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Particles migrating and plugging mechanism in loosen sandstone heavy oil reservoir and the strategy of production with moderate sanding

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PARTICLES MIGRATING AND PLUGGING MECHANISM IN LOOSEN SANDSTONE HEAVY OIL RESERVOIR AND THE STRATEGY OF PRODUCTION WITH MODERATE SANDING

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ABSTRACT
Fine rock particles is easy to be suspended and carried in loosen sandstone heavy oil reservoir due to the higher density and viscosity of heavy oil. The sand particles settle down, bridge and clog in pore and throat, as the result, the filtration resistance in reservoir will be redistributed. It significantly impacts on the well productivity. In this paper, the process of sand particles transporting and clogging in tunnels of rock is observed utilizing a microscopic visualization model with the unconsolidated sandpack. Furthermore, the mechanism of fine particles migration and clogging and the effects to percolation capacity of porous medium is investigated through the dynamic permeability changes in the weak-consolidated sandpack tube is monitored under different conditions of particles suspended fluid injection. It is shown that the performance of permeability decline with particles migration is affected by the size and sorting of mobile particles and throats, concentration of suspended particles, total amount of particles and the pressure drawdown or fluid flowing velocity, the maximum permeability reduction and the clogging transition time is determined by the minimum size of bridging particles. As a field application example, the strategy of production with moderate sanding in loosen sandstone heavy oil reservoir is discussed at the end of this paper

INTRODUCTION
Rock particles migrate with in-situ fluid in porous medium of loosen sandstone heavy oil reservoir is the common phenomenon as weak or none cohesion of rock in which rock particles is easy to be suspended and transported by the heavy oil with higher density and viscosity. The process of startup, migration, settlement and retention of particles in pores will be different depends on the entrainment capacity of in-situ fluid during the reservoir exploitation, therefore, the dynamic of permeability in formation and the productivity of oil well will be changed in different manners.

Phenomenon and mechanism of particle migration within the reservoir cause abnormal production decline in oil wells has been widely recognized (Gruesbeck and Collins, 1982). Researches on rock mechanics to the generation of mobile particles (Morita and Whitfill, 1989) and mechanism of formation damage due to particles migration and deposition (Chang and Civan, 1991) have be reported. Experimentally and theoretically, it has been summarized that the in-situ fluid velocity, entrainment and deposition capacity, the relationship between particles and pore throats are key factors to the particles migrating and plugging (Muecke 1979). In some cases, the formation conductivity can be stimulated by the outward particles migration (Kenney and Lau 1985; Skempton and Brogan 1994). In most current studies, the particle type is mainly targeted to the formation clay minerals (Priisholm et al. 1987; Baghdikian 1989), asphalts, the mechanical solids in injection fluid, grains produced by the physical and chemical reactions due to incompatibility between injection fluids and formation fluids and rocks. Major scope of there studies are wellbore close area with high speed fluid streams or in the holes of perforation (Tran et al. 2009). Researches specifically to the particles potentially migration and its influence to the flow ability in the weak or unconsolidated sandstone have not be widely reported. In many cases, the microscope visual simulation experiments of particles migrating and clogging are conducted in the glass or polymer etching microscopic model with capillary network (Javadpour and Fisher 2008), however, this kind model can not be used to simulate the real unconsolidated sandstone with unstable structure. Stability of sand arch is study through the tri-axial core tests at different loads in an oil and water two phase environment (Hall 1970 and Bianco 2001). It is shown that this stability depends on the size

of sand arch and wetting phase saturation. This conclusion is applied to the sanding process of rock with a certain bonding strength. The critical conditions of particles migrating and plugging, including particle sedimentation and its effects on flowing pressure in different flow rates and in different particle concentration, is investigated via micro capillary model with different diameters (Rahman et al. 1994), However, the detailed mechanism is very different between the flow process in a capillary and in the porous sandstone with actual structure of three dimensional pore throat. The evaluation experiments to formation damage from the sand particles migrating and plugging is usually conducted through the displacement in a short sandpack tube (Muecke 1979; Gruesbeck and Collins 1982; Egbogah 1984; Gabriel and Inamdar, 1983), however, the system error is exist due to there are too few of particle which is hard to be measured moving within this small core column, therefore, a certain randomness is in the experiment result.

In this paper, the process of rock particles start up, migration, sedimentation and plugging in actual pore tunnels of loosen sandstone is simulated and observed through a microscopic visualization sandpack model. Furthermore, the infinite inflow process in actual formation is simulated through the continuous sand mixing injection to the poor consolidated sandpack tube. In this procedure, influence of particle migration and plugging to the flow capacities in porous media can be analysis according to the dynamic changes of permeability which is monitored under different injection conditions.

It has been fully realized that well productivity will be reduced as the rock particles migration and clogging in pores and throats of the loosen sandstone reservoir. In order to achieve a stable well production, there are three typical techniques which are applied to prevent formation damage from migration of rock particles, such as optimization of sand control well completions, formation acidizing and stimulation near wellbore and stable the grain structure of potential mobile particles by tackifier injection (Nguyen et al. 2005). However, the effect of these strategies will be significantly reduced in loosen sandstone heavy oil reservoir as the mobile sand generation is unavoidable since instability of rock skeleton close wellbore and erosion sanding in the poor and unconsolidated formation which is carried by the heavy and viscous oil.

Based on experimental investigations in this study, the mechanisms of oil production with moderate sanding in loosen sandstone heavy oil reservoir is explained, and further strategies to stable the oil production is proposed.

1 Visualization of Particles

1.1 Experimental Procedure

The micro-visualization experimental device is assembled by a high strength hollow transparent plexiglass sandpack box, a solid suspended fluid container, a motor stirrer, a particles meter and the computer monitoring system, as shown in Fig. 1.

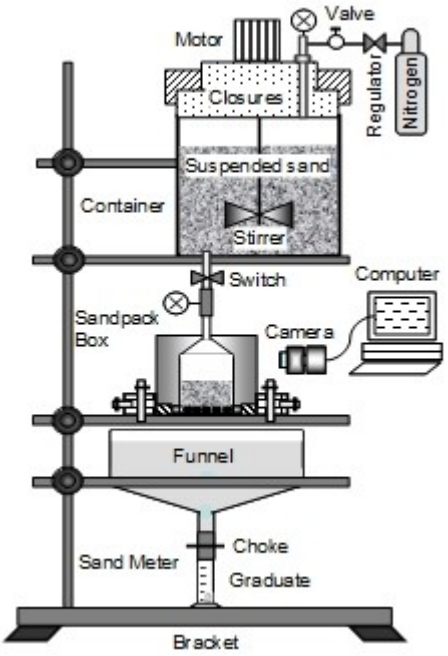

Figure 1: MICRO-VISUALIZATION DEVICE

The transparent plexiglass box is packed with river sand which is sieved according to the size composition of rock grain in the actual loosen sandstone reservoir, as shown in Table 1.

Table 1: SIZE DISTRIBUTIONS IN SANDPACK

No.	Size μm	Sample 1	Sample 2	Sample 3
		Wt，%	Wt，%	Wt，%
1	500/1000	7.58	3.88	20.38
2	250/500	15.03	7.77	40.76
3	125/250	32.78	46.60	15.50
4	80/125	19.84	31.07	14.01
5	60/80	12.20	7.77	6.79
6	40/60	7.09	1.94	1.71
7	20/40	5.48	0.97	0.85
D_{50}，um		210	180	355

The fine quartz sand with median particle size (d_{50}) of about 20μm, which looks like the white powder in pictures, is mixed with 1% solution of guar gum thickener as the substitutes of mobile rock particles and viscous heavy oil respectively in the actual formation.

Before the experiment, first, put the sand filling box immersed in water slowly from its lower part and let the air discharged from upward to avoid the interference of air bubbles in sandpack. Then components are assembled in accordance with the connection diagram as shown in FIG.1. The liquid flow velocity is adjusted by the inlet valve and the process of particles migrating and clogging is observed and recorded by a microscopic camera.

1.2 Experimental Observations

Phenomenon of particles migrating and plugging will be observed and analysis under sand mixing fluid injection

with denser mesh at the exit end of sandbox, as shown in FIG. 2. On the other hand, the inside tunnels cleaning due to fine particles departure is recorded under fresh water injection, as shown in FIG. 3. Fine particles migrating and clogging in different manners will be observed under different sizes of filling sand and mobile quartz sand in different flow velocity.

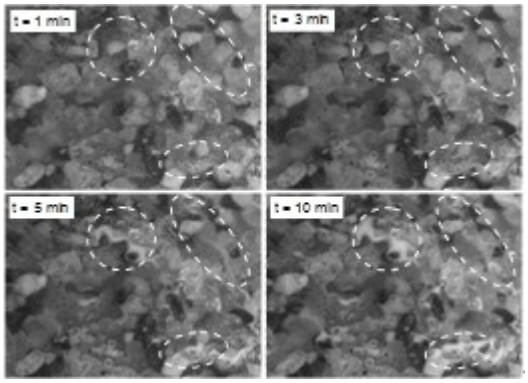

Figure 2: CLOGGING DURING PARTICLES INJECTION

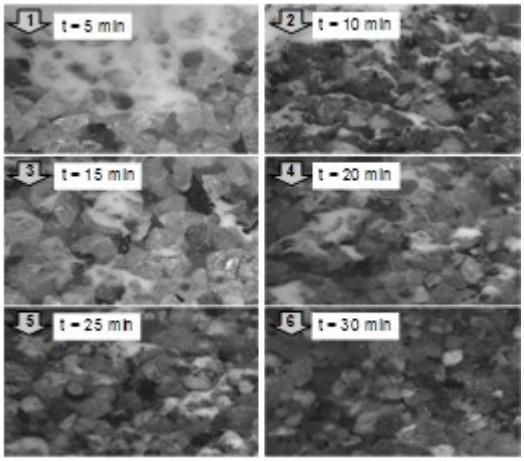

Figure 3: CLEANING DURING WATER INJECTION

1.3 Experimental Analysis

Features of particle migrating and plugging in loosen porous medium are analysis based on microscopic images and summarized as follows:

1. Not all tunnels are allowed the entrance of particles, the migration path is depend on the size and shape of particle and inside tunnel
2. Particles sedimentation in tunnel occurred under a lower flow velocity
3. As flow velocity increases, status of particles from rest to motion in this sequence: in-situ rotation, intermittent rolling within the tunnel, jumping, and moving with fluid; the higher flow velocity, the more participating particles
4. Bridging occurred at pore constriction, and further plugging is induced due to reduced flow rate and entrainment capacity
5. Bridging and clogging is originally formed by bigger particles and these inside tunnels will be finally blocked completely from the subsequent superimposed bridging by smaller particles
6. Particle gravitational settling occurred when flow into an enlarged tunnel due to the flow velocity decreases; Particles will be mobile again with increase of flow velocity
7. To the unconsolidated sandpack model, the skeleton stability is worse with smaller grain size, in which the range of particles motion is more limited
8. The faster fluid flow, the more fine particles will be entrained and the stronger destroy ability to rock skeleton are observed in this investigation. Also a bigger particles motion range and a shorter clogging transition time will be achieved with faster injection
9. Phenomenon of loosen and mobile in rock skeleton are recorded during the injection rate is changed. It is indicated that the formed stable plugging zone in tunnels is collapsed

2 MECHANISMS OF MIGRATION

2.1 Experimental Procedure

Certain amount of cement powder is mixed in the sandpack which is consistent with the grain size distribution of actual loosen sandstone sample. A sandpack tube with weak cementation which is similar to the actual loosen sandstone is made after water soaking, drying at room temperature, porosity and permeability testing. Fine quartz sand, which median sizes (d_{50}) are approximately 1/6 and 1/4 median size (D_{50}) of rock skeleton grains, stay in the container with 1% solution of guar gum thickener and suspended through the continuously stirring. Solids concentrations are set to 10,100, 200 and 500PPM, respectively. Fine particles in different amount is suspended in the viscous fluid and injected into the sandpack tube continuously to simulate the infinite inflow in the actual formation near the wellbore. The effect of particles migrating and clogging in tunnels to the flow capacity in porous media is evaluated via the performance of permeability decline monitoring at different cumulative injection.

2.2 Experimental Observations

The permeability is significantly decreased with the continuously particle-fluid injection, as shown in figures 4 and 5. It is obvious that the permeability reduced in the uniform amplitude under smaller particles concentration, for example, not more than 100PPM, however, this performance will be changed in a larger concentration, for example, 200 or 500PPm. There is a relatively rapidly drawdown in initial phase but gradually become gentle latter. This phenomenon is more apparent in the bigger size particle case.

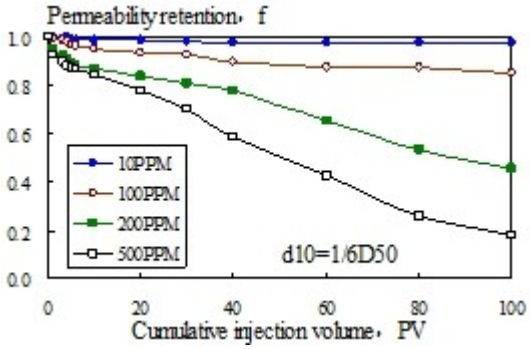

Figure 4: PERMEABILITY DECLINE IN SAMPLE-1

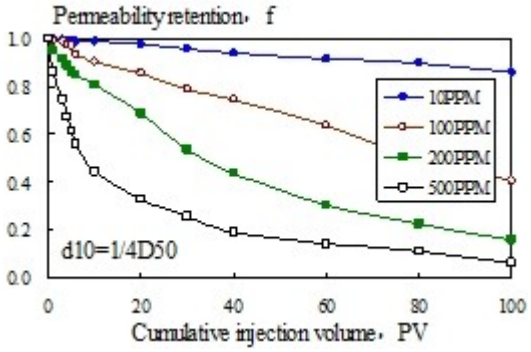

Figure 5: PERMEABILITY DECLINE IN SAMPLE-2

2.3 Experimental Analysis

Particles bridging and clogging at the inlet end of the sandpack tube becomes easier in a larger solids concentration, therefore the permeability is reduced rapidly. On the other hand, the deep invasion from the subsequent injected particles is prevented by this earlier blockage, as the result, the reduction of permeability will be in a slower trend.

The main factors reducing permeability from the particle migration include: size ratio relationship between mobile particles and tunnels throat, size sorting, concentration of suspended particles, the total amount of transporting particles and the flow pressure gradient or flow velocity.

1. Median size (d_{50}): bigger particles in tunnel make a faster bridging and clogging, however, it also prevent the further solids invasion
2. Minimum size (d_{90}): the lowest flow capacity of the blockage zone is determined by the minimum size of mobile particles according to the principle of superimpose bridging, as shown in figure 6

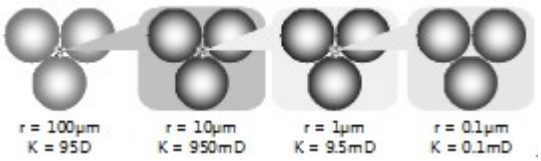

Figure 6: SCHEMATIC OF SUPERIMPOSED BRIDGING

3. Sorting: the bridge with higher stability will be constructed with wider distribution of particles size
4. Concentration: the higher concentration of solid phase will make more obvious bridging and clogging to the same particles size
5. Injection time: the total amount of particles is depended on the solids concentration, flow velocity and total injection time. Clogging in tunnels will be the final stage if the amount of particles is enough
6. Pressure gradient: the injection velocity and then the total amount of mobile particles are depended on the pressure gradient. However, the formed bridges in tunnels could be destroyed if there is a sufficient pressure pulsation since the rock skeleton is unstable in this loosen sandpack tube, as the results, the permeability will be enhanced for a while until the next bridging and clogging

3 Strategy of Moderate Sanding

3.1 In-Situ Particles Migration

It is inevitable that in-situ sand particles migration in loosen sandstone heavy oil reservoir as the poor cohesion of rock skeleton and the viscous fluid. The major source of particles produced with oil is the free unconsolidated solids and particles eroded in weak cemented formation. There is higher mobile particles concentration adjacent to the wellbore due to more powerful solids entrainment capacity of fluid with greater flow velocity in the smaller flow area within the less radial distance. The seriously in-situ blockage caused by the mobile sand particles will be a big issue if the completely sand control strategy is applied in this situation in which a more fine size of particle is not allowed to pass through. As the result, the in-situ permeability in reservoir close to the wellbore and therefore the decline of well productivity will be rapidly and significantly as particles migration and continuously superimpose bridging and clogging since there are more fine solids and the minimum in-situ flow capacity in clogging tunnels are depended on the minimum size of bridging sand particles.

3.2 Principle of Moderate Sanding

Since the minimum permeability is depended on the minimum size of bridging particles in tunnels, the degree of in-situ flow capacity reduction could be reduced if a larger minimum size of bridging particles is achieved. This is the original start point of oil production with moderate sanding.

The main principle of production with moderate sanding is: mesh size of the sand control screen in the well completion tool is optimized according to the size and sorting of the mobile particles in formation, so the particles which is less than this particular size will be allowed to pass through the sand control screen and is produced to surface with reservoir fluid. The blockage in tunnels of rock and the degree of permeability decline due to the superimpose bridging and clogging in porous medium will be obviously reduced as some fine solids is departure from the in-situ tunnels and the minimum size of bridging particles is larger than the situation in regular completely sand control strategies. Furthermore, the total sand production will be decreased since the sand control is still effective to most other particles with larger size. The oil well productivity is enhanced or partially recovered and the behavior of sand production is under

control are the main contributions of this smart sand management strategy to the production in the loosen sandstone heavy oil reservoir. From this point of view, offshore oil companies can benefit from this strategy since the limitations of sand production

3.3 Key Technology Strategies

It is difficult to achieve the ideal moderate sanding in actual oil reservoir since the complex structure of rock, the different size and shape distribution in throat and mobile particles and the heterogeneity in actual reservoir. Blockage is the final stage of each open tunnel in rock and well productivity decline due to particles clogging is inevitable in loosen sandstone heavy oil reservoir, however, all these negative effects will be delayed or reduced as the departure of these minimum fine particles. The key technologies included in this strategy are:

1. Optimization of sand control parameters: as the final well productivity is depended on the minimum size of bridging sand, it is more important to choose the applicable well completions with sand control based on the situations in reservoir, such as rock cohesion, size distribution and sorting of natural mobile and potential mobile particles and of opening tunnels in rock, properties of fluid, and so on.
2. Optimization of well working constraints: The amount of mobile particles and the range of mobile zone disturbed by particles migration are determined by the fluid flow velocity and pressure gradient in reservoir, the bridging and clogging dynamic in tunnels of rock is affected by the size, sorting and concentration of solids. So the well productivity is mainly affected by the production rate in the same in-situ reservoir conditions. It is concluded that the optimized production rate and pressure drawdown under the constraints from the maximum processing capacity to the output sand will make sure the field operator to achieve a better profit.

CONCLUSIONS

The following conclusions can be drawn from this study:

1. In the loosen sandstone, the amount of mobile particles and the range of disturbed zone due to solids motion and the reduction of in-situ permeability is determined by the size, sorting, concentration of particles and fluid flow velocity in tunnels of rock
2. The final stable permeability of blockage zone depends on the minimum size of bridging particles as superimpose bridging and clogging in tunnels. Based on this principle, it is suggested that the reservoir close wellbore will be stimulated during production with moderate sanding in which some fine solids will departure from rock and produced to surface with oil
3. Clogging and clear is the dual effect at the same time of particles migration in loosen sandstone porous medium. Both are effective in the production with moderate sanding. As a kind of smart sand management strategy, the under controlled sand production and the reduced production decline are achieved through the optimized mesh size of sand control screen.

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