

The impact of silt content on the flocculation process of clay-silt mixtures

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INTRODUCTION

Flocculation of natural mud has a great potential to alter flocs with sizes, densities, and shapes (and thus settling velocity) that are vastly different from original constitutive primary particles, which will further influence sediment transport processes, including floc deposition or settling, sediment consolidation or perturbation, and erosion or initiation. It has been acknowledged that the turbulent shear effect and sediment concentration are the main factors influencing the flocculation processes in energetic environments such as coastal regions and estuaries by increasing or decreasing the collision frequency or efficiency of particles. As natural environments contain suspended sediment of both cohesive sediment and non-cohesive sediment, which makes the flocculation processes more complex. Though the flocculation behaviors on mud-sand mixtures have been extensively investigated, few efforts have been made to assess in detail the impact of clay-silt interactions on the properties of flocs formed. Therefore, in this study, a series of experiments were conducted to investigate how silt (its presence and content; changes in composition) influences floc properties under equilibrium turbulent shear conditions (Figure 1).

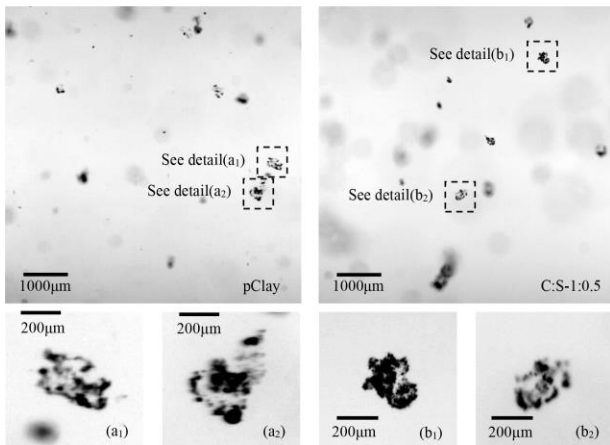


Figure 1 Sample images captured using the camera setup with a LED lighting source for cases pClay and C:S-1:0.5. a₁, a₂ and b₁, b₂ are enlarged images of individual flocs

METHODS

A series experiments on the flocculation processes of clay-silt mixtures were conducted with a flocculation tank. The mixing tank was equipped with a marine impeller and a camera system to observe the flocs (Figure 2). The experimental setup was firstly calibrated using glass beads to test the accuracy when measuring floc size. The measured size distribution of glass beads compares well with that measured by Marvin 3000.

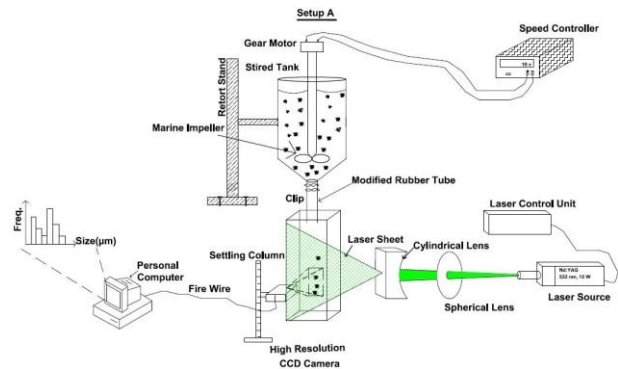


Figure 2 A schematic diagram of the experimental setup (PTV system).

RESULTS and DISCUSSION

The floc-size (or particle) distribution of pure silt (25 mg/l SSC) was compared to that of pure kaolinite clay minerals with the same SSC after 100 minutes of shear time at a 59 rpm impeller rotation rate. The results are shown in Figure 3. This demonstrates that the average size of silt particulates (flocs) remained generally constant (Figure 4a) throughout the 100 minutes of turbulent shear application. Though the distributions of silt particles < 50 µm (i.e., very fine silts) may flocculate, but their proportions relative to the total particles in suspension are small and may be negligible. Unlike pure silt, flocs of pure clay grew very fast in very large proportions.

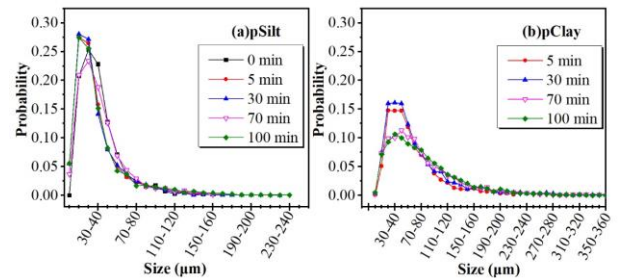


Figure 3 Spatio-temporal coastline change of Sanmen Bay

The time-series floc-size evolution of different clay-silt mixtures is shown in Figure 7a. Quantitatively, there was a notable difference in size between the flocs formed in pure clay and those formed in the clay-silt suspension at any given period of the flocculation process. after 720 minutes of mixing, the $d_{e, avg}$ for pure clay increased from 3 µm to approximately 117 µm, while that of the C:S-1:2.5 case increased approximately from 40 µm to 88 µm. One key observation is that as the silt composition increased in the clay-silt mixture, the equilibrium average size of flocs/silt particles decreased from 117 µm (pure clay) to 88 µm (clay-silt mixtures). It should be noted that at 0, 5 and 30 minutes, when the flocculation time was short, the $d_{e, avg}$ for pure clay was smaller than those of

mixtures, which was due to the bulk increase in proportions of large silt particles in suspension.

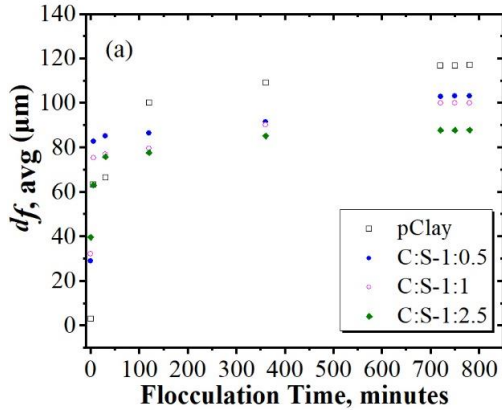


Figure 4 Time evolution average floc size of pure clay and mixtures of clay-silt sediment at specific flocculation time periods.

The semiempirical flocculation model to evaluate the effects of sediment concentration and shear rate on the balance between breakup and aggregation processes was presented as:

$$\frac{dd_f}{dt} = \frac{k_A}{nf} C_c G d_f^{4-nf} - \frac{k_B}{nf} G^{q+1} (d_f - D_p)^p d_f^{2q+1} \quad (1)$$

Assuming the fractal dimension nf equals 2.0, under equilibrium conditions (i.e., $\frac{dd_f}{dt} = 0$), $d_{fe} \gg d_p$, and equilibrium floc size d_{fe} can be obtained:

$$d_{fe} = \frac{k_A C}{k_B \sqrt{G}} \quad (2)$$

Therefore, as indicated in Equation 2, the measured floc sizes $d_{e, avg}$ is expected to scale with $C/G^{1/2}$. C_c is the concentration of cohesive sediment. In this study it was found that the measured floc sizes $d_{e, avg}$ scales with $C^{(1-\frac{C_s}{C})^{1/2}}/G^{1/2}$ (Figure 5).

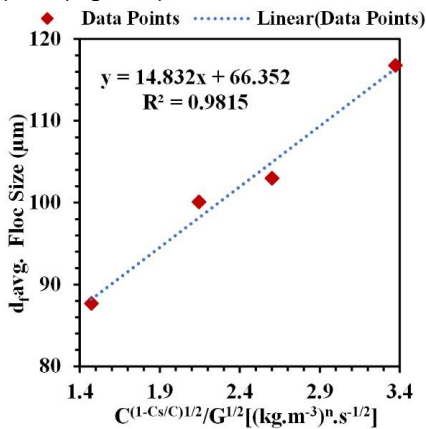


Figure 5 Variation in representative floc sizes ($d_{e, avg}$) versus flocculation parameters $C^{(1-\frac{C_s}{C})^{1/2}}/G^{1/2}$ at equilibrium.

CONCLUSION

In this study, a series of laboratory experiments were conducted using different mixes of pure clay and pure silt

under turbulent shear mixing in a stirred tank and subsequent size measurements in a settling column. The results demonstrate that the presence of pure silt in different proportions will affect floc properties, including the time evolution and equilibrium floc size and floc size distribution, relative to pure clay suspension under steady-state shear conditions. The silt particles in the clay-silt suspension mixture produced a smaller time evolution and equilibrium clay-silt floc size relative to the size of the pure clay floc. The correlation between maximal or average floc sizes and combined parameter $C^{(1-\frac{C_s}{C})^m}/G^{1/2}$ can be obtained.