Sedimentation analysis of Montmorillonite flocs in a 2D slit between flat plates
2次元平板スリット間におけるモンモリロナイトフロックの沈降解析

Adachi Yasuhisa[1], Md Roknujjaman[1], Yoshida Keisuke[2], Muhamad Ezral Bin Ghazali[1], Li Jiawei[1], Kyotoh Harumichi[2], and Asada Yohei[1]

[1]Faculty of Life and Environmental Sciences, University of Tsukuba, [2]Department of Engineering Mechanics and Energy, University of Tsukuba

Abstract

The aim of this research is to examine the process of montmorillonite floc sedimentation within narrow gaps using PIV analysis. In this experiment, a green laser was instructed from above the slit container to analyze the velocity patterns and sedimentation behavior. However, cohesive montmorillonite flocs were utilized as tracers in this investigation. Consequently, our observations revealed that as the flocculation phase progressed, interactions among the flocs collapses, leading to a rapid sedimentation of the flocs. Furthermore, we observed that larger flocs settled more quickly in comparison to their smaller counterparts. Moreover, we found that an increase in the thickness of the slit container resulted in a higher maximum settling velocity and a shorter transition time from the flocculation stage to the settling stage.

Key words: Montmorillonite flocs, Sedimentation, PIV.

1. Introduction

The sedimentation behavior of flocculated materials is important for cohesive sediment transportation. In 1962, Michaels and Bolger introduced an analytical approach to hinder sedimentation in flocculated materials using kaolin suspension, requiring an assumption about the representative size of flocs [1]. They also highlighted the applicability of the formula derived by Richardson and Zaki in 1952 for monodispersed fluidized beds [2]. In our previous study, we reported the importance of the effect of cylinder heights in the generation of turbulent flow and container size [3, 4]. Increasing the initial height will promote the sedimentation rate due to the development of large flocs, which was regarded as the feed-forward mechanism. However, the observation has some limitation to the temporal changes of height and the maximum velocity of the interface boundary. For this reason, in this study, the characteristic of turbulence was demonstrated using Particle image velocimetry (PIV) in the sedimentation of 2D model flow except 3D model because 3D model is more complicated compared 2D model. Therefore, the primary aim of this research is to investigate the sedimentation behavior in a 2D flow using PIV analysis.

2. Experimental Setup and Material

The experimental layout illustrated in Figure 1. This container featured varying slit thicknesses of 10 mm, 15 mm, and 20 mm, respectively. We filled the rectangular settling container with prepared flocculated Na-montmorillonite, and the sedimentation process of the montmorillonite suspension in each container was illuminated using a laser sheet (Nd: YAG laser LA-D40-CW, Omicron, Germany). We captured the sedimentation flow within a 2D system using a NIKON D7200 digital camera (Nikon, Japan) at a frame rate of 30 frames per second (fps). The working liquid for this experiment was a mixture of water, Montmorillonite gel, and a sodium chloride solution. To prepare it, we first added 18.86 g of montmorillonite gel to 1L of water to achieve a volume fraction of 2.0×10^-4. Next, we introduced 1L of 2M sodium chloride solution to the montmorillonite suspension, resulting in a 2M NaCl montmorillonite suspension. For detailed instructions on the preparation of the montmorillonite sample and flocculated Na-montmorillonite, please refer to Ezral et al.'s paper [3, 4].

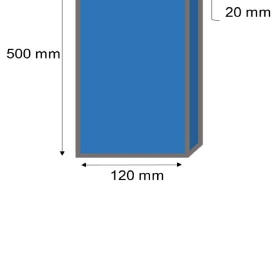

Fig. 1 Schematic diagram for the experimental setup using PIV technique.

3. Results and discussions

Fig. 2 illustrates the experimental results for a container with a 20 mm thickness of the floc growth over time. Initially, during the first 5 minutes, we observed the flocculated stage, characterized by particle diffusion and gradual floc formation. The flocs were initially small, resulting in a gradual decrease in the interface height. Over time, the flocs began to form a cohesive system. Subsequently, from 5 minutes to 20 minutes, the settling stage occurred, driven by the interactions among flocs formed during the flocculated stage. This led to a rapid sedimentation process, with larger flocs settling faster and collisions between flocs of different settling rates, promoting further floc growth and creating a downward flow. This process, known as the feed-forward mechanism, played a crucial role in expediting sedimentation.

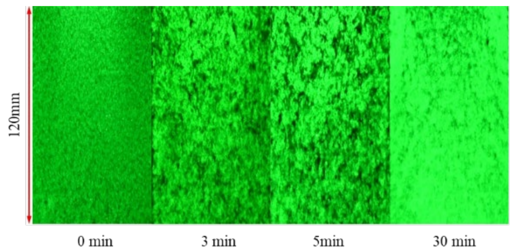

Fig. 2 Growth process of montmorillonite flocs over time

Furthermore, we examined the temporal changes in the settling interface boundary height for different initial suspension heights within rectangular containers of 20 mm and 15 mm thicknesses, as shown in Fig. 3. We found a sedimentation curve pattern similar to previous research [4] when analyzing the 2D behavior in these containers. The initial flocculation stage was notably apparent, particularly for higher initial suspension heights. Additionally, Fig.4 represents the comparison of velocity distribution based on container thicknesses of 10 mm, 15 mm, and 20 mm. We observed that as the container thickness increased, the maximum flow velocity also increased, and there was a tendency for the time required to reach this maximum velocity value, indicating the duration of the flocculation stage, to decrease.

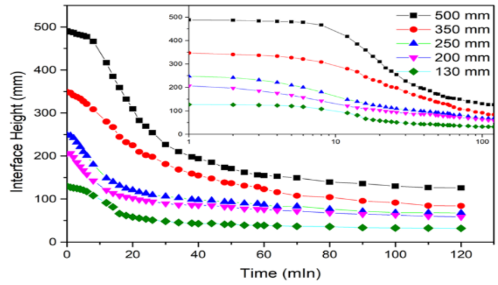

Fig.3 Interface height as a function of initial suspension height for sedimentation in the rectangular settling containers at 20 mm thickness

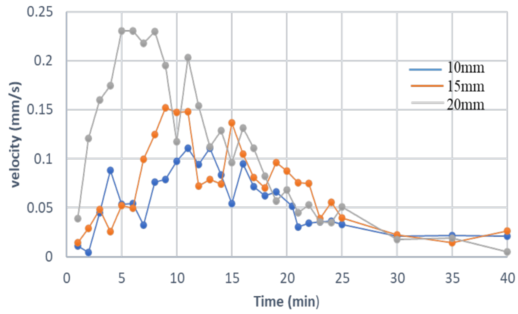

Fig. 4 Average flow velocity distribution using PIV analysis at different thickness of container.

Conclusion

In this study, the sedimentation behavior of montmorillonite flocs using a rectangular tank with a narrow gap in a 2D system was examined using PIV analysis. Based on our observation, we confirmed that at initial time, the particles gradually collide with surrounding particles as a result the size of floc were small but after increasing time, the floc interaction formed during the flocculated stage collapses, the flocs started rapid sedimentation. It was also observed that the larger floc settles more quickly compared to small flocs. Also, the presence of the initial flocculation stage was apparent in the case of higher initial suspension height. Additionally, as the thickness of the slit container increased, the maximum settling velocity also increased, and the time from the flocculated stage to the settling stage decreased.

References

[1] Michaels, A. S., & Bolger, J. C. (1962). *Industrial and Engineering Chemistry Fundamentals*, *1*(1), 24–33.

[2] Richardson, J. F., & Zaki, W. N. (1954). *Chemical Engineering Science*, *3*(2), 65–73.

[3] M.E. bin Ghazali, Y. Adachi, Colloids Surf. A. 630 (2021) 127–567

[4] Ghazali, M. E. B., Argo, Y., Kyotoh, H., & Adachi, Y. (2020). *Paddy and Water Environment*, *18*(2), 309–316