



Experimental Investigation on Relationship between Sedimentation Rate Constants of Solid Materials

K.Senthilkumar (Corresponding author)

Department of Chemical Engineering

Erode Sengunthar Engineering College, Thudupathi

Erode-638057, Tamilnadu, India

Tel: 91-4294-232-701 E-mail: uksen2003@yahoo.co.in

V. Sivakumar

Department of Chemical Engineering

Kongu Engineering College, Perundurai

Erode-638052, Tamilnadu, India

Tel: 91-4294-225-026 E-mail: drvsivakumar@yahoo.com

T. Kannadasan

Director of Research

Anna University- Coimbatore, GCT Campus

Coimbatore-641013, Tamilnadu, India

Tel: 91-422-245-4571 E-mail: tkannadasan56@yahoo.com

Abstract

It has been found that the sedimentation process is a rate-governed process, which is a combination of a constant rate and falling rate. The various solid materials like Silicate, Calcium Carbonate, and Barium Carbonate were taken and ground in prototype ball mill and sieved to different size fractions and different consistence sedimentation tests were conducted. In this study, an attempt has been made to draw some correlations between sedimentation rate constants (overall sedimentation rate constant (K_o), sedimentation rate constant for constant rate period (K_c) and falling rate constant (K_f)). Variation of K_o on various particle sizes and slurry consistency has also been reported in this work.

Keywords: Sedimentation rate, Sedimentation rate constant, Falling rate, Sedimentation rate correlation

1. Introduction

The separation of dilute slurry by gravity setting into a clear fluid and slurry of higher solids concentration is called sedimentation. Sedimentation is applied in many chemical engineering operations and processes such as filtration, fluidization, two- phase flow and environmental engineering (McCabe et al., 1993). The rate data of sedimentation process is very important for designing equipment used in chemical and metallurgical practices for separating suspended solid particles from liquid or gas stream (Mondal and Majumdar, 2004). Industrial sedimentation operations may be carried out batch- wise or continuously using thickeners. The hydrodynamic analysis of the sedimentation process facilitates the design of thickener (Coulson et al, 1962). Viscosity of the medium is the main physical property, which affects the sedimentation. Density of particles is again an important factor that affects the settling velocity of the particles. When the density of the particles is more, then the settling rate is also more. Batch sedimentation is employed for bio-processing or the process fluids in recycle. Batch sedimentation is mainly used in pharmaceutical industries. Continuous sedimentation is the process in which the solids are settled continuously. This type of sedimentation is found in chemical industries, which reuse the process water or fluid. They are carried out in large diameters and shallow depth diameters, with slowly revolving rakes for removing the sludge. In the binary system, two different sizes of particles are taken and are used for the study of sedimentation process. The mechanism of binary system of sedimentation can be well understood (Brown, 1962). In general, a binary mixture consisting of particles of equal densities will give rise to four zones during the course of sedimentation.

From the literature (Brown, 1962), it is observed that the sedimentation rate is proportional to the difference between the interfacial height at any time (H) and that attained at equilibrium (H_E) [when no further change in the height of sedimented layer occurs]: $(-dH)/dt \propto (H - H_E)$. In general, the entire sedimentation period is found to be a combination of a constant rate period, which is followed by a falling rate period. The sedimentation rate falls till it vanishes at equilibrium height (H_E). Depending upon the type of period, the proportionality constant is known as constant rate (K_c) or falling rate period constant (K_f) respectively, which are operative between the intervals, $H_c \leq H < H_o$ for $0 < t \leq t_c$ and $H_E \leq H < H_c$ for $t_c < t \leq t_E$. If this condition is applied on overall basis between the initial interfacial height (H_o) and the equilibrium height H_E , the rate constant is called overall sedimentation rate constant (K_o). In this study, an attempt has been made to draw the correlations between these sedimentation rate constants K_c , K_f and K_o . Variation of overall sedimentation rate constant (K_o) on various particle size and slurry consistency has also been described in this work.

2. Materials and Methods

The solids of various materials like Calcium Carbonate (CaCO_3), Barium Carbonate (BaCO_3) and Silicate were taken and ground in proto type ball mill and sieved to four different size fractions of 52/60, 60/72, 72/100 and 100/200 mesh BSS corresponding to particle size of 0.246mm, 0.212mm, 0.147mm and 0.072mm respectively. To make them dust free, the individual size fractions were washed in a gentle stream of water. The required quantities of the solids were put inside a 500 ml-measuring cylinder to make the slurry of a particular consistency. A strip of graph paper was attached to a measuring cylinder to ensure more precise reading. The slurry was stirred and allowed to settle. The height of interface was read from bottom and kept on being continuously recorded with time t , measured by a stopwatch to denote the rate of sedimentation at any time instant. The true density was measured by specific gravity bottle (Perry & Green, 1997).

3. Results and Discussion

In the experimental data, for each of the runs, the initial height of the slurry (H_o) (at $t=0$), was obtained directly and the equilibrium height (H_E) was determined graphically from the rectangular plot of H against t . It is clear from these plots 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 sedimentation rate. The critical height (H_c) was obtained from a differential plot of the variation of $-\Delta H/\Delta t$ against time t , as the break point between the constant and falling rates.

Though it has been mentioned that the rate of sedimentation is proportional to $(H-H_E)$ and raised to the power 1.0 (Brown, 1962, Perry & Green, 1997), it has been found in the present study that this assumption fails to give good result which is obtained by putting the exponent of $(H-H_E)$ as 0.1 instead of 1.0. The modified exponential term gives a good result in the standard deviation between the calculated and experimental values of H . So, the proportionality is modified as,

$$-dH/dt \propto (H - H_E)^{0.1} \quad (1)$$

The proportionality constant is known as Sedimentation rate constant K . This equation (1) is integrated between the desired limits to obtain the values of different K .

For constant rate period,

$$-dH/dt = \text{constant} \quad (2)$$

Integrating this equation between the limits $H_c \leq H < H_o$ for $0 < t \leq t_c$

$$(H_o - H_c)/t_c = K_c \quad (3)$$

Where, t_c is the critical time (the value of time t corresponding to the break point between constant and falling rates) and the corresponding height is the critical height (H_c).

For falling rate period,

$$-dH / (H - H_E)^{0.1} \propto dt \quad (4)$$

Integrating this equation between the limits $H_E \leq H < H_c$ for $t_c < t \leq t_E$

$$1.1[(H_c - H_E)^{0.9} - (H - H_E)^{0.9}] = K_f t \quad (5)$$

For overall conditions,

$$-dH / (H - H_E)^{0.1} = K_o dt \quad (6)$$

Integrating this equation for entire period of the initial interfacial height (H_o) and the equilibrium height H_E ,

$$1.1 [(H_o - H_E)^{0.9} - (H - H_E)^{0.9}] = K_o t \quad (7)$$

The values of K_f and K_o can be easily calculated from the rectangular plots of the left hand side of equation (5) and equation (7) against t or $t - t_c$, respectively as the corresponding slopes. The unbiased values have been determined by

using least square technique. The values of K_c can be calculated directly by using the equation (3) for each of the experiments performed. The calculated values of K_o , K_c and K_f are tabulated in the Table 1 and Table 2.

In the process of finding the type of relationship between the rate constants K_c , K_f and K_o , it has been found that the variation of overall sedimentation rate constant (K_o) with the summation of the constant and falling rates (K_c+K_f) as shown in Table 3 and Table 4 and also plotted on a rectangular graph paper which forms a straight line. This relation can be expressed by (in general)

$$K_o = m (K_c + K_f) + C_1 \quad (8)$$

The values of m and C_1 have been calculated by using least square technique for all the runs and which is given in Table 5.

The overall sedimentation rate constant is also found to be dependent on slurry concentration for a constant particle size. Such dependence can be expressed with a fair degree of accuracy by the relation,

$$K_o = A_1 (C)^{B_1} \quad (9)$$

The plot plotted between $\ln(K_o)$ versus $\ln(C)$ satisfies the relation expressed in equation (9). From the results (Table 6) it is observed that the value of B_1 has decreased with increase in particle size in slurry and the value of A_1 has also decreased with increase of particle size of the slurry of the same consistency.

4. Conclusion

The batch sedimentation tests were conducted for the various materials like Silicate, Calcium Carbonate, and Barium Carbonate with various particle sizes and concentrations. Correlation has been made to relate the sedimentation rate constants like K_c , K_f , and K_o . Variation of K_o on various particle sizes and slurry consistency has also been reported in this work. In addition, over all sedimentation rate constant and slurry concentration were related by the equation $K_o = A_1 (C)^{B_1}$. The values of A_1 and B_1 were related with particle size of the solid particles in the slurry.

References

- Warren L. McCabe, Julian C. Smith & Peter Harriott (1993). *Unit operation of chemical engineering*, McGraw Hill publications.
- Mondal, P., Majumdar C.B (2004). Sedimentation of Hematite Water Slurries, *Journal of the Institution of Engineers (I)*, 85, 20-23
- Coulson J. M., Richardson J. F., Buckhurst J., Harker J. H. (1962). *Coulson & Richardson Chemical Engineering (volume 2)*, Asian Book Pvt. Ltd., 131
- Brown G. G. (1962). *Unit Operation*, Asia publishing house, Calcutta, 117
- Robert H. Perry & Don Green (1997). *Perry chemical engineer's hand book* (7th edition), McGraw Hill publications

Nomenclature

A_1	: Coefficient
B_1	: Coefficient
BSS	: British standard sieves
C	: Percentage slurry consistency, (Kg/m ³)
C_1	: Coefficient
H	: Height of interface, m
H_E	: Interfacial height at equilibrium, m
H_o	: Initial height of the suspension (at $t=0$), m
K_o	: Overall sedimentation rate constant, (m) ^{0.9} (sec) ⁻¹
K_f	: Rate constant for falling rate period, (m) ^{0.9} (sec) ⁻¹
K_c	: Rate constant for constant rate period, (m) (sec) ⁻¹
$ K $	: Modulus of K
C_1	: Coefficient
$-r_c$	: Rate of sedimentation, cm/s
D_p	: Diameter of particle, cm
t	: Time, sec
t_c	: Critical time, s
t_E	: Equilibrium time, s

Table 1. Experimental values of K_o , K_c and K_f for CaCO_3 and BaCO_3

Materials	Constant rate constant, K_c			Falling rate constant, K_f			Over all rate constant, K_o		
	5%	10%	15%	5%	10%	15%	5%	10%	15%
CaCO_3	0.0853	0.0650	0.0317	-0.10794	-0.0356	-0.0535	0.0624	0.0491	0.0294
BaCO_3	0.148	0.1378	0.1308	-0.23323	-0.1827	-0.1188	0.1118	0.0977	0.0751

Table 2. Experimental values of K_o , K_c and K_f for Silicate

Materials	Constant sedimentation rate period constant, K_c				
Silicate (BSS)	5%	10%	15%	20%	25%
52/60	0.1203	0.1111	0.1025	0.1006	0.0915
60/72	0.1181	0.0974	0.0946	0.0931	0.0898
72/100	0.1086	0.0914	0.08333	0.0837	0.0754
100/200	0.0892	0.0872	0.0833	0.06926	0.0608
Falling sedimentation rate period constant, K_f					
Silicate (BSS)	5%	10%	15%	20%	25%
52/60	-0.253	-0.18528	-0.18882	-0.16147	-0.13203
60/72	-0.20459	-0.16349	-0.1514	-0.12318	-0.12299
72/100	-0.19042	-0.16628	-0.13685	-0.10249	-0.12653
100/200	-0.13137	-0.14448	-0.1086	-0.13229	-0.1155
Overall sedimentation rate constant, K_o					
Silicate (BSS)	5%	10%	15%	20%	25%
52/60	0.110702	0.094218	0.089433	0.086678	0.078563
60/72	0.104175	0.08577	0.078971	0.073904	0.071563
72/100	0.096321	0.080232	0.070811	0.064602	0.062312
100/200	0.064096	0.073587	0.064914	0.063097	0.055385

Table 3. The values of (K_c+K_f) and K_o for CaCO_3 and BaCO_3

Materials	For 5%		For 10%		For 15%	
	K_c+K_f	K_o	K_c+K_f	K_o	K_c+K_f	K_o
CaCO_3	-0.02257	0.062473	0.029412	0.049105	-0.02178	0.029244
BaCO_3	-0.08523	0.11187	-0.04493	0.097779	0.011909	0.075109

Table 4. The values of (K_c+K_f) and K_o for Silicate

Silicate (BSS)	5%		10%		15%		20%		25%	
	K_c+K_f	K_o	K_c+K_f	K_o	K_c+K_f	K_o	K_c+K_f	K_o	K_c+K_f	K_o
52/60	-0.1327	0.2348	-0.0742	0.1247	-0.0863	0.0840	-0.0607	0.0707	-0.0405	0.0658
60/72	-0.08649	0.1519	-0.0661	0.1153	-0.0568	0.0793	-0.030	0.06744	-0.0332	0.0634
72/100	-0.08182	0.1393	-0.0748	0.1058	-0.0535	0.0738	-0.0189	0.0634	-0.0511	0.061
100/200	-0.04217	0.1307	-0.0572	0.0999	-0.0253	0.0673	-0.063	0.06085	-0.0547	0.0593

Table 5. Value of constant for the relation among K_o , K_c and K_f

Materials	Constants	
	m	C1
CaCO_3	19.4213	-0.442
BaCO_3	0.51445	0.0706
For Silicate		
52/60 BSS	2.2346	-0.0603
60/72 BSS	1.6798	-0.0039
72/100 BSS	1.6362	-0.0029
100/200BSS	-14.867	0.8046

Table 6. Value of constants for the relation between K_o and C

Materials	Constants	
	A_1	B_1
CaCO_3	0.0093	-0.6539
BaCO_3	0.04099	-0.3445
Silicate	A_1	B_1
52/60 BSS	0.06139	-0.1955
60/72 BSS	0.05085	-0.2350
72/100 BSS	0.04186	-0.2787
100/200BSS	0.0382	-0.346