How do floc characteristics change once they have deposited to a bed, and how, if at all, are they modified during re-entrainment? (Abstract: EP21E-1892)

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Introduction

Background: In many environments, recently deposited flocs (< 1 day) can be re-entrained by increases in stress at the bed. For example, flocs deposited to the bed during high or low slack may experience significant erosive forces during the ebb or flood. Being able to properly characterize this reentrainment process is important for adequately modeling mud transport in systems that see either simultaneous erosion and deposition of flocs (such as in a river or turbidity current) or systems that have periodic erosion and deposition (such as estuaries and fresh shelf deposits that are reworked by waves). Thus, in order to account for the re-suspension process of mud transport models, data and understanding surrounding the change in size of freshly deposited flocs, their resuspension efficiencies, and their change in size after resuspension are needed.

Research Questions: We examine whether or not flocs characteristics are modified during the re-entrainment process. Specifically, we investigate the following: **(1)** Does the flocs grow in size once deposited on a bed? and **(2)** What are the factors that dictate the re-entrainment efficiency which in turn influences the floc growth rate and equilibrium floc sizes after resuspension.

Methods and primary data

Two sets of laboratory experiments were conducted to examine the influence of re-suspension on floc growth rate and floc equilibrium size. In the first set of experiment (Set A), the cycle of high shear (40 s^{-1}) and low shear (10 s^{-1}) were applied to relatively low concentrations, i.e., 25 and 400 mg/L, of a suspension of mud. In the second set of experiment (Set B), the suspension of mud with a concentration of C = 10,000 mg/L was let settled in a certain time before the same shear rate (40 s^{-1}) was applied to re-suspend the deposited sediment. The experiments tested different consolidation times, or the time that sediment rested on the bed, at T = 6, 12 days and T = 6 hours (Fig. 1).

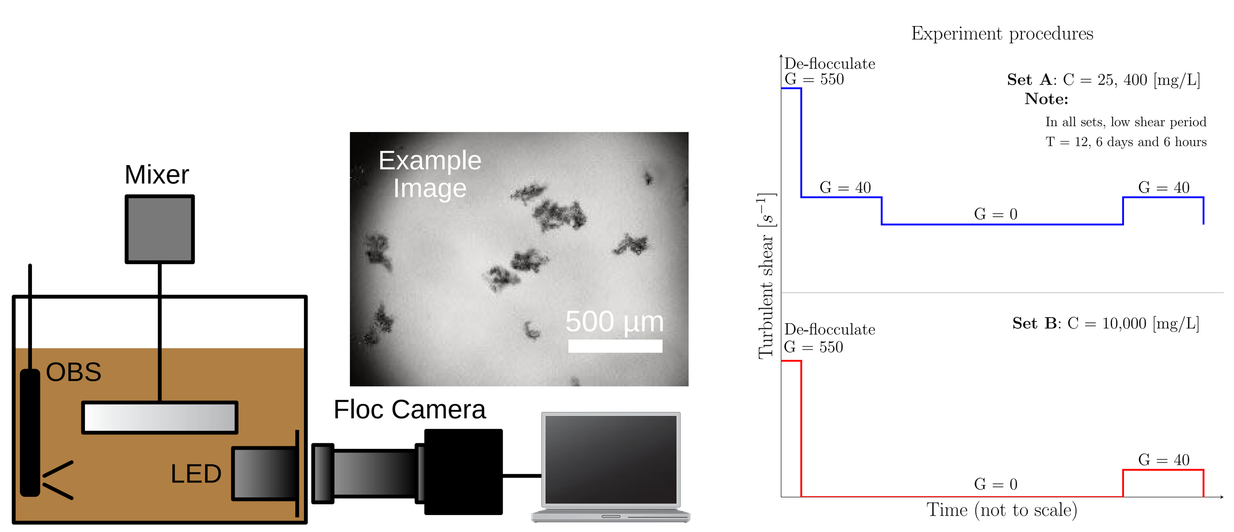

Figure 1: Experimental apparatus

The **primary data** from the experiments used to examine the research questions are the floc size distribution and concentration time series.

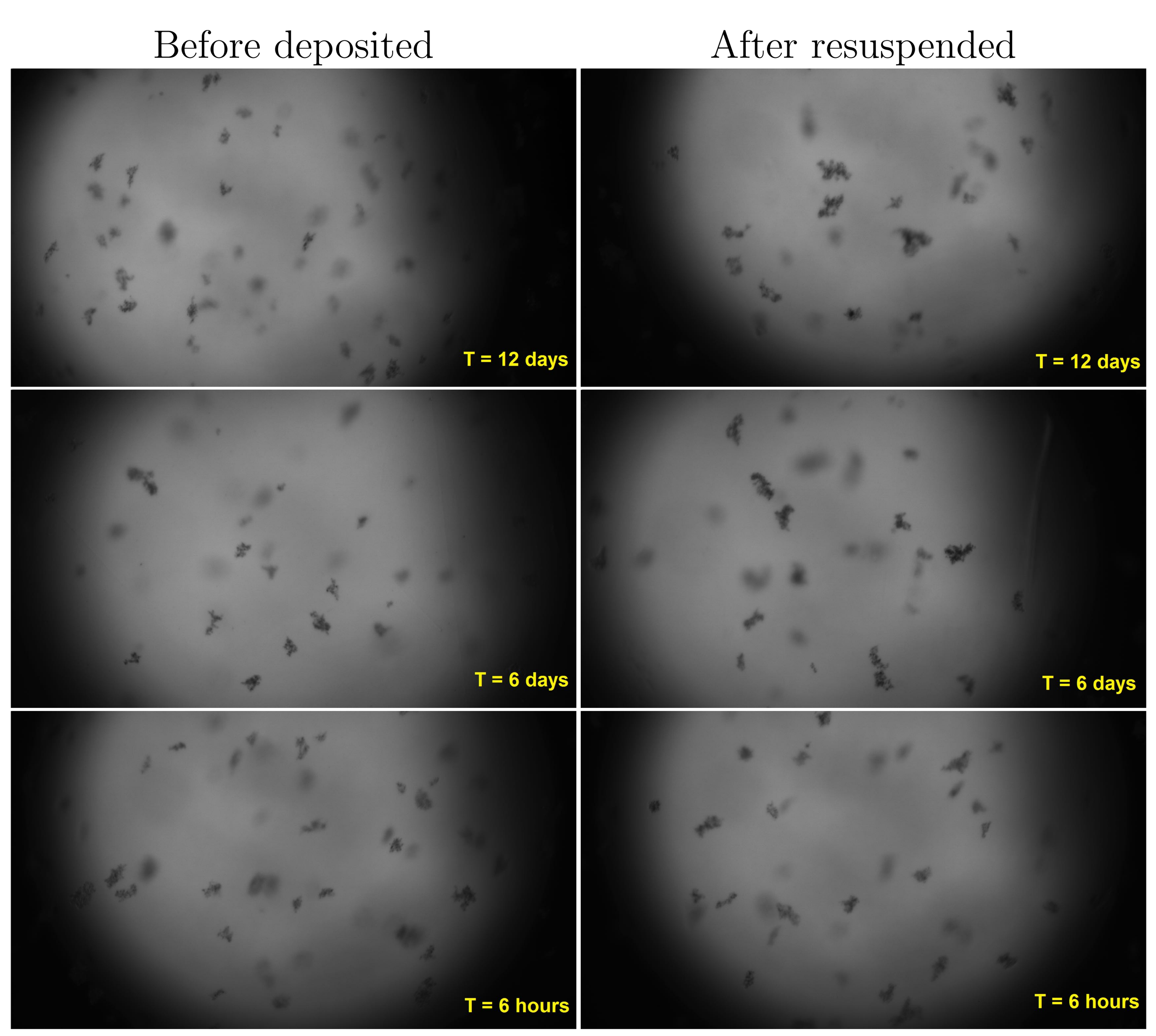

Figure 2: Sample images of equilibrium floc size before and after re-entrainment. The only difference in experimental condition is the consolidation time. From top to bottom the consolidation time reduced from T = 12, 6 days to 6 hours. In all experiments, 25 mg/L of clay is used.

Results

Results from the experiment (Figs. 2 and 3) show that there is a positive relationship between the consolidation time and equilibrium floc size after resuspended. Longer consolidation time resulted in larger resuspended floc but lower concentration of resuspension of mud.

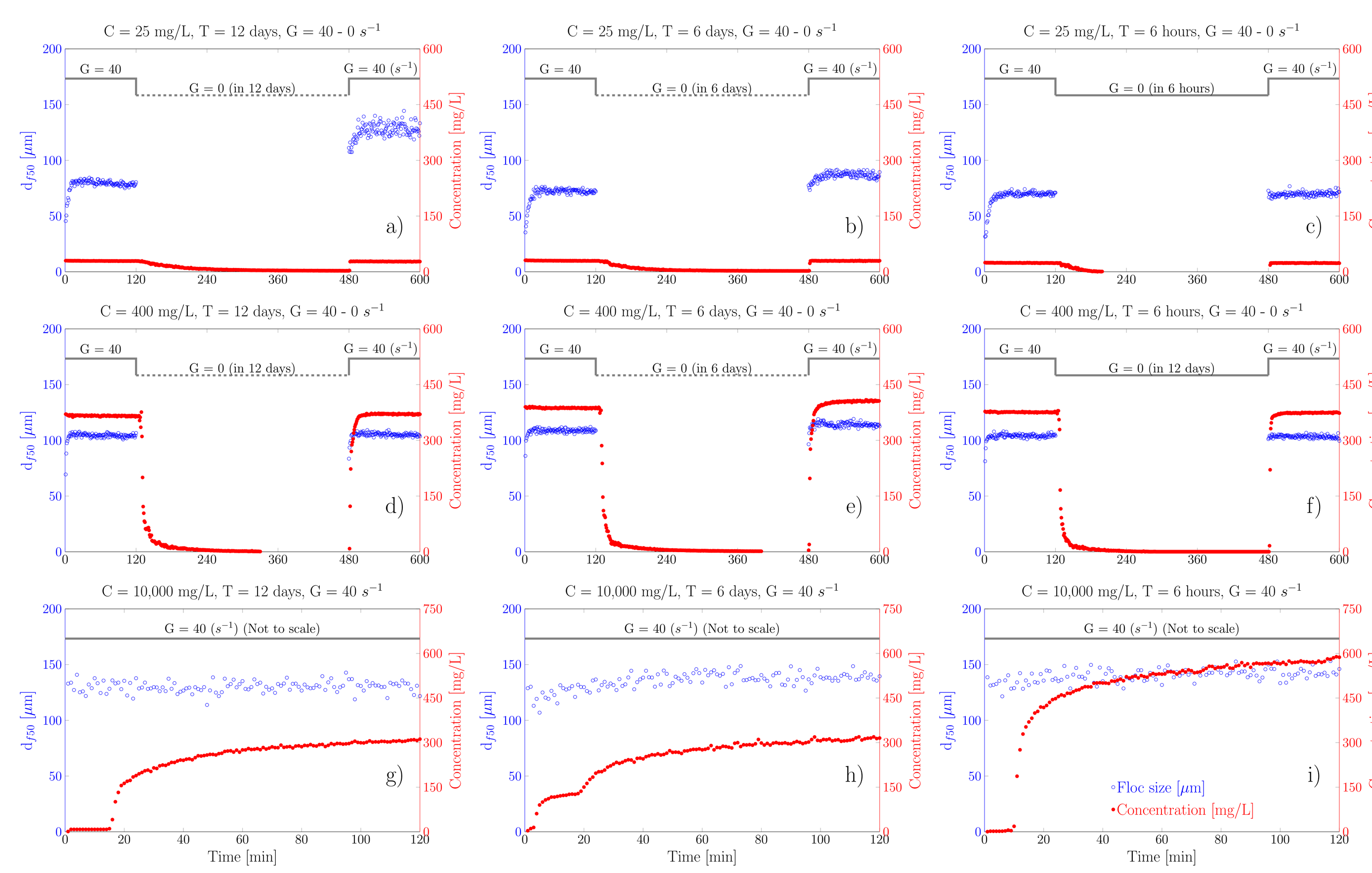

Figure 3: Floc size and concentration time series. Each row shows different concentration conditions, i.e., 25, 400 and 10,000 mg/L. Each column shows different consolidation time, from left to right T = 12, 6 days and 6 hours.

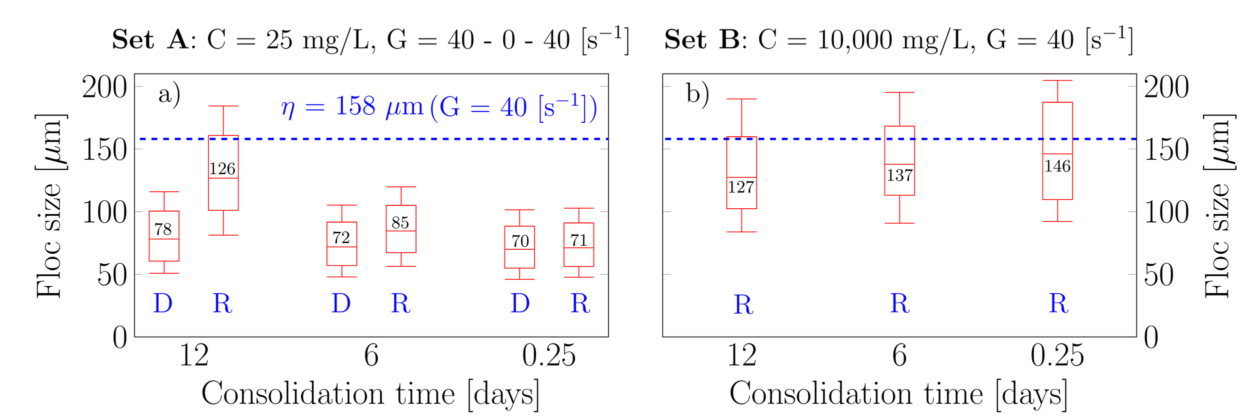

Figure 4: Floc characteristics before deposition and after resuspension in both Set A and B experiments. The data used to compute the floc characteristics is from the last five minutes at the end of each run. The bars in the boxplot from top to bottom present d_{f95}, d_{f84}, d_{f50}, d_{f16}, and d_{f5}. The number inside the boxplot is the value of d_{f50}. D stands for before deposit. R stands for after resuspend.

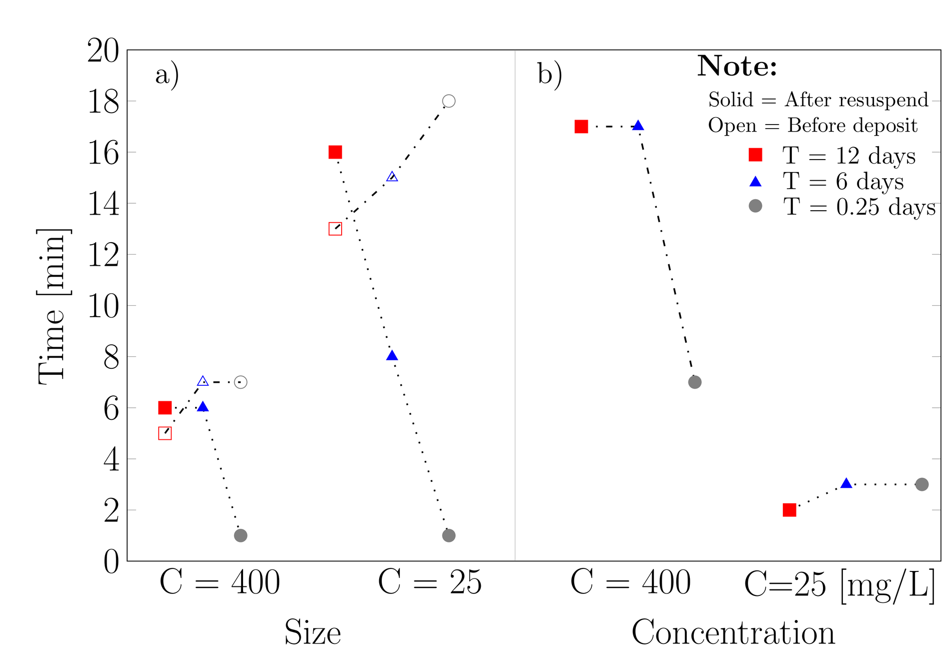

Figure 5: Time that floc size and concentration reach equilibrium. The data is from Set A experiments where the shear is always strong enough to resuspend all the deposited sediment.

Changes in floc size after resuspension

The floc sizes were modified during the re-entrainment process depending on the consolidation time and the concentration.

At low concentration, i.e., Set A, the resuspended-floc-size is **larger** than that of deposited-floc-size's. Figure 3. a, b, and c illustrate that at concentration C = 25 mg/L, the turbulent shear was vigorous enough to bring all the deposited mud into suspension; hence the concentration before and after re-entrainment were the same. However, the equilibrium floc size after re-entrainment was significant larger than when it deposited. Figure 4.a shows the floc characteristics before deposit (78 μm) and after re-entrain (126 μm) to the water column. The differences in equilibrium floc size reduces with shorter consolidation time (Fig. 3.a,b,c and 4.a).

Changes in floc size after resuspension (cont.)

In contrast, *at high concentration*, i.e., Set B (C = 10,000 mg/L), the resuspende-floc-size is **smaller** than the deposited-floc-size's (Fig. 3.g,h,i and 4.b). As can be seen in Figure 4.b, the re-entrained floc size get smaller with the increase of consolidation time. This phenomenon implicates that larger and stronger flocs still stayed on the bed and did not resuspend. In other words, the deposited floc becomes stronger during the consolidate time.

Decrease in re-entrainment concentration

The turbulent shear of G = 40 s^{-1} will resuspend the maximum capacity of mud that the shear can scour out of the bed and keep in suspension. In Set A, all deposited mud will be re-suspended once shear was applied. However, under an abundance mud environment, such as in Set B, the shear could not re-suspend all the mud on the bed. The strengthening of the bed with the increase of consolidation time manifest itself through the concentration time series data in Figure 3.g,h,i.

Time to equilibrium

Similar to the floc size and suspended concentration, the flocculation time is also a function of the 1) concentration and 2) consolidation time. Figure 5.a shows that the flocculation time is directly proportional to the time that the mud stayed on the bed. However, the impact of consolidation time on flocculation time was not as significant as the influence of concentration. As can be seen in Figure 5.a for concentration ranging from 25 to 400 mg/L, the magnitude of changes due to concentration are remarkable greater than that of changes due to consolidation time. Observation from Figure 3 and Figure 5 illustrate that flocs reach greater equilibrium size in shorter time which implicates that flocs did not really grow in size once it deposited, rather the floc strength was enhanced.

Concentration and consolidation time also play important role in modifying the time that suspended concentration needs to reach equilibrium. For low concentration, i.e., C = 25 mg/L, the required time for the system to get back to the level before deposit is somewhat independent of consolidation time (Figure 5.b). At high concentration, the consolidation time dictates the resuspension rate; yet such influence becomes unremarkable when T > 6 days.

What does it mean to re-entrainment modeling?

Erosion rate coefficient Equation 1 is a widely used erosion rate function in which the erosion rate coefficient, M, is very difficult to measure/model (Winterwerp et al., 2012; Mathew and Winterwerp, 2017). M is often kept constant, but also can be varied with time and depth. This study shows that the floc size and concentration reach equilibrium in the order of 20-120 minutes, implicating that during this period the erosion rate coefficient is a function of concentration, consolidation time. Beyond this time frame, it would be reasonable to consider the erosion rate coefficient is a constant.

$$E = M\left(\frac{\overline{\tau}_b - \tau_{cr}}{\tau_{cr}}\right) \quad (1)$$

Floc characteristics As show in Figures 3 and 5 the floc growth rate and equilibrium floc size were altered during resuspension process, particularly at lower concentrations. The strength of resuspended floc is expected to be slightly stronger than the deposited floc's. Further investigation is required to quantify if this modification would change the floc fractal dimension.

Conclusions

These experiments show that equilibrium floc size and flocculation time are modified during re-entrainment process resulting from the increase in floc strength during the consolidation. The increase in floc strength manifests itself through a larger equilibrium floc size at low concentration experiments (Set A) and/or lower resuspended concentration in high concentration experiments (Set B). The data also indicates that in the order of 20-120 minutes the erosion rate coefficient is a function of time, consolidation time and concentration. Beyond this time, it is reasonable to treat erosion rate coefficient is a constant.

References

Mathew, R. and Winterwerp, J. C. (2017). Surficial sediment erodibility from time-series measurements of suspended sediment concentrations: development and validation. *Ocean Dynamics*, 67:691–712.

Winterwerp, J. C., van Kesteren, W. G. M., van Prooijen, B., and Jacobs, W. (2012). A conceptual framework for shear flow-induced erosion of soft cohesive sediment beds. *Journal of Geophysical Research*, 117:C10020.