CFD Simulation einer neuartigen hydraulischen Untertagepumpe zur Förderung von Erdöl

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Summary:

Most artificial lift systems used in the oil industry, like Sucker Rod Pumps, Progressive Cavity Pumps, Electric Submersible Pumps are limited in their range of applicability by installation depth, wellbore trajectory, the chemistry of pumped fluid and production rate. The within this article presented new patented hydraulic pumping system, installed in a concentric completion, can overcome most of these limitations.

The presented hydraulic pumping system requires completion with two flow conduits to steer the downhole piston and achieve the lifting of the pumped fluid to surface. The downhole pump can be installed on wireline, by circulation or on the conventional way during work over the operation. The pumping system itself consists of a special piston design, which is pushed downward by the hydrostatic weight of the fluid in the tubing string. The upward motion is a result of an increase in tubing annular pressure, achieved by a surface compressor. This new pump type is designed at the Montanuniversitaet Leoben, Austria and is tested at the universities Pump Testing Facility (PTF). A computation fluid dynamics simulation, using the open-source software toolbox OpenFOAM®, assists the design process to investigate the fluid flow behaviour.

The nature of this reciprocating pumping system causes a transient velocity field of the fluid used. As any positive displacement pump, the efficiency of this pumping system will suffer if free gas is present at the pump intake. Thus the field of application is just for non or slightly compressible fluids. To simulate the pumping action accordingly, the transient incompressible solver pimpleDyMFoam is used. It allows tackling the challenging task of coupling a dynamic mesh movement with the fluid flow in the well. The dynamic mesh contains, based on the geometry of the pump, a sliding mesh interface between the tubing and the moving pump assembly. It utilizes the OpenFOAM's Arbitrary Coupled Mesh Interface (ACMI) and a deforming mesh region that models the intake and discharge volumetric chamber changes as the pump plunger moves up and down.

The conducted study provides details about the forces, acting on the pump piston, the geometry of the pumping system and its performance. The results are used in the optimization and further development of the hydraulic subsurface pump concept. The simulation has provided detailed insight into this promising pumping system.

Keywords:

Hydraulic pump, Concentric tubular system, OpenFOAM CFD simulation

1 Hydraulic Pump in a concentric tubular completion:

The hydraulic pumping system consists of surface and downhole components. At the surface, a hydraulic pump and the pressure vessel is installed to generate the required high-pressure fluid stream. The downhole pump is installed in the concentric tubular system, that provides three flow conduits: the inner tubing, the inner tubing – outer tubing annulus and the outer tubing-casing annulus. This arrangement is used on the one hand to reduce the wellbore size, in comparison to a standard dual completion, and on the other hand, to reduce the liquid flow velocities thus pressure losses in the system. Figure 1 presents the disassembled hydraulic downhole pump.

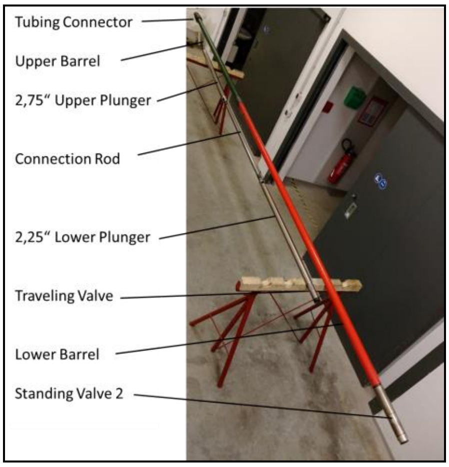

Figure 1: 275/225 Hydraulic Downhole Pump [1]

At the bottom of the outer tubing string, a ball valve and a valve seat (Standing Valve 1) is installed to protect the reservoir during work over periods from high pressures. At the lower end of the inner tubing, a barrel is installed, having another valve (Standing Valve 2) installed at the bottom, to prevent undesired communication. The lower barrel is connected by a crossover to the upper, slightly bigger barrel. In the barrels, a reciprocating piston assembly, consisting out of three major components is installed: the small diameter piston at the bottom, the big diameter piston at the top and the connection rod, where its length defines the maximum stroke length of the plunger assembly thus the production rate per stroke.

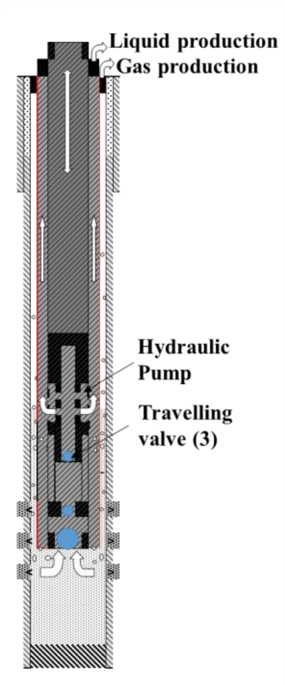

Figure 2: Schematic of the hydraulic downhole pump

The small plunger possesses a ball valve (Travelling Valve) at the bottom, and the big piston is closed at the upper end. The lower piston comprises also a connection channel, connecting the intake chamber with the discharge chamber. The discharge chamber is opened by the predrilled section to the outer tubing – inner tubing annulus, and to the surface, hence the fluid is produced through the inner annulus. The inner tubing is filled with the hydraulic fluid to assure the assisting u –tube effect and increase the pumps efficiency. The pumping motion is generated by an adjustment of the head pressure at the inner annulus. The upstroke is achieved by an increase in head pressure, whereas the downstroke is the result of a reduction of the head pressure below a certain level. Figure 2 presents a schematic of the hydraulic downhole pump, installed in a concentric tubular completion.

2 Computational Fluid Dynamic Simulation:

The concept of the hydraulic subsurface pump was validated using Computational Fluid Dynamics (CFD). A simplified 2D pump model was developed and implemented using the open-source software toolbox OpenFOAM [2] and its supporting library swak4Foam [3].

The produced fluid is assumed incompressible. Thus transient incompressible Navier-Stokes equations are governing the fluid flow during the pump cycle. The turbulent viscosity ν_t is supplied by the turbulence model. The selected turbulence model is the two-equation *k-ω* Shear-Stress Transport (SST) by F. R. Menter [4] for Reynolds averaged simulation (RAS). The *k-ω* SST model is a low-Re turbulence model and can describe laminar to turbulent flow transition within the pump.

The discretization of the equation system [5] and its implementation is realized by OpenFOAM's solver *pimpleDyMFoam*. The solver *pimpleDyMFoam* supports the dynamic mesh movement [6, 7] needed to model the reciprocating piston and the intake chamber in the simulation. Figure 3 presents the simulation result during the upstroke.

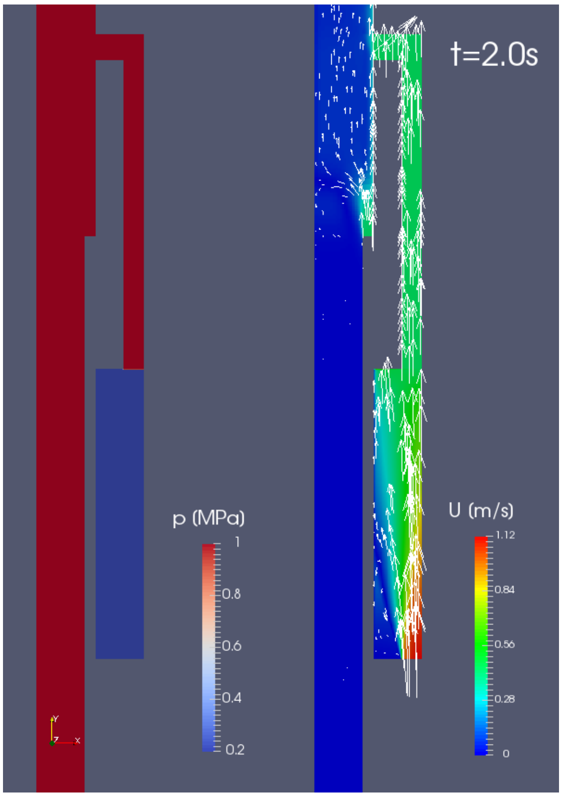

Figure 3: Upstroke, t=2s (x-axis scaled 5×)

In addition to the velocity field in the pump itself, the simulation provides the motion characteristic of the piston assembly, depending on the applied pressures and used fluids. A characteristic results for the pump, presented in Figure 1, is a production rate of about 70m³/day when applying a static tubing annular pressure of 20bar and an alternating annular tubing pressure amplitude of 16bar. The amount of required fluid to be injected is roughly half of the produced amount.

3 Conclusion

- The new hydraulic pumping system is prone to be used in enhanced oil recovery fields as well as for unloading of gas wells.
- A CFD simulation is essential during the design process because of the high viscous fluid-solid piston interaction
- The simulation provides detailed information about the required pressure regimes and the motion of the pump piston.

4 References

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