A finite velocity simulation of sedimentation behaviour of flocculating particles – A real-time model evaluation

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ABSTRACT

A mechanistic velocity model is developed to simulate the behaviour of flocculating colloidal particles in turbid water. The current model is based on one-dimensional mass transport in the vertical direction as an integrated form of the model derived by Ramatsoma and Chirwa. The percentile removal model achieved more accurate simulation of physical experimental data than known models such as the Ozer's model and San's model. In this study, an integrated velocity form was used to estimate flocculent settling velocity of fine suspended particles under near quiescent conditions. Model closeness to experimental measurements was determined as a function of the sum of squares error (SSE) between model data and experimental data. The proposed velocity model offers a distinctive advantage over the interpolated-isopercentile based models which are prone to numerical errors during interpolation. The results contribute towards the ultimate goal of achieving full automation of the design of gravitational particle separation devices for water and wastewater treatment.

Keywords: flocculation model, semi-empirical system, velocity integrated model, continuity model

NOMENCLATURE

α	fitting parameter in San's model (dimensionless)
α_i	the model fitting parameters in Özer's model (dimensionless) (i = 1, 2, and 3)
β	fitting parameter in San's model (dimensionless)
a	fitting parameter in Piro and co-workers' model and Je and Chang's model (dimensionless)
b	fitting parameter in Piro and co-workers' model and Je and Chang's model (dimensionless)
D	depth travelled by particle during settling (L)
D_z	dispersion coefficient in the vertical direction (L^2T^{-1}).
h, H	ordinate representing depth
k	fitting parameter in San's model (dimensionless)
n	fitting parameter of the power law model and exponential model (dimensionless)
P	percentage removal $(1-X_j/X_o) \times 100$
P"	percentage remaining in suspension $(X_j/X_o) \times 100$
r_i	semi-empirical optimisable parameters of Ramatsoma and Chirwa's model (i = 1, 2, and 3)
t	time of settling (T)
T	ordinate representing time
U_z	vertical water velocity (LT^{-1})
v	settling velocity (LT^{-1})
V_s	flocculent settling velocity (LT^{-1}),
x	solids concentration in the power law model and exponential model (ML^{-3})
X_j	suspended solids concentration in layer j (ML^{-3})
X_o	initial concentration in the column (ML^{-3})
z, Z	vertical distance (L)

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INTRODUCTION

In water and wastewater treatment facilities, the mass transport and behaviour of fine-grained cohesive sediments is influenced mainly by flocculation effects and nominal settling velocities of particles. Hence the understanding of batch settling processes of flocs is fundamental for effective thickener/clarifier design and control. The behaviour of flocculating particles and settling trajectories of individual particles is very complex. Flocculation effects and velocities are usually investigated using jar tests to establish dose, and settling columns to evaluate the flocculation behaviour.

Constant spatial and temporal variations and fluctuating initial conditions in physical sedimentation systems result in difficulty and uncertainty in the predictions of medium- and long-term behaviour of the settling particles (Xu et al., 2008; Mikkelsen et al., 2005). During the design of sedimentation tanks, data from settling columns are interpreted by a graphical technique. Firstly, samples are collected from different column depths at different times and are analysed for total suspended solids concentration (TSS). The batch settling data is then utilised to compute iso-percentage removal profiles as a function of time and depth. From the graphs, one can predict or calculate the removal efficiency, overflow rate and settling velocities of particles. However, it is common practice in industry to manually construct the isopercentile curves due to their non-linear nature. This practice is tedious, inaccurate, and susceptible to human error.

There is also the problem of irreproducibility since no two different technicians can construct exactly the same curves. When using currently proposed models to fit the percentage removal data, some fit the data well only at short retention times and others tend to violate the physical meaning of settling data profiles (Je and Kim, 2002). The use of inaccurate settling equations could lead to significant errors of aggregate properties.

This article evaluates a model based mainly on the prediction of the settling velocities derived as the integrated form

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