Migration and clogging of silty fines by two-phase flows and its effect on sediment permeability

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Introduction

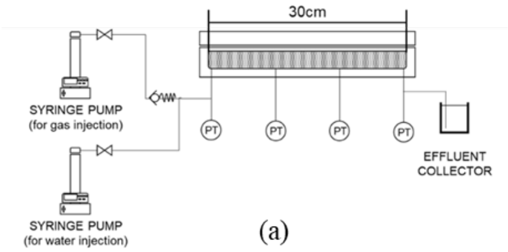
Depressurization of hydrate-bearing sediments (HBS) is considered as one of the most promising methods for methane production from natural gas hydrate deposits (Moridis et al., 2007), however the depressurization of HBS inevitably accompanies with various problems, including compression and mechanical failure of sediments (Kwon et al., 2013), sand production (Uchida et al., 2016), and fines migration (Lee et al., 2013). Recent trials of field-scale hydrate production tests (e.g., the Nankai Trough) have demonstrated that the solid transport, such as sand production and fines migration, can be a significant problem (Uchida et al., 2016). Furthermore, the fines migration can alter the hydro-mechanical properties of sediments hence deteriorate the long-term fluid productivity by increasing permeability where displaced, or by causing local pore clogging where deposited (Moridis et al., 2011). However, such transport behavior of fine particles and its impact on sediment properties remain poorly examined.

There have been studies that investigate the interactions among fluids, fines and pores to capture the dynamics of fines migration by physical experiments (e.g., Muecke, 1979; Wan and Tokunaga, 2002; Valdes and Santamarina, 2006; Jung et al., 2017). Particularly, it has been experimentally proven that the air-water interface enhanced fines migration and promoted pore clogging (Wan and Tokunaga, 2002; Jung et al., 2012). However, a quantitative analysis on the effect of fines migration on sediment permeability is yet limited. Therefore, this study explored the effect of fines migration induced by two-phase flows, and quantitatively analyzed the extent of fines migration and its effect on sediment permeability.

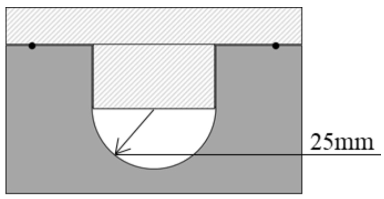
Materials and Methods

In our experiment, F110 sand (D_{50} = 142 μm) and silica silt (D_{50} = 20 μm, S_a = 4.2m^2/g) were chosen to represent the host sand and the fine particles, respectively. The F110 sand was specifically chosen because its grain size distribution was close to that of sand-dominant sediments in the hydrate deposits of the Ulleung Basin, offshore Korea (e.g., UBGH2-6B-22R, Cha et al., 2016). Nitrogen gas was used as a gas phase and deionized water was used as a brine phase for the two-phase flows.

All the fines migration tests were conducted in the 1-D flow cell of which the flow channel had a half-circle section with the diameter of 10 mm and the length of 300 mm, as shown in Fig. 1. The fines-sand mixed samples with 11% fine content (FC = 11%) were hand-tamped inside the 1-D flow cell. The samples were saturated with water and the initial permeability was measured prior to testing the fines migration (or clogging). Thereafter, the fluids, either single-phase fluid or two-phase fluid, were flowed at constant flow rates while monitoring the pressure changes at the four locations along the channel. When there was no further pressure change during the fluid flow, the test was halted and the cell was disassembled. In all cases, the post-sampling was conducted to determine the final fine contents along the channel. The experiments were conducted at various flow rates (Q = 5, 10, 20, 30, 40 ml/min) and with the various gas-water volume rations for the two-phase fluid flows (S_{gas}:S_{water} = 0:1, 0.25:0.75, 0.5:0.5; 0.75:0.25).



(a)



(b)

Fig. 1: (a) A schematic drawing of the 1-D flow test setup, and (b) the y-z sliced section of 1-D flow cell.

Results and Discussion

Pore clogging was confirmed with sudden pressure jumps during the flow. When there was no clogging, no pressure jumps were observed. As the flow rate increased, the clogging more readily occurred. Accordingly, we found clear transition zones of flow velocity above which clogging occurred and below which no clogging took place. Such transition zones appeared to exist at ~8–10 mm/s for the single-phase flows, and it was at ~2–4 mm/s for the two-phase flows, as shown in Fig 2a. These flow velocity values indicate the critical flow velocity above which the pore clogging readily takes place. Upon clogging, the sediment permeability significantly dropped by more than 50%. Complete clogging often led to the permeability reduction by more than one order of magnitude (Fig. 2a). Fig. 2b shows the local maximum FC changes (i.e., $\Delta FC_{max} = \max(FC_{final} - FC_{initial})$) for the tested cases. For the single-phase flows, ΔFC_{max} showed a clear increase in the clogging regime where the flow velocity was greater than the critical flow velocity. Contrarily, the two-phase flow test results showed an opposite trend to the single-phase flows, where ΔFC_{max} consistently decreased with an increase in flow velocity even though it is in the clogging regime for the two-phase flow conditions. In a water-saturated pore, the fines are spatially distributed fairly well, but, in a partially saturated pore with a gas bubble, the fine particles are likely to be aggregated at water-gas menisci. This fines aggregation at the gas-water interfaces increases the likelihood to cause clogging even with less travel distance of fines migration. Thereby, we presume that the decreasing ΔFC_{max} with increasing flow velocity implies that the clogging by fines occurred with less fines migration for two-phase flow conditions.

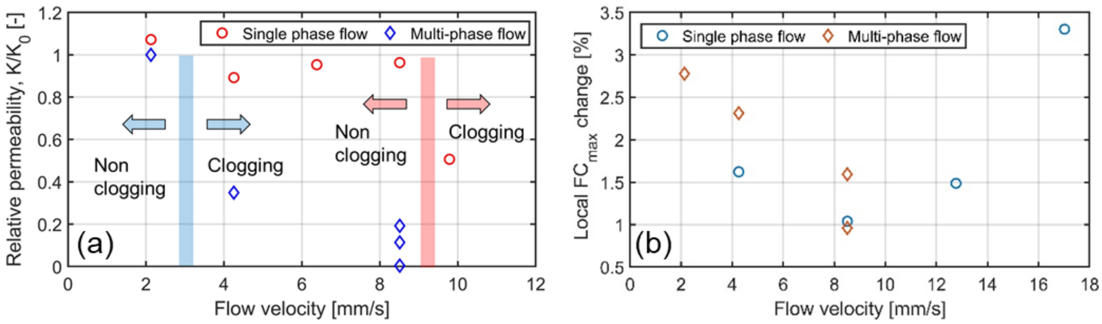


Fig. 2: (a) Relative permeability changes during the single- and two-phase fluid flow, and (b) the maximum variation of local fines content measured after experiment.

Acknowledgement

This research was supported by a grant(17CTAP-C129729-01) from Technology Advancement Research Program (TARP) funded by Ministry of Land, Infrastructure and Transport of Korean government, and by the National Research Foundation of Korea (NRF) grant funded by the Korea government (Ministry of Science, ICT & Future Planning) (No. 2017R1C1B2007173).

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