Numerical study on the interaction of solid grains with fluid in the production of natural resources

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The sanding is recognized as one of the main problems in producing hydrocarbon resources. Although it is important to predict the occurrence of the sanding during production, the prediction or countermeasure still remains to be established. In this study, we conduct numerical simulation of fluid-solid multi-phase flow in order to investigate the factors which affect the occurrence of the sanding. Our numerical model is a fluid path consists of a set of planar plates of a finite length filled by fluid and a mound of small solid grains. A fluid flow is produced by the pressure gradient with different magnitudes between the both end of the path. We found that a few small grains leave the mound with a high pressure gradient whereas no floating grains were observed with a low pressure gradient. We also observed a reasonable change in the flow velocity and relative permeability when the floating of small grains occurs. This result indicates that the sanding can be detected by observing the time variation of flow rate during production.

1. INTRODUCTION

In the circumstances that there is no change in the increase of the demand of energy resource all over the world, we need to try to fulfill the demands at every moment. This requires not only exploring new reservoirs but also enhancement of production of hydrocarbon resources. One of the main problems affecting the amount of production is the sanding phenomenon that is caused by small sand or the other types of solid grains stagnating the flow pass. Although the importance of the phenomenon has been recognized, symptomatic treatments are only to be employed to keep the production on-going but not so many theoretical work has been done.

In our previous study[1)], we study the sanding phenomenon in a porous medium using numerical experiments based on the smoothed particle hydrodynamics (SPH) method. Their results demonstrated the importance of small sand grains in terms of the influence to the fluid flow. Unfortunately, they assumed sand particles had started flowing with the fluid and they did not discuss how the sanding had taken place. It is therefore necessary to take into account how sand particles starts floating in the flow.

In the present study, we focus on the generation of small grains using some numerical experiments. We use the SPH method as a numerical simulation method, and examine the condition of generation of sanding phenomenon.

2. NUMERICAL METHOD

In this research, we use SPH method which is one particle methods. In particle method, simulation model is constructed by finite number of particles. All particles can move freely from mesh and have physical quantity independently[3)]. The physical quantity of a particle **A** is computed by summation of physical quantity of surrounding particles.

$$A(\mathbf{r}_i) = m_j(A(\mathbf{r}_j)/\rho_j)W(\mathbf{r},h) \quad (1)$$

In equation (1), m is mass of a particle and ρ is density. W is the weighting function.

We move all particles according to the Navier-Stokes equation.

$$Du/Dt = -(1/\rho)\nabla P + \nu \Delta u + f \quad (2)$$

P is pressure and u is velocity of a particle, ν is viscosity kernel and f power from outside. We cannot compute the power by collision of sand grains with SPH. So, we use the distinct element method (DEM) for solid grains.

$$\mathbf{F}_{x,ij} = \mathbf{k}_x * \mathbf{dx}_{ij} + \mathbf{c}_x * (\mathbf{dx}_{ij}/dt) \quad (3)$$
$$\mathbf{F}_{y,ij} = \mathbf{k}_y * \mathbf{dy}_{ij} + \mathbf{c}_y * (\mathbf{dy}_{ij}/dt) \quad (4)$$

K is spring kernel and **c** is dashpot kernel. We assume sand grains rigid body. In every step we modify sand grains to keep ordinary shape.

3. SIMULATION MODEL

We set simulation model in a parallel plate with horizontal length of 5.0mm and vertical width of 1.0mm. Before simulating generation of sanding, we have to make a mound of sand grains in the parallel plate. We use the falling method with gravity to make it. In the falling method, each sand grain falls from random position to the position.

Figure 1 shows the snapshots of distributions of small grains at initial and final states. We have 100 small grains between the channel, and the radius of each grain is 50 μm. The grains form a mound under gravity force as shown in the lower figure. We start flow simulation using the final condition by applying the pressure gradient. Table 1 shows the parameters used in this study. We change the pressure gradient to investigate the generation of the sanding. Under three different pressure gradient, we examine whether sand grains float into the flow or not.

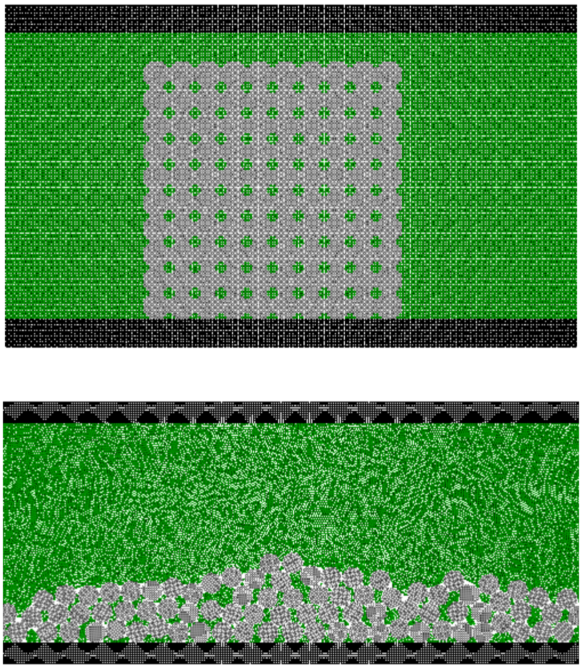

Figure 1 Two phase of simulation model: upper: initial state, lower: final state.

Table 1 Simulation parameters

Water density	1014(kg/m3)
Sand density	2535(kg/m3)
Viscosity	0.001(kg/m/s)
Simulation time	1.05(s)
Pressure gradient (Model 1)	101.4(Pa/m)
Pressure gradient (Model 2)	304.2(Pa/m)
Pressure gradient (Model 3)	507.0(Pa/m)

4. RESULTS

In Figure 2, we show the snapshots at the same time in different models: model 1 and model 3. From these pictures, only in model 3, two sand grains floated into the fluid. We color these grains in orange. In Figure 3, we show the time variation of fluid velocity. Floating has occurred only in model 3. We calculated fluid resistance from the Stokes's low. Representative length is radius of sand grains and representative velocity is fluid velocity. The value of fluid resistance that sand grains need to float is between 3.4$*\mathbf{10^{-8}}$ to 5.7$*\mathbf{10^{-8}}$.

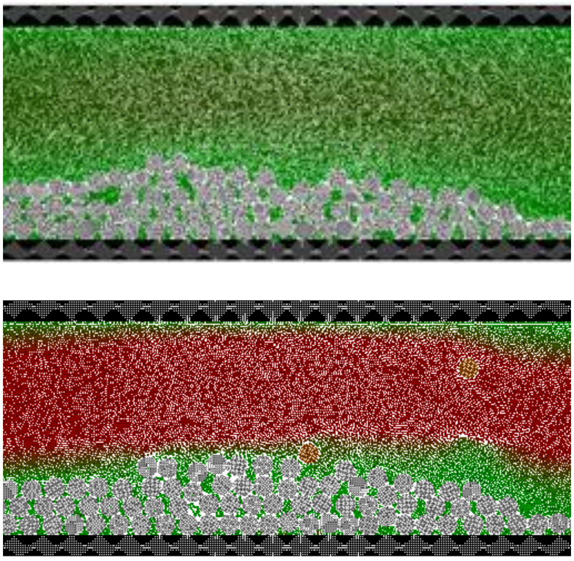

Figure 2 Snapshots in the different models at the same time (1.04s). Upper is in model 1 and lower is in model 3.

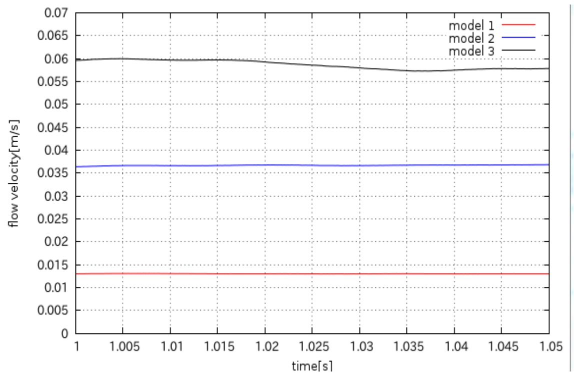

Figure 3 Time variation of fluid velocity graph of every model

We also calculate the permeability change of model 3 to investigate the effect of the sanding on fluid flow. Figure 4 shows the relative permeability change with time. After floating grains into fluid flow (1.02s), the relative permeability starts to increase. These results indicate that the generation of floating sand grains can be detected by changing flow rate during production.

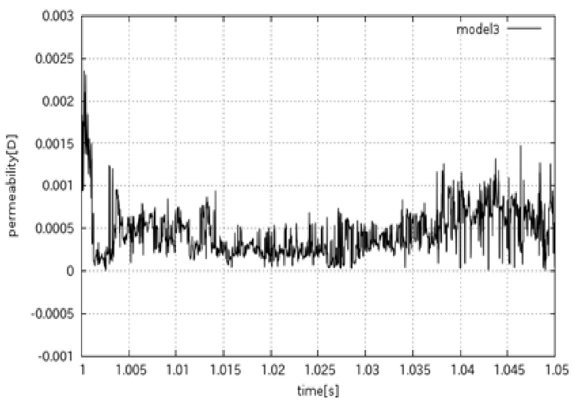

Figure 4 Permeability change in time

5. CONCLUSION

We investigate the effect of pressure gradient on the generation of floating sand grains. We simulate fluid-solid multi-phase flow under different pressure gradient using the SPH method. The result shows that the floating grains can be observed only in the high pressure gradient case. Furthermore, the generation of the floating grains affects the flow velocity and the relative permeability. This result indicates that the occurrence of the sanding can be suppressed by controlling the flow velocity in a reservoir, and captured by time variation of flow rate during production.

REFERENCES

1) Tanimoto, N., Mikada, H., and Takekawa, J., 2016, Simulation changing permeability due to flowing solid particles using SPH, Kyoto Univ., Grad. thesis.
2) Otsuki, S., 2010, Applications of Solid-Liquid Two-phase System to Resource Engineering by Using Hybrid LB-DEM Simulation, Kyoto Univ., ph.D.thesis.
3) Carlson M, Mucha P. J., and Turk, G., 2004, Rigid fluid: Animating the interplay between rigid bodies and fluid. In ACM SIGGRAPH 2004 Papers, SIGGRAPH 2004, 377-384. DOI: 10.1145/1186562.1015733