Fines migration and clogging behavior study using 2D micromodel

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ABSTRACT

Fines migration and clogging behavior in porous media have been studied for oil extraction, sand production in oil reservoirs, fracturing in sediments, and methane extraction from hydrate-bearing sediments, which are affected by fine particle-pore throat size ratio, fine particle concentration, ionic strength of fluids, and two-phase flow. While previous studies reported valuable results, the data are not enough to cover broad range of particle types and sizes, and pore-throat size in hydrate-bearing sediments. The impact of fines migration and clogging behavior during gas production from hydrate-bearing sediments has been studied using 2 dimensional micromodels with a wide range of fines sizes and concentrations. Results show that (1) the required fines concentration for the clogging decreases as the fine particle-pore throat size decreases, (2) the ionic strength affects clogging in pore throats that depends on the fine types, (3) the clogging easier occurs in two-phase fluids flow than single-phase flow.

Keywords: fines migration; clogging; methane hydrate; two-phase fluids flow, pore-fluid chemistry

1 INTRODUCTION

Fines migration and clogging behavior in porous media have been studied for several purposes such as oil extraction, sand production in oil reservoirs (Muecke 1979; Gruesbeck and Collins 1982), fracturing in sediments (Shin and Santamarina 2010), and methane extraction from hydrate-bearing sediments (Jung et al. 2012; Cao et al., 2018), which are affected by fine particle-pore throat size ratio, fine particle concentration, ionic strength of fluids, and two-phase fluids flow. While previous studies reported valuable results, the data are not enough to cover broad range of particle types and sizes, and pore-throat size in hydrate-bearing sediments. Also, methane extraction from hydrate-bearing sediments causes two-phase fluids (i.e., methane and water/brine) flow in porous media and water freshening in fluids, which influence on fine migration and clogging behavior. Thus, the impact of fines migration and clogging behavior during gas production from hydrate bearing sediments has been studied using 2 dimensional (2D) micromodels with a wide range of fines sizes and concentrations.

2 EXPEREIMENTAL STUDY

2.1 Materials

Silica silt, mica and kaolin have been used in this study, which are widely obtained in natural hydrate-bearing sediments. Table 1 shows particle sizes of fines used in this study. A wide range of fine particle concentrations have been used in this study between 0.1% to 20%. Also, deionized water (DW) and 2M brine were used to explore the effect of ionic strength on fine migration and clogging behavior.

Table 1. Particle sizes of fines

Fine particles	Median particle size (μm)
Silica silt	10.5
Mica	17
Kaolinite	4

2.2 Micromodels

2D micromodel have been developed in this study, which was made by polymetric materials known as polydimethysiloxane (PDMS, MacDonal and Whitesides, 2002). Fig. 1 shows the experimental setup consisting of a 2D micromodel, microscope, syringe pump, pressure regulator, ISCO pump, camera, and CO_2 cylinder. The size of 2D micromodel is 20 mm × 10 mm. D and o represent the circular host particle size and the pore throat size, respectively.

2.3 Experimental procedure

The system was cleaned with deionized water. Then, experimental setup was dried at the room temperature (25 ± 1 °C) for 72 hr and was assembled (Fig. 1). Deionized water (DW) containing fine particles was injected into 2D micromodel to saturate. After DW percolated the micromodel, 100 PV (pore volume) DW was continuously injected into the micromodel to make sure no change of particle concentration in pores. If clogging was observed at the given conditions (i.e., particle-pore throat size ratio and fine concentration), that fine concentration was defined as 'the critical clogging concentration'. If there was no clogging in pores, the next test was repeated with more fine particle concentration at the same particle-pore throat size ratio. Experiments was repeated until looking for then critical clogging concentration. After completion of single-phase flow tests, deionized water (DW) was withdrawn while CO_2 gas was injected into micromodel. The constant flow rate was controlled.

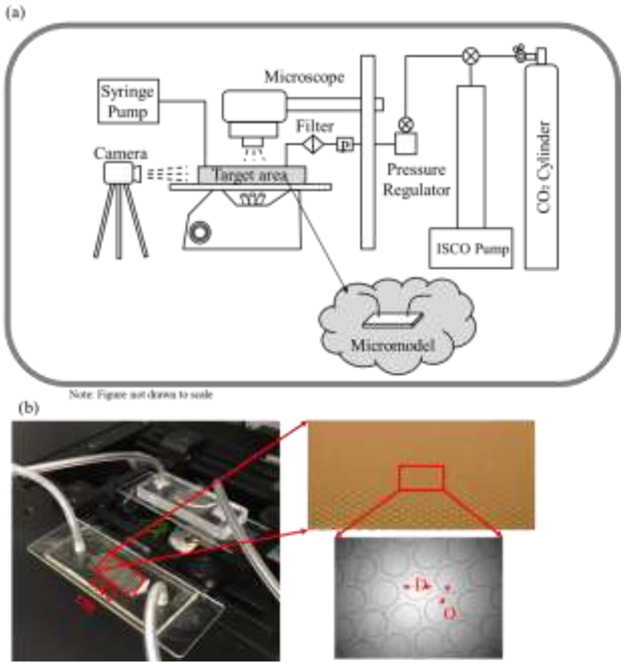

Fig. 1. The setup of 2D micromodel (Jung et al. 2018; Cao et al. 2018)

2.4 Results

Fig. 2 shows the effect of pore throat size on the clogging behaviors inside 2D micromodel. At the same 0.5% fine concentration, the clogging was observed at 40 μm pore throat size while there was no clogging at 60 μm. Generally, fine particle concentrations increased as the fine particle-pore throat size ratio decreased with all fines.

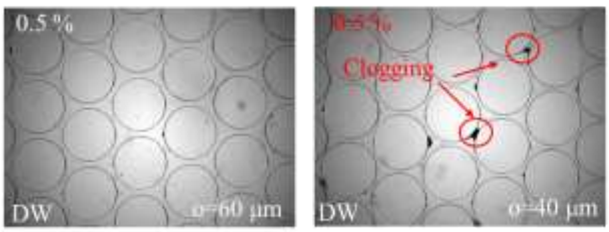

Fig. 2. Pore throat size effects on clogging behaviors during deionized water (DW) flow with kaolinite

Fig. 3 shows the effects of ionic strength of fluids on the clogging behaviors in pore throats. For the kaolinite, the clogging was not observed in deionized water (DW) but in 2M-brine at the same conditions (i.e., fine concentration, pore throat size). It implies that water freshening during methane production from hydrate bearing sediments including mainly kaolinite causes less clogging in pores.

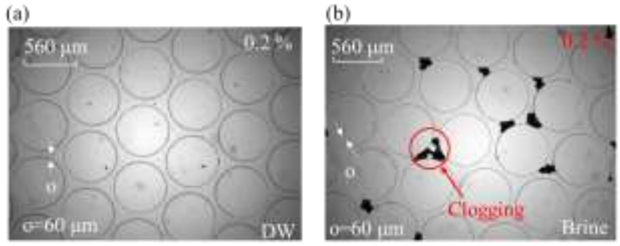

Fig. 3. The effects of ionic strength of fluid on clogging behaviors in pore throats; (a) DW with kaolinite, (b) 2M-brine with kaolinite

Fig. 4 shows the effects of ionic strengths for both silica silt and kaolinite. In case of mica, there was no difference between DW and 2M-brine. However, while the clogging of silica silts easier occurred in 2M-brine, kaolinite causes less clogging in 2M-brine except 60 μm pore throat size. It means that water freshening can cause more clogging during gas production from hydrate-bearing sediments including a lot of kaolinite particles. Thus, the decrease in relative permeability of hydrate-bearing sediments including mainly kaolinite particles can be expected, which causes the decrease in production efficiency.

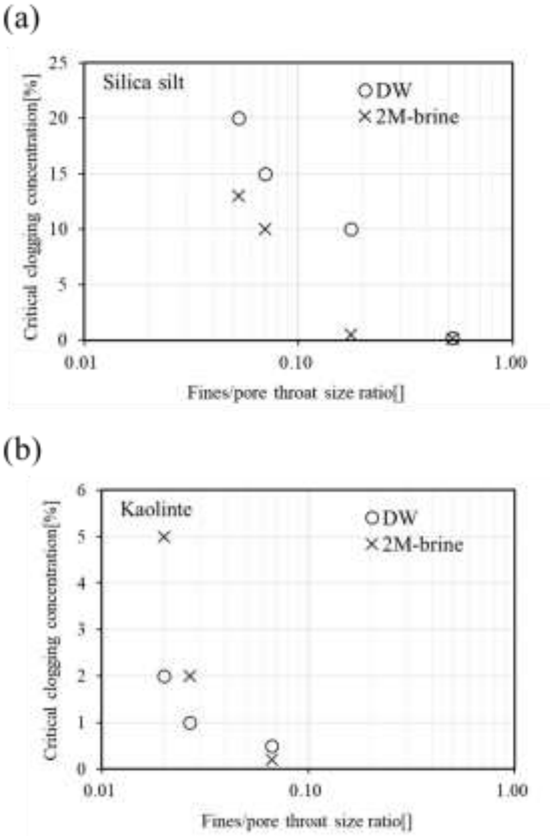

Fig. 4. The effects of ionic strength of fluids (DW or 2M-brine) on clogging behaviors in pore throats; (a) DW with silica silt, (b) 2M-brine with kaolinite.

Fig. 5 shows the effects of two-phase flow on the clogging behaviors in pore throats. Results show that clogging occurred during two-phase flow even though there was not clogging in single-phase flow. As two-phase fluids flow in the porous media, more amount of fine particles accumulates at the fluid-fluid interface, which causes the clogging in pore-throats.

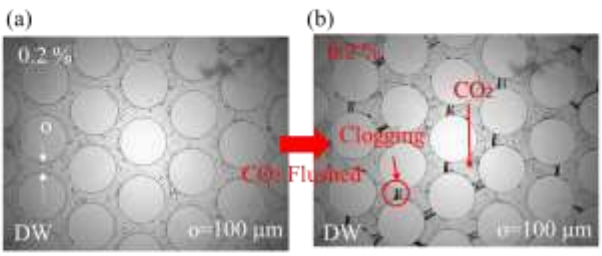

Fig. 5. The effects of two-phase fluids flow on clogging

Fig. 6 shows all experimental results with both single- and two-phase flow. In all cases, clogging can be easily observed in two-phase flow. Hydrate dissociation for the gas production generates both methane gas and fresh water into sediments, which causes the two-phase fluids flow in porous media. Thus, more clogging can be expected during methane extraction from hydrate bearing sediments.

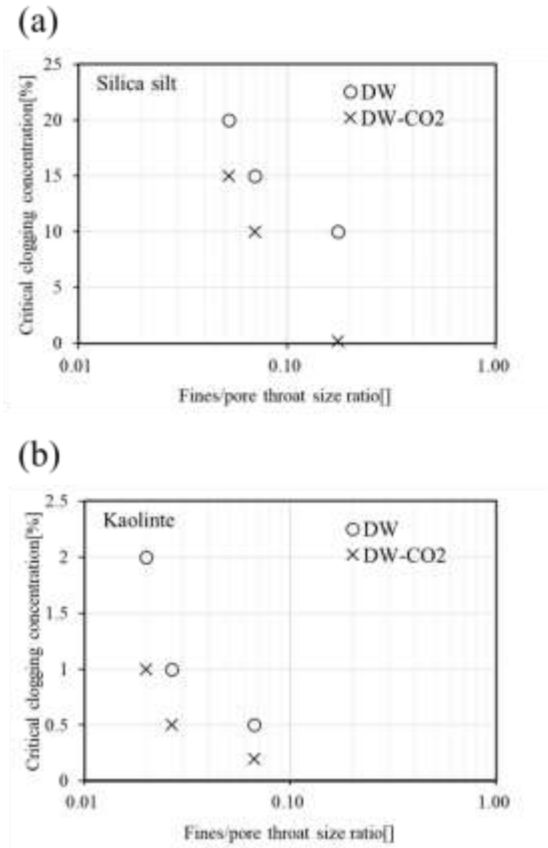

Fig. 6. The effects of two-phase fluids flow on clogging behaviors in pore throats; (a) silica silt, (b) kaolinite.

3 CONCLUSION

2D micromodel tests have been conducted to explore the effects of fine particles size, pore throat size, ionic strength, two-phase flow on fines migration and clogging behavior during gas production from hydrate-bearing sediments. Many findings of this paper are following;

(1) The critical clogging concentration is defined as the minimum fines concentration to initiate the clogging in pores at the given conditions such as pore throat size and particle size.
(2) Critical fine particle concentrations increased as the fine particle-pore throat size ratio decreased with all fines.
(3) Ionic strength influences on the fine clogging. For example, while the clogging of silica silts easier occurred in 2M-brine, kaolinite causes less clogging in 2M-brine. Also, mica shows no effect of ionic strength on the clogging. Thus, types of both fine particles and fluids are critical to affect the fines clogging.
(4) Clogging easily occurs during two-phase fluids flow comparing to single-phase flow. Thus,

easier clogging can be expected during methane production from hydrate-bearing sediments.

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REFERENCES

Muecke, T. W. (1979). Formation fines and factors controlling their movement in porous media. J Petrol Technol 31:144–150.

Gruesbeck, C. and Collins, E. (1982). Entrainment and deposition of fine particles in porous media. Soc. Petrol. Eng. J. 22 (2), 847–856.

Shin, H. and Santamarina, J. C, (2010). Fluid-driven fractures in uncemented sediments: underlying particle-level processes. Earth Planet Sci Lett 299:180–189.

Cao, S.C., Jang, J., Jung, J., Waite, W.F., Collett, T.S., Kumar, P. (2018). 2D Micromodel Studies of Pore-throat Clogging by Pure Fine-grained Sediments and Natural Sediments from NGHP-02, Offshore India. U.S. Geological Survey data release. https://doi.org/10.5066/P9PZ5M7E.

Jung, J.W., Jang, J., Santamarina, J.C., Tsouris, C., Phelps, T.J., Rawn, C.J. (2012). Gas production from hydrate-bearing sediments: the role of fine particles. Energy Fuels 26 (8), 480–487.

MacDonald, J.C., Whitesides, G.M., (2002). Poly (dimethylsiloxane) as a material for fabricating microfluidic devices. Accounts Chem. Res. 35 (7), 491–499.

Jung, J.w, Cao, S.C., Shin, Y.H., Al-Raoush, R.I., Alshibli, K., Choi, J.W. (2018). A microfluidic pore model to study the migration of fine particles in single-phase and multiphase flows in porous media. Microsyst. Technol. 24, 1071–1080.