EQUATION FOR FITTING DISPERSED SYSTEMS GRAVITY AND CENTRIFUGE SETTLING DATA

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ABSTRACT

Liquid phase accumulation kinetics during sedimentation and centrifugation serves as a source of information about the average settling properties of dispersed systems. A power order fitting function is proposed for describing the dependence of accumulated liquid phase volume on settling time. The function validity was tested for numerous experimental settling data under gravitational and centrifugal forces for different dispersed systems. The obtained results give good correlation between experimental data and fitting curves even when settling displays a lag period. The main advantage of the proposed model is the possibility to fit the liquid phase accumulation kinetics in a wide range of settling time and solids concentration. The power order fitting function allows simulating the liquid phase accumulation in the case of limited experimental data.

KEYWORDS

Sedimentation, Centrifugation, Suspension, Activated Sludge, Simulation

1. Introduction

Sedimentation and centrifugation processes have a wide range of application to concentrate and separate dispersed systems containing particles, colloids, macromolecules. These processes are often used to characterise the physical-chemical properties of dispersed systems.
The existence of numerous factors affecting settling processes is not favourable to find out a general solution for the settling kinetics. A fitting function for the liquid phase accumulation that could be applied in a wide range of dispersed systems properties and concentrations would be very useful. The fitting function should hopefully be suitable for simulating the liquid phase accumulation process in the case of limited experimental data. This is the aim of the present work.

2. Model selection

When the dependence of suspended solid or sediment growth on time is considered, the settling process is usually described from the point of view of solid phase accumulation. This approach has intrinsic difficulties related with differences in sedimentation velocity of particles of different size and/or density as well as with the consolidation phenomena occurring in the sediment. On the other hand, from this point of view, the liquid phase accumulation modelling can be less complex and

simplifies the data fitting, since it reflects the average overall phenomenon in the sediment.

Based on an asymptotical analysis of the experimental data, a power order fitting relationship (1) was developed for centrifugation ($a \leq 1$) by [1;2]. The dimensionless fitting function was obtained for a fugate (liquid phase) volume V and was able to adequately describe the dependence of liquid volume V on time t for a centrifugation of activated sludge

$$v = V / V_\infty = k_s t^a / (1 + k_s t^a) \quad (1)$$

where V_∞ is the decanted liquid volume at equilibrium ($t = \infty$); k_s and a are the model parameters. At the initial settling stage, when $k_s t << 1$, $v \approx k_s t^a$. In the case of activated sludge, parameters a and k_s depend on a set of conditions, namely, the coagulation/flocculation pre-treatment, the ratio of organic/non-organic components in the solid, the type of activated sludge process, among others.

A preliminary analysis of the relationship (1) shows the possibility of extending this model to other cases. The present work will thus be devoted to analyse the behaviour of model (1) in a generalised case of a > 0. As an alternative to volumes V and V_∞, the supernatant liquid thickness h and h_∞, respectively, may be used in equation (1): $h = h_\infty k_s t^a / (1 + k_s t^a)$.

3. Analysis of the extended power order model

By representing the coefficient k_s in (1) as $k_s = (1/t_s)^a$ it is possible to write $k_s t^a = (t/t_s)^a = (t^*)^a$, where t_s is the system time constant, $t^* = t/t_s$ is the dimensionless time, and a > 0, model (1) becomes:

$$v = (t^*)^a / [1 + (t^*)^a] \quad (2)$$

As $t = t_s$ then v = 0.5, the parameter t_s corresponds to the time when v = 0.5 ($V = V_\infty / 2$ or $h = h_\infty / 2$). Another useful property of the model at t = 1.0 is that the equality $v/(1-v) = k_s = (1/t_s)^a$ occurs.

The knowledge of the liquid accumulation velocity $w = dv/dt$ is important for process control and optimisation. The liquid phase accumulation velocity w vs. t obtained from equation (1) at a > 0 has the form (3) and is presented in Fig. 1 in logarithmic scale.

$$w = (k_s a t^{a-1}) / (1 + k_s t^a)^2 = [a(1/t_s)(t^*)^{a-1}] / [1 + (t^*)^a]^2 \quad (3)$$

The sedimentation time corresponding to the velocity maximum can be determined at a > 1.0 by the following relation: $t_{\max} = [(a-1)/k_s/(a+1)]^{1/a}$ or $t_{\max} = t_s \cdot [(a-1)/(a+1)]^{1/a}$. Based on this function, velocity and other characteristics of a settling process may be simulated.

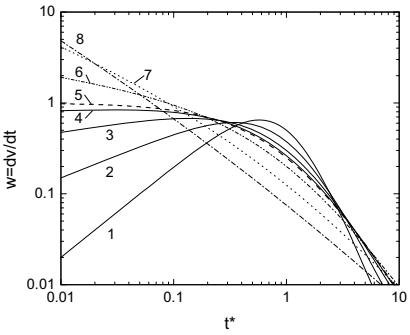

Figure 1. Dependence of w, equation (3), on t^*, assuming t_s = 1.0: 1 – a = 2.0; 2 – 1.5; 3 – 1.2; 4 – 1.05; 5 – 1.0; 6 – 0.8; 7 – 0.5; 8 – 0.3.

4. Validation of the fitting function

The validity of equation (1) for different settling processes (sedimentation and centrifugation) was tested using different experimental data published by several authors, as will be mentioned below. Data were treated by means of graphical data acquisition with further application of the fitting procedure. Experimental results were fitted using a weighted non-linear regression method. The accuracy of calculated parameters depends on the accuracy of experimental data and on the precision of the data acquisition. Fitting results for different dispersed system may be seen in Figs. 2 – 4. Results obtained for the different experimental data are described below.

Settling of mineral and organo-mineral suspensions

Liquid phase accumulation h during sedimentation of coal sludge with concentration C = 90 g/L from fig. 6-11 [3] is shown in Fig. 2. The obtained fitting curve seems to be more reliable (square of a regression coefficient r^2 = 0.99946) than the simulation made with the Wilhelm-Naide model cited in [3]. With the proposed equation (1) of the present work there are no outlyers.

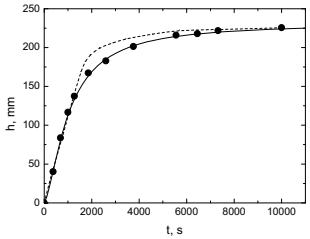

Figure 2. Supernatant accumulation h vs. t during sedimentation of 90 g/L coal sludge (data from fig. 6-11 [3]). Dashed curve – Wilhelm-Naide model; solid curve – fitting with equation (8): h_∞ = 231.54 mm, a = 1.5, k_s = 0.00003 $s^{-1.5}$ or t_s = 1036 s.

The next examples (Figs. 3) were obtained from data of figure 2 (AII) taken from [4], Fig. 3a, and figure 1 of [5], Fig. 3b. Figure 3a (industrial sludge 7.2 g/L) was treated by adding talc (ρ_s = 2800 kg/m^3, average particle size 6 micron) in different dosages.

By fitting equation (1), r^2 was in the range 0.99877 – 0.9997 and χ^2 in the range up to 0.00004. Example in Fig 3b shows the activated sludge sedimentation at different concentrations of the solid phase with a similar range of correlation coefficients.

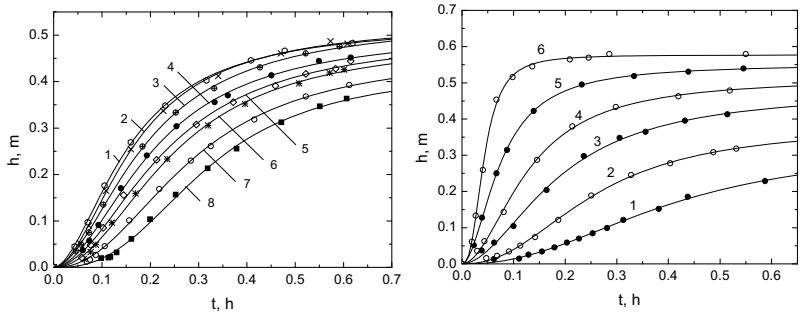

Figure 3. Sedimentation of activated sludge. (a) – Industrial sludge of 7.2 g/L with different dosage of talc, g/L, [4]: 1 – 10.5; 2 – 8.5; 3 – 6.5; 4 – 4.5; 5 – 2.5; 6 – 1.5; 7 – 0.5; 8 – Control. (b) – Sludge type "B" of different concentration, g/L: 1 -15.6; 2 – 12.7; 3 – 9.7; 4 – 7.7; 5 – 5; 6 – 3; data from [5].

Centrifugation of organic and organo-mineral suspensions

Examples in Fig, 4 represent settling curves under centrifugation. Centrifugation data fitting are shown for sewage sludge (a) and flocculated clay sludge (b). As can be seen, equation (1) gives good results for different dispersed phases and different centrifugal forces.

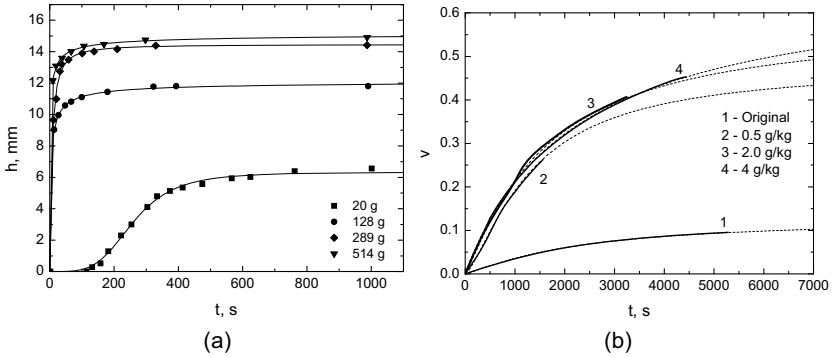

Figure 4. (a) – Centrifuge settling of sewage sludge (3% DS) conditioned with 5000 μg/g of the high-molar-mass polyelectrolyte at different centrifugal accelerations; data of Fig. 4 from [6]. (b) - Centrifugal dewatering curves of original and flocculated (g/kg DS) clay sludge at 1,000 rpm; data of Fig. 5 from [7].

6. Conclusion

The power order fitting function (1) proposed in this work can be used to describe the dependence of accumulated liquid phase volume on settling time. The function was tested on numerous experimental sedimentation and centrifugation data of different dispersed systems, and gave good correlation between experimental data and fitting curves even when settling had a start-up phenomenon such as a lag period. The main advantage of the proposed model is the possibility to fit the liquid phase accumulation kinetics for a wide range of settling time and solids concentration. The power order fitting function may also be used to simulate the liquid phase accumulation in the case of limited experimental data, especially in centrifuge settling mode.

Acknowledgement

The authors wish to thank FCT for the grant provided to Dr. Alexander Yelshin (Aliaksandr Yelshyn). This work was developed under the framework of the project POCI_EQU_58337/2004, funded by FEDER.

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