Sand migration analysis in heterogeneous gas hydrate-bearing sediments during depressurization

Shun Uchida[1 *] and Yongkoo Seol[2]

[1] Rensselaer Polytechnic Institute, Troy, USA
[2] National Energy Technology Laboratory, Morgantown, USA
* uchids@rpi.edu

Introduction

Gas hydrate-bearing sediments are known to exhibit hydrate-dependent strength and stiffness. Through the phase change of solid hydrates into gas, the process known as hydrate dissociation, the sediments undergo complex stress redistribution and deformation. One of the key issues involving sediment deformation in gas hydrate reservoir is sand mobilization, which could potentially hinder gas productivity if flowing sands migrate into the well, as has been observed in the past field-scale gas production operations via simple well depressurization method (Dallimore et al., 2012; Konnno et al., 2017). Motivated by these incidents, Uchida et al. (2016a) developed an analytical thermo-hydro-mechanical sand migration model in gas hydrate-bearing sediments based on the assumptions that sand mobilization is primarily caused by sediment shear deformation and high hydraulic gradient. These two conditions tend to exist to a greater extent in gas hydrate reservoirs compared to conventional gas reservoirs because hydrate dissociation induces sediment deformation and introduction of gas into fully-water-saturated pores raises the hydraulic gradient. Furthermore, when hydrate dissociation propagates in non-uniform manner, there is possibility of additional shearing deformation due to differences in the rate of deformation. Therefore, this paper investigates the effect of hydrate saturation heterogeneity on sand migration.

Model description

This study adopts the thermo-hydro-mechanical sand migration model (Uchida et al., 2016a) that requires six parameters as listed in Table. 1. In simple terms, the model assumes that sand migration increases with shearing deformation and hydraulic gradient. The parameters ω_1 and ω_4 entail shearing deformation and are thus positively correlated to sand migration. In contrast, ω_3 and i^{cri0} are related to the critical hydraulic gradient (below which no sand mobilization occurs) and thus negatively correlated to sand migration. The parameter ω_2 determines the rate of sand mobilization and is selected to be large enough to have no rate dependency. The parameter ω_5 makes migrating solids settle but this phenomenon is not considered in this study. The values of these parameters are therefore important and require rigorous evaluations. However, the focus of this study is to better understand the effect of hydrate heterogeneity on overall sand migration. Therefore, for simplicity, this study employs the values used to match overall produced sand at the Nankai 2013 gas production test (Uchida et al., 2016b).

Table 1: Sand migration model parameters

Symbol	Physical meaning	Value
ω_1	Stress reduction due to sand mobilization	1.0
ω_2	Rate of sand mobilization	0.1 hour^{-1}
ω_3	Critical gradient increase with hydrate	3.0
ω_4	Shearing to mobilization potential conversion	1.0
ω_5	Settling/lifting for migrating sands	0
i^{cri0}	Critical gradient	5.0

Two cases are considered in this study, one is homogenous hydrate-bearing sand reservoir with 80 % of hydrate saturation and the other is heterogeneous hydrate-bearing sand reservoir with series of alternating hydrate saturations of 75 % and 85 %, as illustrated in Fig.1. For simplicity, this study focuses on a 1-m-section of the hydrate reservoir. To facilitate this simplification, the vertical boundaries are assumed periodic (no mechanical deformation and no mass flow). The well boundary is mechanically fixed but open for mass flow including migrating sands. The initial temperature is T = 19.4^{o}C, the initial pore pressure is P_w = 28.5 MPa, the initial effective vertical stress is σ'_z = 2.8 MPa, the intrinsic permeability is $\mathbf{K}$ = 1000 mD and the effective permeability is derived by using the power of 4.2, that is, $\mathbf{K}(1\text{-}S_h)^{4.2}$ where S_h is the hydrate saturation. For gas production, the well pressure is lowered to 3.5 MPa over two days and kept constant thereafter.

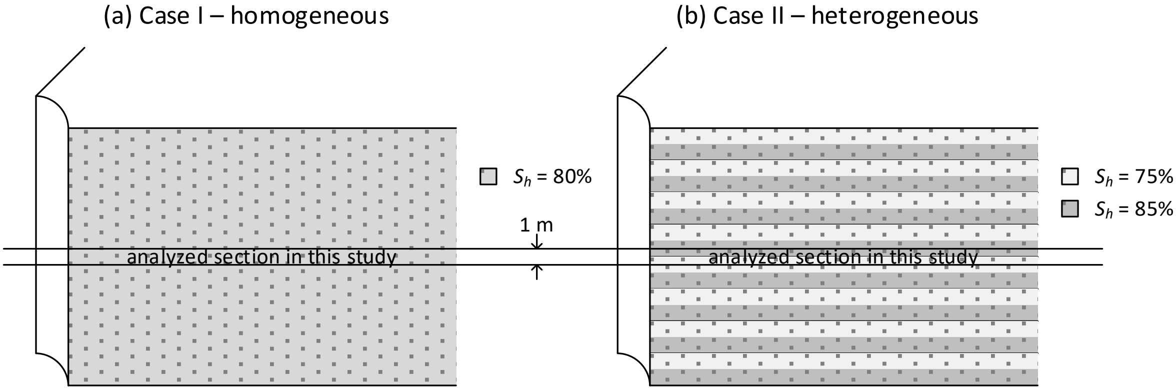

Fig. 1: Model geometries considered in this study

Key findings

Fig. 2 presents the development of the area where the sands are mobilized for the two cases. It is clear that the development of sand migration is affected by the heterogeneity. The important feature due to heterogeneity is that the upper layer (contains more hydrates) near the wellbore induces greater sand migration. The lower layer is initially more permeable and thus hydrate dissociation occurs relatively quicker, leading to stress relaxation. This is followed by stress redistribution from the lower to the upper layer (still relatively stiffer), making the upper layer carry greater effective stresses. With time the upper layer also undergoes hydrate dissociation, deforming more than the lower layer. Because of this, sand migration occurs eventually more in the upper layer. This highlights the importance of incorporating the heterogeneity in hydrate saturation to accurately capture the sediment deformation pattern and, consequently, sand migration.

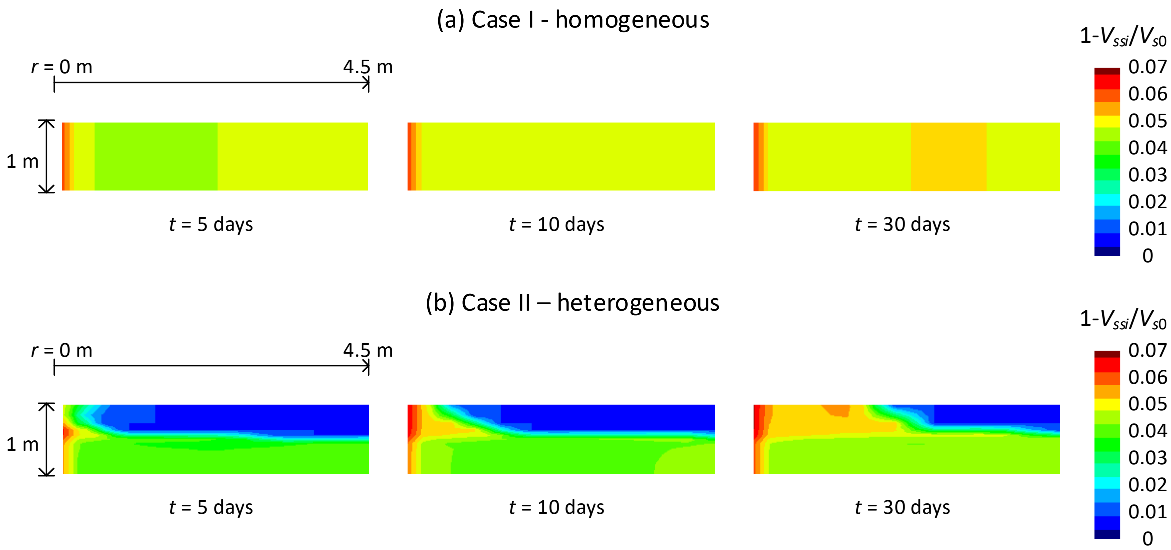

Fig. 2: Development of sand mobilization near the well

References

Dallimore, S. R., Wright, J. F., Yamamoto, K., Bellefleur, G. (2012) Proof of concept for gas hydrate production using the depressurization technique, as established by the JOGMEC/NRCan/AURORA Mallik 2007-2008 gas hydrate production research well program, Mackenzie Delta, Northwest Territories, Canada. Bulletin of the Geological Survey of Canada 601: 1–15

Konno, Y., Fujii, T., Sato, A., Akamine, K., Naiki, M., Masuda, Y., Yamamoto, K., Nagao, J. (2017) Key findings of the world's first offshore methane hydrate production test off the coast of Japan. Energy & Fuels 31 (3): 2607–2616

Uchida, S., Klar, A., Yamamoto, K. (2016a) Sand production model in gas 365 hydrate-bearing sediments. International Journal of Rock Mechanics and Mining Sciences 86: 303–316

Uchida, S., Klar, A., Yamamoto, K. (2016b) Sand production modeling of the 2013 Nankai offshore gas production test. In: Energy Geotechnics 1: 451–458