Sucker Rod Pump Performance in Polymer Back-producing Wells – Simulation, Laboratory and Field Testing

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Introduction

Artificial lift systems (ALS) are used in mature oil fields, which have insufficient pressure to produce hydrocarbons naturally. Nowadays, sucker rod pumping systems hold a significant share of the artificial lift market [12]. In Lower Austria, for several decades, oil is produced by the use of sucker rod pumps. However, in the past decades, the large fields became super mature, and hydrocarbons' economic recovery is challenging. With oil viscosities of 16 cp, respectively 10 cP, the oils are ranked as low viscous oils. The polymer injection is supposed to increase the oil recovery of two heavily water flooded horizons and reduce the water cut.

Typical chemicals used for enhanced oil recovery are polymer, alkali, and surfactants [10]. Polymers, mixed with the processed and reinjected oil field water, increase the aqueous phase's viscosity, reducing its mobility ratio. Oil recovery is increased by reducing the permeability to water in the reservoir [29], as the waterfront moves from the injection well towards the producer. Combinations of the typical chemicals, such as surfactant – polymer flooding and, alkaline surfactant-polymer flooding, were limited to field pilots so far [30]. The chemicals added to the reinjected oil field water and caused by their reactions with the reservoir fluids alter the fluid behavior from Newtonian to non-Newtonian. Once the modified water phase and oil mixture reaches the producer, the artificial lift system needs to lift it to the surface. Therefore, a particular focus needs to be set on the performance of existing and new lifting systems in these fields.

Field experience from existing chemical EOR fields showed problems, which are untypical for conventional oil production. A review of the Daqing oil field in China reported severe problems with sucker rod pumps. Carbonate and silicate scale deposition destroyed the downhole pump gradually and resulted in a decline of the pressure capacity and an increase in leakage rate. An anti-scaling artificial lift strategy was introduced to increase the running lives of progressive cavity pumps [35]. Scales on tubing, rods, barrel, and plunger were seen in beam pump applications, which resulted in stuck pump situations and broken rods as a result of fatigue [34], causing an average pump running time decrease from 500 days to 37 days [24]. Severe buckling and rod–tubing wear was reported for beam pumps because of considerable friction at the pump plunger [36]. Sucker-rod failure was extre-

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mely high for beam-pumping wells [7].

Scale prevention and removal techniques have been applied to increase the mean time between failures. A new trend of well failures was observed at beam pumps in a polymer flooding oil field south of Oman [1]. The downhole equipment failures have increased significantly since the injected polymer is back-produced. The high shear stresses, caused by the non-Newtonian mixture of polymer – water – oil, resulted in floating rods and massive rod – tubing wear. Demin et al. [6] analyzed the rheology of viscous-elastic polymer fluids and the associated effect upon production equipment (2004), mainly focusing on polyacrylamide (PAM) flooding Daqing oilfield, China. Especially for beam pumps, eccentric mechanical wear, caused by the fluid stream‘s normal force, was seen, which caused a concise service life. Jiang (2016) [14] evaluated the effect of rod guides in an alkaline-surfactant-polymer flood field. An essential reduction of the system efficiency has been seen. Boyer and Dorado (2009) [3] published a method for mitigating rod floating in rod pumped wells using a variable speed drive system. The authors conclude that rod floating is caused by excessive viscous rod drag forces along the rod string, and a speed reduction can significantly reduce these.

The field redevelopment in the Vienna basin considers the drilling of several infill wells for injection and production. The new production wells will be equipped with electric submersible pumps, as this type provides a higher production capacity than sucker rod pumps. Nevertheless, the existing production wells are equipped with sucker rod pumps that will not be replaced by electric submersible pumps [13]. As a result, a close investigation of sucker rod pumps‘ performance in their environments is required.

Substantial scientific work has been done in the past to investigate the pump behavior of Newtonian liquid mixtures. In contrast, the objective of this article is to evaluate the performance of sucker rod pumping systems for pumping Non-Newtonian fluids, especially the rod fall velocity and rod string floating, which is not shown in literature so far, by applying CFD simulations and a large-scale lab tests.

Polymer Composition and Properties

The tested polymer is characterized as a standard partially hydrolyzed polyacrylamide (HPAM). The tested polymer concentration is defined as equal to that of polymer back-producing wells in the field. HPAM is dissolved in produced filtered water at a polymer concentration of 2000 ppm, which results in the target viscosity of 20 cp at shear rates below 10 s^{-1}, at a temperature of 35°C, and a density of 1,200 kg/m^3. This type of fluid is classified as viscoelastic fluid, which combines the elastic behavior of solids with the viscous behavior of fluids [33]. This non-Newtonian fluid shows a change in viscosity with shear rate [28]. The polymer solution shows a pseudoplastic shear thinning behavior at the macro scale and can be described by the Power Law Fluid Model (Fig. 1) [2].

Fig. 1 Pseudoplastic shear thinning behavior of the polymer

The polymer system viscosity is dependent on the fluid temperature, the polymer concentration, its molecular weight distribution, and the degree of chemical or mechanical degradation. The shear-thinning behavior of the used polymeric systems was determined in the lab before being used for testing. The mixed polymer shows zero shear rate viscosity at a shear rate below 1 1/s with 0.09 Pas and infinite shear viscosity above about 150 1/s with 0.01 Pas at a temperature of 15°C. The significant temperature dependency of the polymer results in a drop in viscosity with the increase in temperature. Figure 2 presents the viscosity versus shear rate behavior. The temperature-dependent coefficient K drops with temperature, whereas the n is the exponent that remains relatively constant. In Figure 2, the rheological parameters of the polymer solution after testing at 15°C are included. A significant drop in viscosity can be seen, which is the result of a severe degradation caused by the contact of the polymer with the test equipment and oxygen.

Fig. 2 Dynamic viscosity versus shear rate behavior / semi-log plot

Figure 3 presents the shear stress – shear rate behavior of the polymer system. The highest shear stress is reached for low temperature and high shear rate with about 1.6 Pa at 145 1/s. Significantly lower shear stresses are caused by the degraded polymer solution, taken from a sample after the laboratory tests have been performed.

Fig. 3 Shear stress versus shear rate behavior / log-log plot

Viscous Fluid Effects on the Rod String

Sucker rod pumps seem to suffer less when pumping a non-Newtonian polymer solution than other artificial lift systems. Nevertheless, the requirement of the field redevelopment on sucker rod pumps is to produce 250 m^3/d of back - produced polymer solution. Al-Sidairi et al. (2019) [1] and Zhongxian et al. (2017) [36] indicated severe erosion, wear, and corrosion failures of sucker rod pumps due to polymer back production. In addition, a significant reduction of the rod fall velocity was indicated because of viscous friction on the sucker rod string, causing the rod string to float. Finally, rod string buckling might damage the rod and tubing string. The rod fall velocity is the result of the sum of all forces acting on the rod string. The most significant forces acting on the rod string during a pumping cycle in a vertical well section (concentric tubing – rod string geometry without contact between rod string and tubing inner wall and Coulomb friction) assumed) are stated by Takacs (2015) [32]. The viscous friction force F_μ depends directly on the fluid's viscosity (Eq. 1) [25]. In contrast, the turbulent drag force F_D shows a quadratic relation to a solid object‘s movement speed in a fluid (Eq. 2) [9]. Both act at a sucker rod string in motion and contribute to the produced fluids‘ resistance against its motion.

$F_\mu=\mu A_s\ v/y$ Eq. 1

Where A_s is the surface area of a solid object in the fluid, v is the movement velocity of the solid object in the fluid, and y is its distance perpendicular to another solid surface.

$F_D=C_D A_s$ ☒v^22
Eq. 2

where C_D is the drag coefficient, which depends on the shape of a solid object in the fluid and the actual Reynolds Number, and ρ is the density of the fluid. The polished rod load $F_{pol.rod}$ during the downstroke can be calculated by Eq. 3, where $F_{rod\ string\ in\ air}$ is the rod string weight in the air, F_B is the buoyancy force, and $F_{fr,Coulomb}$ is the Coulomb friction force considered if the rod string is in contact with the inner wall of the tubing in inclined wellbores or doglegs.

$F_{(pol.rod)}=F_{(\ rod\ string\ in\ air)}-F_B-(F_\mu+F_D)-F_{(fr,Coulomb)}$
Eq. 3

In sucker rod pump operations, much higher viscous friction forces occur during the downstroke than during the upstroke because of the higher relative velocities between the rod string and produced fluid. During the downstroke, the rod string submerges in the tubing fluid. During the upstroke, the tubing fluid moves almost parallel with the rod string in the same direction, and no significant relative velocity develops. The downstroke is the main subject in various publications investigating rod string floating and viscous friction in general [3, 32]. The rod string is slower moving downwards than the horsehead, wireline hanger, and carrier bar, as the polished rod velocity surpasses the rod fall velocity. As a result, the polished rod clamp detaches from the carrier bar. As density changes marginally between standard production and chemical enhanced oil recovery, viscous friction is the reason [4, 26]. Dynamometer cards can be used to identify rod string floating. Close to or zero loads during the downstroke typically indicates rod string floating, even if not visible at the surface. Boyer and Dorado have published example dynamometer cards [3].

Rod string floating has severe consequences on the unit loading and the production rates since it significantly shortens the effective pump plunger stroke length. Crankshaft and gear reducer torques increase as there is no rod string-weight support when lifting the counterweights. Consequently, the lifting efficiency and energy efficiency decrease. An efficiency study of SRPs in the Daqing Oil Field (China) reflects these trends. Sucker rod pump system efficiency decreases with increasing polymer solutions and increases viscous friction between the rod string and those solutions. During various polymer flooding stages in this oil field, system efficiencies drop from 42% in the pre-polymer flooding time to 33% during the main polymer slug. Stroke length and pumping speed have been seen as one of the main efficiency drivers. The larger the stroke length, and the higher the pumping speed, the higher the system efficiency [14]. In the polymer floods in the Sleepy Hollow Reagan Unit (US) and Marmul Oil Field (Oman), decreased gross productivities due to system efficiency losses were observed too [27]. The critical rod fall velocity determination is the primary target to optimize SRP systems in this application field.

Large-Scale Pump Test Facility Tests

The pump test facility at the Montanuniversitaet Leoben was used to investigate a large-scale lab test of the polymer solution‘s viscous effect on the sucker rod string [18, 19]. The large-scale lab test‘s objectives are evaluating the viscous friction force for pure water and the 2000 ppm HPAM polymer solution for different movement velocities in vertical and inclined (30°) operating modes for the calibration of the CFD simulation.

Test Preparation

The test facility was prepared by installing several meters of a 3 ½ in. tubing, the housing for the test equipment. A stainless-steel tubing was selected, as laboratory tests have indicated a substantial alteration of the HPAM polymer solution if being in touch with carbon steel. The tubing was closed via a flange equipped with a drain valve at its bottom end, which allowed draining and exchanging the used liquids for the various test runs quickly. At the top, the tubing is flanged into the facility‘s wellhead. The tested equipment is a 1.8 m long, 1 in. sucker rod string segment with one 3 ½ in. rod guide and a regular-sized coupling at the top (Fig. 4). The coupling is connected to the polished rod and connected by a 500 N bending beam type load cell to the test facility‘s sled. The rod string segment‘s weight with the polished rod was taken in air and is 13.76 kg (135 N). After installation, the installed equipment was completely submerged in liquid.

Fig. 4 Schematic of tested equipment

The tubing‘s liquid volume with the equipment to be tested being installed was evaluated with 25 liters. The HPAM polymer solution was prepared with 20.5 liters of water with a potassium chloride concentration of 2 wt.% and 4.5 liters of 11,000 ppm mother polymer solution provided by the industry partner.

In the field, the pump jack‘s movement [31], which shows some kind of sinusoidal behavior, dictates the polished rod velocity. The elasticity of the several hundreds of meter long rod string influences its movement characteristics. Commercial software or Finite Elements Simulations [8, 17] can be used to analyze the rod string velocity at any point in detail. The maximum velocity causes the highest friction force, most interesting during the pumping system‘s downstroke. Commercial software was used to evaluate the rod string motion for a rod string design comparable to Well 1, a stroke length of 1.8 m, at 4 and 6 SPM. The analysis showed that the maximum system velocities of 0.36 m/s for 4 SPM (Fig. 5) and 0.58 m/s for 6 SPM are reached at the polished rod at a position of about 0.82 m.

Fig. 5 Rod string velocity distribution of 1.8 m stroke length and 4 SPM

Test Program

Several test runs with pure water and the 2000 ppm HPAM polymer solution were performed in vertical and inclined positions. The test velocities were chosen in the range of 0.2 m/s and 0.58 m/s (6 SPM). In addition, one test run without a rod guide in pure water was performed to assess the rod guide‘s influence on the viscous friction. The rheological parameters were taken before and after the tests (Fig. 2 & 3). For the laboratory tests, a load cell was installed on top of the polished rod and connects the test equipment to the drive of the pump test facility. The load cell reading was recorded continuously.

Test Evaluation

Viscous friction acts against the rod string motion direction and reduces the effective polished rod load or load cell readings in the lab tests. As a result, each test scenario will return different load cell readings. Each test scenario was run for several strokes. The load trend goes in line with the velocity trend. During the acceleration and deceleration periods of the sled, the load increases during the upstroke and decreases during the downstroke. A significant drop in the load during the downstroke can be observerd.

For evaluating the recorded data, several strokes at stabilized conditions (constant speed) were considered. The recordings at constant speed were taken, and the averaged load cell force $F_{pol.rod}$ calculated. Based on the $F_{pol.rod}$ the viscous friction force $F_{vis.friction}$ is calculated by a rearrangement of Eq. 3 (see Eq. 4).

F_(vis.friction)=F_μ+F_D=F_(rod string in air)-F_B-F_(pol.rod)-F_(fr,Coulomb)
Eq. 4

Table 1 summarizes the evaluated test results.

It can be seen that the viscous friction at the rod string segment increases for the HPAM polymer solution, with increasing pumping speed, and, slightly, with inclination and rod string/tubing eccentricity. The friction coefficient between the rod guide and tubing can be calculated based on the inclined tests and is about 0.015. A notable decrease in fluid friction was seen when the rod guide was removed. Fluid friction dropped by about 3.4 N for pure water and 4 SPM at the test facility. The results indicate that the rod guide‘s viscous friction is more than 50% of the overall viscous friction at the rod string segment. Figure 10 shows the viscous friction versus speed trend of the vertical test arrangement for water and the HPAM solution. It can be seen that the inclination of the regression lines is almost equal with the one for the HPAM solution being slightly steeper. The trends go in line with the theory.

Numerical Simulation

A CFD model was set up to validate the polymer–rod string interaction numerically.

Geometry and Computational Mesh

The model geometries and the corresponding flow domain meshes for the CFD simulations are created by the open-source CAD modeling software Salome. A 180 cm long sucker rod string segment, with dimensions equal to those used in the lab tests and field sample well, is the basis for the model’s geometry. A 1 in. rod string with a standard size coupling and a 3 ½ in rod guides inside a 3½in. tubing are modelled. Since both vertical and deviated wellbore trajectories are considered, a concentric version for a vertical well section and an eccentric version for a deviated well section is provided. For the eccentric model, an inclination of 30° is defined. Figure 6 shows a representative segment‘s geometry for a vertical wellbore consisting of rod string, coupling, and rod guide.

Fig. 6 Representative geometry for a vertical well section including rod string, coupling, and rod guide

The rod string segment models contain all relevant geometrical information of the sample well’s rod string. In contrast, this component-wise approach allows straightforwardly converting the fluid friction force results of the CFD simulation to a sucker rod string of arbitrary length. Since the back-produced polymer solution‘s flow is of interest, the model regions where fluid flows occur need to be defined by an appropriate mesh. The mesh generated in Salome consists of hexahedral elements. In total, the numerical model consists of 86,000 hexahedral cells. In Figure 7, a representative section of the created flow domain around a rod guide for a vertical well section is depicted. It can be seen that a refinement of the mesh was chosen in regions of edges and small flow cross-sections.

Fig. 7 CFD mesh around the rod guide

The surface irregularities of the rod string, coupling, rod guide, and the tubing‘s inner wall are minor compared to the flow path; moreover, they are also assumed to be in the viscous sublayer, not affecting the flow away from the surfaces. Hence, all actual model surfaces are classified as hydraulically smooth.

Governing Equations

Both fluid types (saltwater and polymer solution) can be considered incompressible; the continuity equation and the Navier-Stokes equations for incompressible fluids are the numerical simulations governing equations (Eq. 5 and Eq. 6).

where ρ is the density of the fluid, v is the velocity field, p is the pressure, ν is the kinematic viscosity of the fluid, g is the vector of the acceleration of gravity, t is the time, and is the nabla symbol. The saltwater, which exhibits a salinity of 20,000 ppm, is treated as a Newtonian fluid. However, since the polymer is considered a Newtonian fluid, the viscosity is not constant but a function of the associated shear rate. To describe the shear-thinning behavior of the polymer, the Power Law model is applied.

The selected numerical solver in OpenFOAM is the so-called pisoFoam solver, a transient solver for incompressible, Newtonian, or non-Newtonian fluids and turbulent flow regimes. The selected turbulence model for all simulated scenarios is the k-ω-SST model.

Initial- and Boundary Conditions

The initial conditions refer to a static situation – no movement of the rod, and the velocity field is zero. Several cycles are simulated to overcome the startup influences. During the rod‘s downstroke, it displaces fluid by its volume, resulting in an upwards flow field. Nevertheless, the fluid velocity is equal to the wall velocity; thus, zero at the tubing wall and the actual rod velocity at the rod wall. The velocity profile will be obtained by prescribing the appropriate boundary conditions (Fig. 8). At the outlet of the flow domain, a zero-gradient boundary condition is applied for the velocity.

Figure 8: The inlet velocity distribution is the boundary condition given and constant across the gap. The velocity field in the middle is the result of the initial and boundary conditions

In terms of pressure, a zero-gradient boundary condition is applied at the inlet and the rod, coupling, and rod guide surfaces, as there are neither pressure sources in the flow direction nor at these surfaces. In addition, a fixed value of zero is chosen for the outflow boundary condition, indicating that there is no backpressure. The simulation evaluates relative pressures, and as the fluid is incompressible, the absolute pressure is insignificant or can be added afterward.

For a stable simulation, the Courant number, a function of the flow velocity, the time increment, and the minimum cell size needs to be smaller than 1. Therefore, the selected time increments are 0.00025 s, resulting in a calculation duration of 5 hours for 1 s of simulation.

Simulation post-processing and analysis

When the simulation has completed successfully, the fluid wall shear stresses at the modeled rod string section surfaces are determined per time increment for each scenario.

Fig. 9 Fluid wall shear stresses at the model surfaces in a vertical well section

The fluid wall shear stresses are the basis for calculating the fluid friction and drag forces at the rod string segment and its components. A depiction of simulated wall shear stresses with saltwater and 2,000 ppm polymer solution visualized with ParaView can be seen in Figure 9. Colour intensity indicates the magnitude of the fluid wall shear stress. For illustration, the sucker rod string, simulated in the vertical direction, is rotated 90° in a counter-clockwise direction.

By integration of the vertical (z-) components of the fluid wall shear stress over the defined surfaces of the model geometry (rod string surface, coupling surface, rod guide surface) in ParaView, it is possible to directly calculate the fluid friction and drag forces acting on the rod string surfaces for each simulated and recorded time step. In addition, ParaView provides the possibility of extracting the various rod string components and analyzing the fluid friction forces acting on them individually. Selected lab test results verified the CFD simulation. Table 2 indicates a good match between lab tests and simulation results. The results show a good agreement.

Tab. 2 CFD simulation verification

Figure 10 presents the comparison of the laboratory test results and the CFD simulation results. It reflects some expectable trends of the friction between the rod string and produced liquids. Fluid friction forces at the rod string are noticeably higher for the 2,000 ppm polymer solution than water, especially at the rod guide and the coupling. Furthermore, the fluid friction forces are proportional to pumping speed, or more specifically, to the relative velocity between the rod string and produced liquids. Inclination has a comparatively small effect on fluid friction. The reason why the maximum fluid friction forces with the polymer solution are higher than for water is that the relative velocity between the rod string and produced liquid during downstroke does not reach values high enough for articulate shear-thinning of the polymer solution and for water to become fully turbulent over a certain period. In such situations, the viscous friction is dominant, and the turbulent drag is relatively small. The trend with increasing pumping speed can already be seen when comparing the above scenarios with 4 SPM and 6 SPM. The effect of saltwater in viscous friction was seen to be insignificant.

Fig. 10 Comparison of the laboratory test results and the CFD simulation results

Field Test and Observations

Sucker Rod Pump operational observations have been made at Well 1. In March 2019, rod string floating was first documented at Well 1, which is part of a polymer flooding injector – producer pilot pattern of the redevelopment project. The 40-375-TH-24-4 downhole pump is installed at a depth of 700 m TVD. The rod string comprises 500 m of 1 1/8” sucker rods with 2 rod guides per rod, 170 m of 1” sucker rods with 4 rod guides per rod, and 30 m of 1 3/4“ sinker bars. The surface unit (Lufkin 1280) is operated at 5.23 SPM.

Figure 11 shows a trend plot of Well 1 from March 2019 till May 2020. Input voltage frequency of the variable speed drive, pumping speed, production rate, and pump volumetric efficiency are shown. Pumping speed adjustments (reductions) were performed whenever the rod string floating was noticed. Nevertheless, it was attempted to run the system at the critical pumping speed, just below the onset of rod string floating. Therefore, the occurrence of high viscous friction of back-produced polymer solutions at the rod string with rod string floating is best identified by analyzing adjustments of prime mover input voltage frequency and pumping speed over the period. Input voltage frequency adjustments have been made between March 2019 and May 2020 to counteract rod string floating and increased downhole pump leakage because of the co-production of formation sand.

On the 7th of March 2019, the prime mover input voltage frequency was reduced because the pumping speed led to rod string floating. The frequency increase on the 28th of June was an attempt to increase the pumping speed and production rate. However, the frequency and pumping speed had to be again reduced on the 3rd of July since rod string floating occurred again. A recent attempt to increase pumping speed and production rate were made on the 11th of July and withdrawn on the 20th of July since rod string floating occurred again. The stepwise prime mover input voltage frequency increases between the 19th of August 2019 and the 17th of January 2020 were made to compensate for the increasing severity of downhole pump leakage – otherwise increasing the input voltage frequency would have led to rod floating again. Although the production rate continuously decreased for the actual target rate of 200 m^3/day to values as low as 130m^3/day between January and May 2020 due to the steadily increasing severity of downhole pump leakage, the input voltage frequency could not be increased further because of the rod string floating issues.

Fig. 11 Well 1 operational and production Data Trend (Gesslbauer, H. 2021)

In the mid of 2020, a rod string exchange was finally done to overcome the rod floating problem. The rod string was replaced by a 98 API rod string (450 m of 1 1/8" rods, 195 m of 1" rods), each having 2 rod guides per rod and 35 m of 1 3/4" sinker bars. The operation parameters were not changed. Since that replacement, no rod string floating has been seen.

Figure 12 shows dynamometer cards for several times of Well 1. The cards from 20.03.2019 and 21.05.2019 looked similar and were taken at a very low polymer concentration period. No rod string floating was observed. The card from 28.06.2020 was taken during a severe rod string floating period. Due to significantly changed conditions, a comparison to the last two cards would be misleading. The card from 25.08.2020 shows the polished rod performance after the rod string change, similar to the initial behavior.

Fig. 12 Well 1 Dynamometer Cards at several time steps

The measurement from 28.06.2019 indicates severe rod floating during the downstroke. The load decreased significantly at positions between 3.3 and 2.1 m; the polished rod clamp was lifted from the pump jack's carrier bar. During the upstroke, an essential load increase was seen. The peak polished rod load increased from 80 kN to 90 kN.

A polymer spike test was performed in Well 2 in addition. Significant influences of the pump performance, when pumping the polymer have been seen (Hoy et al., 2020).

Comparison Field Spike Test and Simulation Results

A detailed comparison of the field spike test results and the CFD simulation results of Well 2 was performed. The Lufkin 640 pump jack reaches a stroke length of about 4.3 m. The maximum rod string downward velocity is 0.6 m/s for 2.6 SPM operating speed.

Tab. 3 CFD simulation results of Well 2

Equipment

Table 3 compares the simulation result of the viscous friction for pure reservoir fluid and the polymer solution for the Well 2 configuration. The simulation indicated a general increase in viscous friction for all components. In total, the viscous friction force increased by 30% from 3,735 N to 4,858 N, which is in absolute numbers 1,126 N. In the field, a drop in polished rod load at the mid of the stroke of about 1.3 kN was seen for the polymer solution, which represents a pretty good match of the simulation.

The challenge is to reduce the influence of the show effects when pumping polymer solutions. On the one hand, particular types of downhole pumps (SRABS) can be used (Langbauer et al., 2013; Langbauer, 2015; Langbauer et al., 2018), which tension the rod string during the downstroke, thereby preventing buckling and are counteracting the downstroke viscous friction. The next step in the research is installing and testing the SRABS pump's performance in a polymer back-producing well, as it promises better performance than a standard downhole pump. In addition, a reduction of the plunger friction force can reduce the compressive loads in the rod string. Another aspect is the detailed analysis of the plunger clearance, as it can significantly contribute to the viscous friction of the pumping system (Kochtik and Langbauer, 2018). Furthermore, to prevent sand from being trapped between the rod guides, being in touch with the tubing, efficient downhole desanders can be used (Langbauer et al., 2020). Finally, effective pump prediction is requested to be aware of the downhole conditions (Chevelcha et al., 2013; Langbauer et al., 2021).

Conclusions

In this article, the fundamentals of polymer flooding as a method of tertiary oil recovery, the respective rheology, and its impact on sucker rod pumping were discussed. Field experience from existing chemical EOR fields showed problems, which are untypical for conventional oil production. Sucker rod string floating and system efficiency losses are attributed to the fluid friction between the sucker rod string and the back-produced polymer solutions. The mechanisms of these issues were reviewed, and the fluid friction forces between the sucker rod string and relevant produced liquids were investigated in a field production test and determined with laboratory tests and CFD Simulations.

The laboratory tests indicated a substantial degradation of the HPAM solution when in touch with oxygen and carbon steel equipment, resulting in a drop to about 30 % of the initial solution viscosity. The laboratory measurements have been used to verify the numerical computational fluid dynamics simulation. A good match was achieved. The results of the simulations provide a basis for the sucker rod string design of polymer solution back-producing SRPs. Generally, polymer solutions change the usual operating conditions for SRPs to operation with increased fluid friction at the sucker rod string, particularly during the downstroke. The issues of SRP system efficiency losses and sucker rod string floating due to fluid friction at the sucker rod string may become more notable in these cases if countermeasures are not implemented in time. The review of field observations has shown that polymer solutions can cause severe rod string flooding. A spike test in the field confirmed the lab and simulation results.

The results of the presented CFD simulation determine the fluid friction forces. This knowledge can serve as a basis for the redesign of SRP rod strings and part of a company-intern design standard for SRPs in polymer flooding projects. In addition, the simulations show that the resulting fluid friction force acting on a sucker rod string is generally higher with polymer solutions than with conventional reservoir fluids. For instance, with 6 SPM and a stroke length of 488 cm, the fluid friction force at a single rod string with 2 rod guides is about 35 % higher with a 2000 ppm polymer solution than conventional reservoir fluids.

Stand-alone pumping speed reduction without rod string redesign reduces fluid friction when back-producing polymer solutions is not a proper solution since it reduces gross production rates. Early rod string redesign would be the right approach to handle increased fluid friction without impairing the production rates. At the same time, no distinct SRP design standard for back-producing polymer solutions has been developed so far. The general conclusion is to reduce the number of rod guides to use a bigger pump size while reducing the pumping speed.

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