THEORETICAL SLIPPAGE ANALYSIS FOR DIFFERENT PUMP CONFIGURATIONS

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ABSTRACT

This is a paper that explores the theoretical changes in pump slippage for different types of rod pumps. For simplicity this analysis will focus on comparing a top hold down pump with a bottom hold down configuration. The two configurations have different forces acting on the pump that has an effect on pump slippage. Current mathematical models commonly used to calculate pump slippage do not take into account these different configurations.

BACKGROUND

Pump slippage is defined as the fluid that passes between the plunger and a barrel of a rod pump. When operating a rod pump it is recommended to slip a small percentage of the produced fluid to provide pump lubrication. Without proper lubrication the plunger and barrel pump components can gall sticking them together. However it is also possible to slip too much fluid resulting in a loss of pump efficiency. So a balance must be made between pump slippage and production. The general rule of thumb for pump slippage is two percent of the produced fluid. Hitting this target is not easy to determine as there are several parameters that must be taken into consideration.

Texas Tech University has spent the last 16 years performing controlled tests to improve on the mathematical model used to estimate pump slippage. Significant discoveries include the addition of the pumping speed to the mathematical model that is currently in use. The present formula recommended for determining slippage below was published in 2007 by the Southwestern Petroleum Short Course paper titled *PROGRESS REPORT #4 ON "FLUID SLIPPAGE IN DOWN-HOLE ROD-DRAWN OIL WELL PUMPS"*.

THEORY

Pump slippage is driven by the difference in pressure above and below the plunger. In order to calculate the slippage you must also know the diametrical clearance between the plunger and barrel, length of the plunger, fluid viscosity, and pumping speed. The present mathematical model used to determine slippage does not take into account the change in diametrical clearance of the plunger and barrel for different pump configurations.

When a bottom hold down pump is installed into a well, the outside of the pump barrel is exposed to the hydrostatic pressure inside the tubing. This hydrostatic pressure also exists inside the barrel above the pump plunger. However during the upstroke when slippage occurs the inside of the barrel below the plunger is at a much lower well bore pressure. The difference in these pressures applies a force that can displace the barrel diameter below the plunger by reducing the diameter. Since the pressure acting on the barrel above the plunger is equal there is no change barrel diameter.

For a top hold down pump the outside of the pump barrel is exposed to the well bore pressure. When a well is pumped off this is generally a much lower pressure compared to the hydrostatic pressure in the tubing where the pump is located. This hydrostatic pressure is present on the inside of the barrel just above the plunger and the difference in these forces displaces the barrel by increasing the diameter. Below the plunger the pressure is equal between the inside and outside of the barrel resulting in no net change of the barrel diameter.

In comparison a top hold down pump should have a slight increase in barrel diameter above the plunger and a bottom hold down will have a slight reduction below the plunger, but what is happening along the length of the plunger? In theory the static pressure acting on the barrel is dependent on the pressure drop profile across the length of the plunger.

ANALYSIS

The pump configuration in this analysis will use a 1.501 inch inner diameter thin walled barrel made from low carbon steel that is not plated. The barrel diameter was chosen as this is in the middle of the barrel diameter tolerance allowed by API 11AX. The plunger is 1.495 inches in outer diameter with a 48 inch fluid seal length. The fluid media will be water at room temperature. The pressure differential across the plunger is 2400 psi. The pressure differential was derived from the maximum well depth that API 11AR will allow for a 1-1/2" RWAC pump using a steel barrel. The model of the plunger will be simplified by making it static.

To solve this analysis we must first determine the pressure profile across the seal length of the plunger. This is critical as the difference in pressure inside and outside the barrel is directly related to the diametrical clearance along the plunger seal length. Changes in diametrical clearance will affect pump slippage. We know the pressure drop is 2400 psi across the plunger. Using modern CFD software the change in pressure along the seal length of the plunger was calculated and found to be very linear in nature.

The following mathematical formula was used to model the barrel displacement for a top hold down pump. It is commonly used for thick walled cylinders with only an internal pressure.

$$u_r = \frac{p_i r_i^2 r}{E(r_o^2 - r_i^2)} \left[(1-\nu) + (1+\nu)\frac{r_o^2}{r^2} \right]$$

Using the static pressure profile discovered in the CFD analysis and the equation above the radial displacement of the inner diameter of the barrel was calculated. The barrel diameter at the top leading edge of the plunger increases to 1.5018 inches and tapers down at a constant rate to the nominal diameter 1.5010 inches. These changes in diameter were used to create a new model that was analyzed using CFD software to calculate pump slippage for the top hold down configuration. The pump slippage according to the CFD calculations was 5.1 barrels per day.

This mathematical formula below was used to model the barrel radial displacement for a bottom hold down pump. It is used for thick walled cylinders with only an external pressure.

$$u_r = -\frac{p_o r_o^2 r}{E(r_o^2 - r_i^2)} \left[(1-\nu) + (1+\nu)\frac{r_i^2}{r^2} \right]$$

The same static pressure profile was used with the equation above to determine the radial displacement of the inner diameter of the barrel. The barrel diameter at the top leading edge of the plunger is at the nominal diameter of 1.5010 inches and tapers down at a constant rate to 1.5002 at the bottom of the plunger. Using the same methods as the top hold down, the bottom hold down slippage was calculated to be 3.4 barrels per day.

CONCLUSION

In comparison the slippage of the top hold down pump had 50% more slippage than the bottom hold down pump. When you compare the diametrical clearance between these pump configurations you get a difference of .0008 inches across the entire length of the plunger.

The change in diametrical clearance between these pump configurations is similar to using a different sized plunger. Using the current Southwestern Petroleum Short Course slippage formula a change in .001 of the plunger can increase pump slippage by 32% when going from a 1.495 inch plunger to a 1.494 inch plunger. This is not too far off from the calculations provided in this analysis.

Although there is a significant difference in slippage for the case in this analysis, it should be understood this difference will be reduced with heavier barrels walls, not using pumps close to their maximum well depth, and using larger plunger clearances. I would also not recommend changing the current mathematical model to include different pump configurations without validating the analysis with real world testing.