Study of the anti-sand sucker rod pump

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Abstract. In order to solve the problem of sand stuck in the sucker rod pump, an anti-sand sucker rod pump is designed. The anti-sand sucker rod pump includes the conventional sucker rod pump and the swirl flow device. The sand particles can be separated from the oil in the swirl flow device, so the plunger of the sucker rod pump cannot be stuck. The motion equation of the sand particles in oil is deduced. The virtual model of the swirl flow device is built in GAMBIT software. And simulation of solid-liquid two phase flow is simulated in software FLUENT. The simulation results show that the swirl flow device can realize the sand particles separation from the oil completely. So the pump can have the effect of anti-sands.

1. Introduction
The sucker rod pump is one of the important equipment’s in the oil production [1]. However, the extracted fluid in many oil wells contains an amount of solid particles (sands). So the conventional sucker rod pump has some problem in the sandy wells. For example, the sands suspended in the oil will cause the wear of the plunger of the sucker rod pump if the sands fall into the clearance between the plunger and the barrel. In the worst case, the pump even is stuck and become failure.

Up to now, some anti-sand sucker rod pumps have been developed to prevent the pump from sand damage [2, 3]. However, these anti-sand sucker rod pumps cannot have a good effect [4]. In recent years, the swirl flow technology has been a research topic in the oil and gas industry [5]. So a new type of sucker rod pump based on the swirl flow is designed in this paper. The principle of the new sucker rod pump is that the swirl flow device in the sucker rod pump can separate the sand from the oil because of the centrifugal force. So the sand cannot fall into the clearance between the plunger and the barrel of the pump.

2. Structure and principle of the anti-sand sucker rod pump
The structure of the anti-sand sucker rod pump is shown in Fig.1. It includes the pump barrel, plunger, standing valve assembly, traveling valve assembly and the swirl flow device. When the sucker rod pump is used to lift the oil in the oil wells, the oil flows into the bottom of the pump through the screen pipe. Although the screen pipe can filter some sands for the pump, there are still some sands which can enter the pump.

The plunger is moved up and down reciprocated by traction of the rod string. When the plunger is moved up, the space between the plunger and the standing valve becomes larger. So the pressure is decreased and the standing valve is opened. The oil is sucked into the pump barrel. In addition, the oil pressure on the traveling valve is increased, so the valve is closed. The oil is lifted into the swirl flow device with the movement of the plunger. On the other hand, when the plunger is moved down, the
space between the pump barrel and the standing valve becomes smaller, the oil pressure increases and the standing is closed. At the same time, the traveling valve is opened and the oil in the barrel is also lifted into the swirl flow device.

For the conventional pump, when there are sand particles in the oil fluid, some sands may fall down due to the gravity. If the sands enter into the clearance between the plunger and the barrel, the plunger will be abrasive, or even cause the sand plug afterward. However, if the sand sucker rod pump in this paper is used, the oil will be moved along the screw line when the oil enters into the swirl flow device. Since the density of the sand is bigger than that of the oil, the sands are centrifugally thrown toward the inside wall of the tube and the oil flow inward of the tube. Next, the sand may move up to the well head, or falling down the annular space, as is shown in Fig.1. In this way, the sand cannot go into the clearance between the plunger and the barrel. So the pump can have the anti-sands effect.

Figure 1. Structure of the sand rod sucker rod pump

1-bridge pipe, 2-bridge nipple, 3-screem pipe, 4-coupling, 5-seat, 6-ball, 7-standing valve, 8-middle barrel, 9-bottom sand abrasive block, 10-plug, 11-seat, 12-ball, 13-traveling seat, 14-plunger, 15-outer barrel, 16-connecting part, 17-upper sand abrasive sand block, 18-annular space for storage sands, 19-nipple, 20-traveling valve assembly, 21-swirl flow device

3. Sand particles flow equation in the swirl flow device

The motion of the solid (sand) particles in fluid can be described in Lagrange equation. When a solid particle moves in the solid-liquid two phase fluid field, it is applied the following forces: gravity, additional mass inertia force, pressure gradient force, Magnus force and Saffman force. So the dynamical equation of a solid particle can be written as:

$$m_p \frac{d\mathbf{u}_p}{dt} = m_p \mathbf{g} + F_{VM} + F_p + F_B + F_{ML} + F_{SL} + F_X$$

In Eq.(1), $m_p$ is the mass of a particle; $\mathbf{u}_p$ is the velocity of the particle; $\mathbf{g}$ is the gravity acceleration; $F_{VM}$ is the additional mass inertia force; $F_p$ is the pressure gradient force; $F_B$ is the Basset force; $F_{ML}$ is the Magnus force; $F_{SL}$ is the Saffman force; $F_X$ is the buoyancy. These forces can be written as follows:

$$F_{VM} = \frac{4}{3} K_m \rho_f \pi r_p^3 \frac{d}{dt}(u_f - u_p)$$

In Eq.(2), $K_m$ is the fluid viscos shear stress; $\rho_f$ and $r_p$ are the fluid density and particle radius, respectively; $u_f$ and $u_p$ are the fluid velocity and particle velocity, respectively.
\[
F_p = \frac{4\pi r_p^3 \rho_f}{3}
\]

\[
F_B = k_B \frac{1}{\rho_{op} r_p^3} \frac{3}{4} \frac{\mu_f \rho_B}{\pi} \int_0^\infty \frac{1}{\sqrt{\tau}} \frac{d}{dt} (u_f - u_p) \, d\tau
\]

\[
F_{ML} = \pi r_p^3 \rho_B a (u_f - u_p)
\]

\[
F_{SL} = k_L \rho_B \mu_f r_p^2 \sqrt{u_p \|u_f - u_p\|}
\]

Where, \(K_m\) and \(K_L\) are the coefficient; \(\rho_B\) is the density of the oil; \(r_p\) is the radius of a solid particle; \(u_f\) is the slip velocity of the oil; \(u_p\) is the slip velocity of the solid particle; \(p_f\) is the pressure of the oil; \(\rho_{op}\) is the density of the solid particle; \(\tau\) is time; \(\omega\) is the angular velocity of the solid particle. Because the average flow rate of the oil in the sucker rod pump is low and the diameter of a sand particle is very small, \(F_{VM}\), \(F_B\) and \(F_X\) are very small. So these forces can be omitted here.

4. Simulation of the solid-liquid two phase motion in swirl flow device

We used the CFD software to simulate the movement of solid-liquid two phase fluid in the swirl flow device. The software are GAMBIT and FLUENT. The GAMBIT software is used to build the geometry model of the swirl flow device. The FLUENT software is used to simulate the movement of the solid-liquid two phase fluid. Firstly, the swirl flow device is modeled in GAMBIT software. The model is shown in Fig.2. The swirl flow device contains two departments: swirl segment and annual passage. Then, the model is meshed, which the type of mesh is TGIRD and the space is 2mm. The inlet for motion simulation is the inlet of the screw slot and the type of simulation is Velocity. The outlet for simulation is the out of the screw slot and the type of simulation is Outflow.

When we simulated the solid-liquid two phase fluid in FLUENT, the RSM turbulent model is used because the movement of the fluid is swirl flow [6]. The algorithm of numerical solution in FLUENT is SIMPLEC. The inlet velocity of the fluid is 1.2m/s. The length of swirl segment is 250mm. The whole length of the swirl device is 600mm.

The simulation results are shown in Fig.3 and Fig.4. The solid particle trace is shown in Fig.3. We can see that the solid particles can realize the swirl flow movement. Fig.4 shows the separation process between the oil and the solid particles. There are all six cross section of the swirl device. The inlet of the swirl device is at \(y=0\)mm, and the outlet is at \(y=600\)mm. In the annular area, the blue color means that the portion of the sand particles is 0% and the red color means that the portion of the sand particles is 100%. In the first picture of Fig.4, the content of sand particles is 10% and is distributed uniform in the oil. Then the sand particles are separated gradually from the oil, which we can see it from the next five pictures. In the last picture, the sand particles are moved in the margin of the annular area and the oil is located in the center of the annular area. So it means the sand particles are separated completely from the oil.

Figure 2. Virtual model of swirl flow device in GAMBIT
5. Conclusion
Sands in the oil well can make the sucker rod pump failure. So the anti-sands sucker rod pump is designed in this paper. The principle of the sucker rod pump is based on the swirl flow. When sands in the oil pass the swirl flow device, sands will be separated from the oil because of the centrifugal force. Then sands cannot fall into the clearance between the plunger and the barrel. The swirl flow device is modeled in GAMBIT and the solid-liquid two phase flow is simulated in FLUENT software. The simulation result shows that the sand is separated from the oil completely.

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