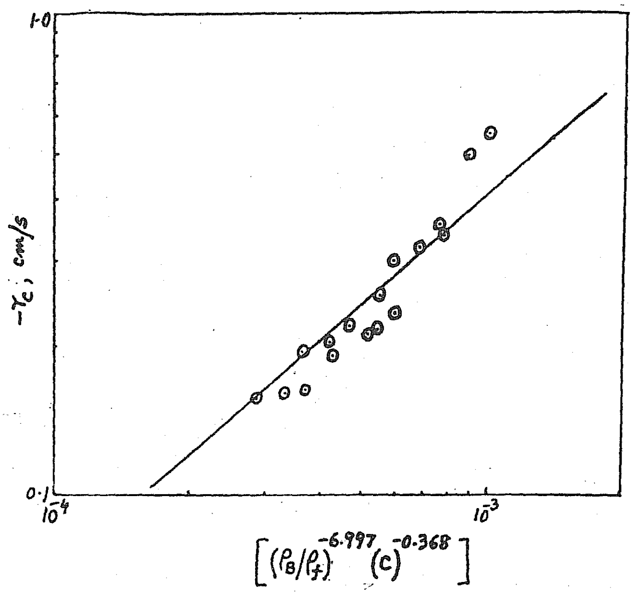

Fig. 5: Correlation Plot for the Constant Rate of Sedimentation

Since the study has been restricted to aqueous slurry, the effect of other suspending liquids cannot be predicted by the proposed correlation because of the fact that by a change in ρ_f, the liquid viscosity also changes. The effect of particle size can, however, be predicted by equation (4) because an increase in ρ_B causes a decrease in the value of d_p which in turn decreases the settling velocity and hence the constant rate r_c, which is shown by Fig. 1. The negative exponent of the group ρ_B/ρ_f in equation (4) is therefore justified. The negative exponent of c in equation (4) is also in full agreement with the more and more flattening characteristics of H versus θ plot with increasing slurry concentration, as shown by Fig. 2. The rate of sedimentation – as mentioned earlier – starts falling off after reaching the critical state. This is depicted by the critical height, H_c, or the corresponding time, known as critical time, θ_c, till the rate becomes 0 at the

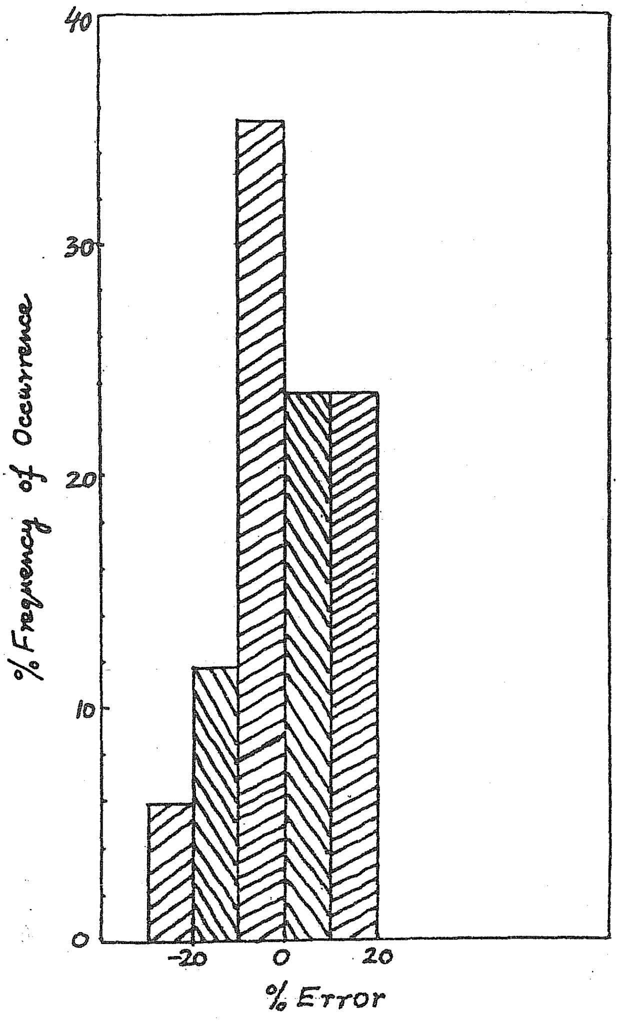

Fig. 6 : Histogram Showing the Frequency Distribution of Errors.

equilibrium height, H_E. A knowledge of such falling rate of sedimentation is also important to be evaluated. Some attempts have earlier been made [6,7] to determine the same in the phenomenon of elutriation of solids by water (which is also an example of physical rate governed process) and in the process of sedimentation of aqueous slurry of high ash coal. In both the cases, the dimensionless quantity $-r_f/-r_c$, has been correlated with the system characteristics, prevailing at the critical condition, i.e., mass fraction of elutriating component in elutriation [6] and the interfacial height in sedimentation [7]. Since no such generalized dimensionless relationship to determine r_f is available for sedimentation, a detailed and systematic investigation can be made by taking different solids and suspending liquids and correlating $-r_f/-r_c$ with various dimensionless quantities, e.g. Archimedes number, the ratio of bulk density of the solids to the fluid density and slurry concentration.

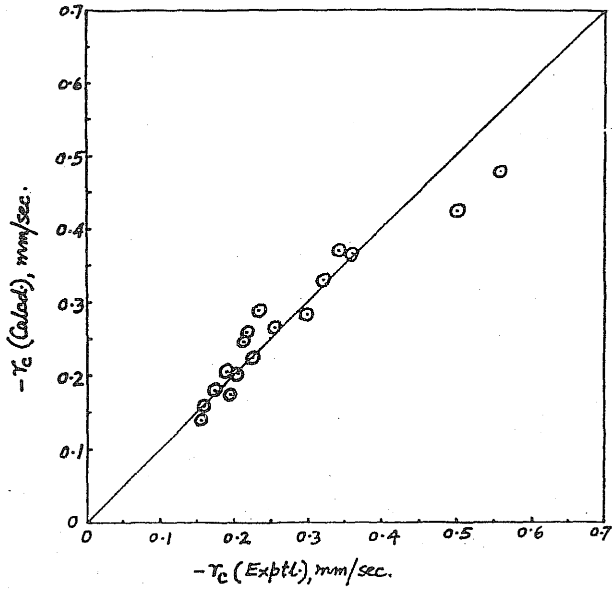

Fig. 7 : Comparison Plot Showing the Difference between the Calculated and Experimental Values of $-r_c$

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Nomenclature

A	Constant in Eqn. (1)
a_1	Exponent in Eqn. (1)
B	Constant in Eqn. (2)
b_1	Exponent in Eqn. (2)
c	Concentration of slurry, volume percent
H	Interfacial height, cm
H_c	Critical height of the interface, cm
H_E	Equilibrium height, cm
H_o	Initial height of the interface at $\theta = 0$ cm.
r_c	Constant rate of sedimentation, cm/s
r_f	Falling rate of sedimentation, consistent unit
X	Coefficient in Eqn. (3)
x_1, x_2	Exponents in Eqn. (3)
ρ_B	Bulk density of the solid, gm/cc
ρ_f	Density of the suspending fluid, gm/cc
θ	Time of sedimentation, sec.
θ_c	Critical time, sec.