The effect of flowing small particles on flow characteristics and closure of pore in porous media

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Sanding is one of problems which prevent efficient producing in oil fields. When we produce fluid resource, small sand particles are generated by breaking of reservoir rocks. These particles flow with fluid resources and prevent its ample liquidity. This results in the reduction of production. Since the sanding results in the reduction of production, it is important to understand the mechanism of the sanding in order to formulate an effective policy. For the fundamental study to know the mechanism, we researched about how each fluid parameter work to that phenomenon by numerical simulation. From the result, when viscosity of fluid is higher, the effect of flowing particles becomes lower. And closing of pore gives effect to producing efficiency until it breaks.

1. INTRODUCTION

In oil production field, sanding is known as very important problem. It is important to control the sanding to keep stable production. So, some scholars studied about how to prevent sand production by the failure of rock with a rock-mechanics. When the effective stress in a reservoir rises, sand particles are caused[1)]. Some scholars have studied the mechanism of sanding (e.g. Otsuki et al, 2010[2)]). However, the effect of sand particles on decrement of production efficiency has not been investigated yet. The reduction of production efficiency by sand particles has already discussed, but the effects of some fluid parameters have not been studied[3)]; e.g. fluid viscosity, pressure gradient, etc. We need to investigate the effect of viscosity and pressure to the decrease of production efficiency by the sand grains because these parameters are primary in any other resource production phenomena.

In the present study, we researched about the effect of fluid viscosity and pressure gradient on the permeability of porous medium. We also consider the shape of sand particle. To make arbitrary shapes of sand in simulation model, we use the smoothed particle hydrodynamics (SPH) method. We researched about the effect of these parameters on flow properties.

2. METHOD

In this study, we use SPH method, which is one of particle methods. Particle method is meth free method. Model is made of finite number of particles. The physical quantity of a particle A is computed with weighting function W.

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

In this equation, r_i is the position vector of particle i, m_j and ρ_j are the mass and density of particle j. And h is the radius of an effect domain. We solve the Navier-Stokes equation to simulate incompressible viscous flow.

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

The first part of right hand means force from pressure gradient, second means force from viscosity, third means external force. Gradient and Laplacian terms in equation 2b are computed with the gradient and Laplacian of W. We move all particles from the equation in every time step. Particles can move freely from meth.

When SPH particles make sand grains, we add one more computation on fundamental computation of SPH, which is written in above in every step. By this computation, sand grains can maintain their shapes. These particles have different positions and velocities from particles make fluid. And they affect to fluid particles in next step. So, it can make interaction between solid and fluid.

The force works between two sand grains are computed by the discrete element method (DEM). If two sand grains are overlapped, the repulsive force works on these two particles. The magnitude of the repulsive force is computed by following equation.

$$F_n = k_n * U_n \quad (3)$$
$$F_s = k_s * U_s \quad (4)$$

In equation (3) and (4), kn and ks are spring constants for normal and shear direction. And Un and Us is overlapping length in each direction.

Simulation models are made between parallel prates. Horizontal length of this is 6.5mm and vertical width is 1.0mm. in center area of model, we set several circular solids. These solids and prates make porous medium. In left side of this area, we set small solid particles they role sand grains. Other part of model is filled up by fluid. At the start of simulation, fluid flow is driven by external force. After 1s passed, we release sand grains. It mimics stable flow with sand grains. Grains flow in porous medium, the permeability of that decreases by grains. We record the decreasing quantity from standard permeability: the permeability when no particle is.

To research the effect of fluid and sand parameters on permeability, we make 5 models which have different parameter. Parameters of every 5 models are in table 1. We simulated 10 times in every model. In every simulation, the initial position of 30 sand grains changes. From the results of these simulations, we studied about the qualitative effect of viscosity, pressure gradient, and shape of grains.

3. RESULTS

In every experiment, permeability decreases due to the sand grains flowing in. And when grains close a pore, permeability decreases more. In one simulation, grains close a pore and keep closing. And the other simulations, closing get broken immediately. In figure 1, we show change of permeability by time. The black line shows the result of simulation where closing keeps. And red line shows the result of a simulation where closing occur and break immediately. From the comparison of these graphs, maximum decrease in red line is bigger than that of black line, but at the end of red line, permeability decrease is nearly zero: permeability become the same as standard permeability. Against in black line, permeability decrease keeps 20% to the end. So, from that, we find that closing of pore affects permeability until it gets broken.

And, we show the maximum permeability decrease in every 50 experiments. Figure 2 shows the comparison of results between two models where viscosity is different. Figure 3 shows that between two models where shape of particle is different. And in Figure 4 shows that among three models where pressure gradient is different.

From figure 2, result in Model 2 is almost smaller than that in Model 1. In simulation number 2, sand grains close a pore. So, we find that when viscosity is higher, the effect to permeability become smaller if grains does not close a pore. From Figure 3, results in Model 3 don’t change very much. As shown in the above, when grains close a pore, permeability decreases drastically. We find that when shape of grains is square, grains rarely close a pore. And from Figure 4, we can’t see any characteristic among the results in Models 1, 4 and 5. So, we find that the influence of pressure gradient is small.

	Model 1	Model 2	Model 3	Model 4	Model 5
Density (kg/m^3)	1014	814	1014	1014	1014
Pressure gradient (Pa/m)	101.4	81.4	101.4	50.7	152.1
Viscosity (kg/m/s)	$1.0*10^{-3}$	$2.0*10^{-3}$	$1.0*10^{-3}$	$1.0*10^{-3}$	$1.0*10^{-3}$
Shape of sand grains	circular	Circular	Square	circular	circular
Simulation time (s)	2.15	3.2	2.15	3.2	1.8

Table 1: fluid and solid parameters in each model

4. CONCLUSIONS

In this study, we research about the effect of fluid and sand parameters to sanding with numerical simulation. We simulate porous flow with sloid grains and record permeability changes. From the results, we find some knowledge. First, closing of pore affects permeability until it breaks. Second, high viscosity counteracts the effect of sand grains. Third, when sand grains have square shape, they rarely close a pore. Finally, the magnitude of pressure gradient doesn't give big effect.

In the future, we plan to study about the mechanism of sand production in consideration of blowing up of sand grains by fluid friction.

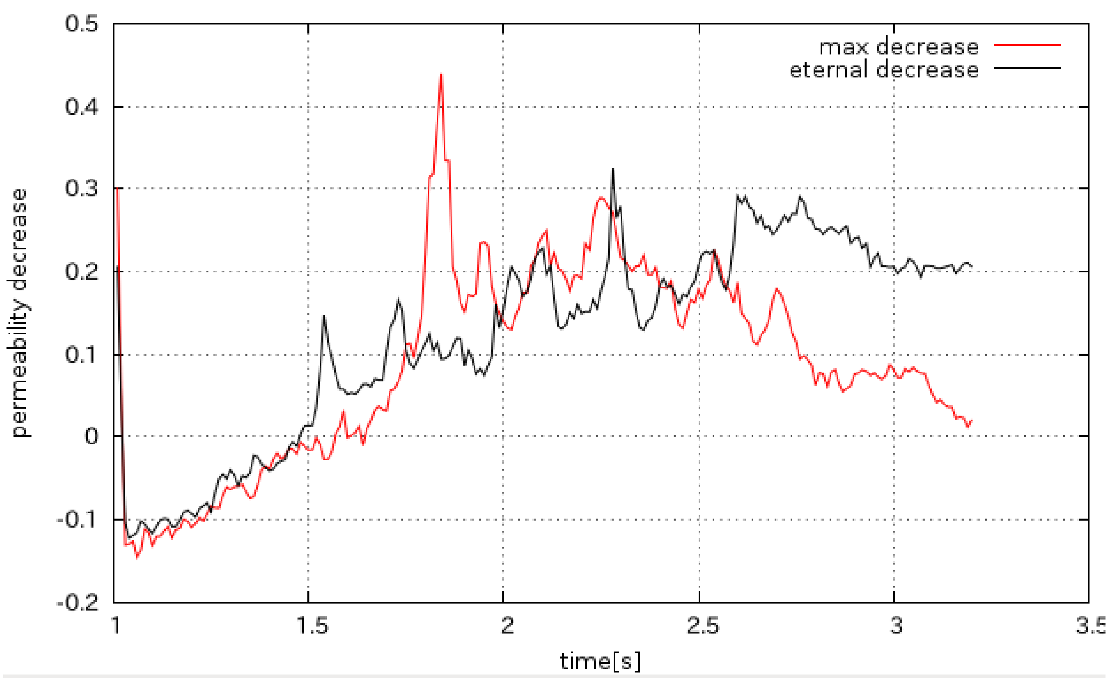

Figure 1: permeability decrease by time in two experiments

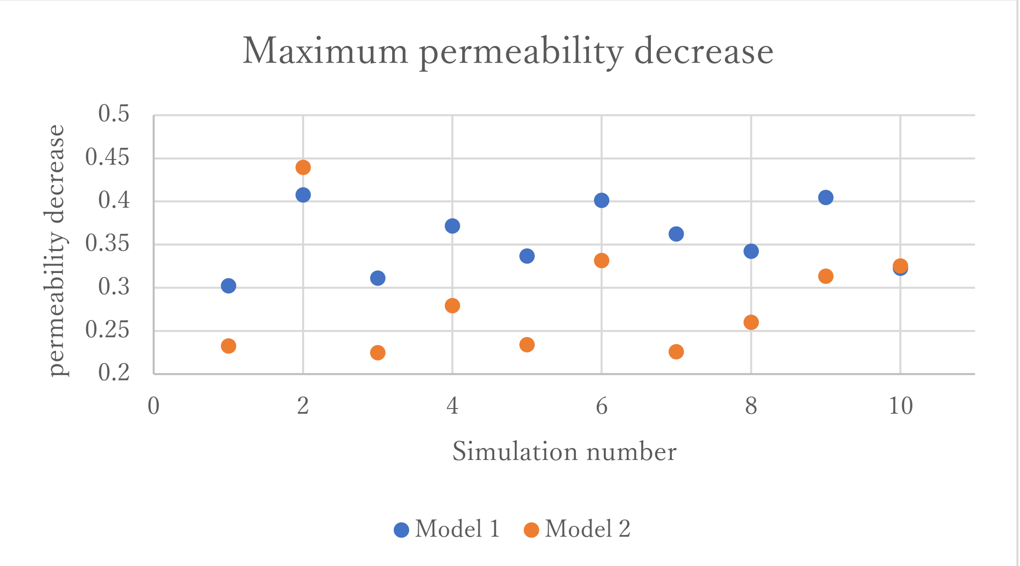

Figure 2: Maximum permeability decrease in Model 1 and 2 experiments

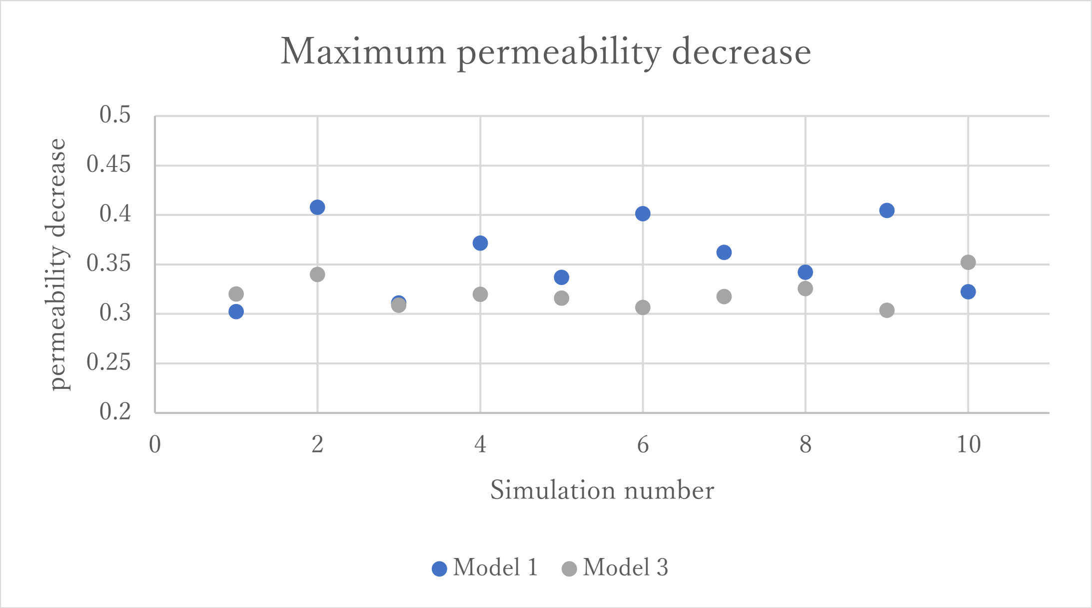

Figure 4: Maximum permeability decrease in Model 1 and 3 experiments

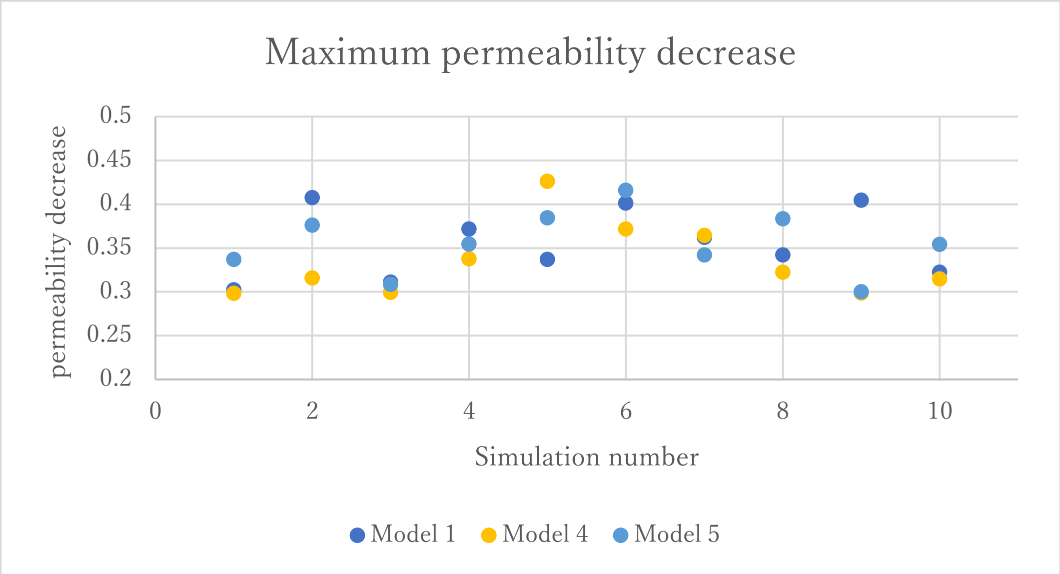

Figure 5: Maximum permeability decrease in Model 1, 4 and 5

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