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OPERATIONAL COMPLICATIONS IN WELLS EQUIPPED WITH SUCKER ROD PUMPING SYSTEMS: CAUSES, CLASSIFICATION, AND IMPACT ON PRODUCTION EFFICIENCY

Abstract. *This article examines the main operational complications arising in oil wells equipped with sucker rod pumping systems. The study systematizes the principal mechanical, hydrodynamic, geological, and physicochemical factors that reduce pump efficiency, increase equipment wear, and shorten well run life. The analysis is based on the operating principle of sucker rod pumping systems, the structure of their main components, and the causes of failures under complicated production conditions. The results show that operational complications lead to production decline, incomplete pump filling, higher energy consumption, accelerated wear of rods, tubing, plungers, and valves, and increased repair frequency. It is concluded that the reduction of complication-related losses requires integrated monitoring, proper equipment selection, optimized operating modes, and timely preventive maintenance.*

Keywords: *sucker rod pumping system, oil well operation, operational complications, rod string wear, gas interference, paraffin deposition, corrosion, production efficiency.*

ЭКСПЛУАТАЦИОННЫЕ ОСЛОЖНЕНИЯ В СКВАЖИНАХ, ОБОРУДОВАННЫХ ШТАНГОВЫМИ СКВАЖИННЫМИ НАСОСНЫМИ УСТАНОВКАМИ: ПРИЧИНЫ, КЛАССИФИКАЦИЯ И ВЛИЯНИЕ НА ЭФФЕКТИВНОСТЬ ДОБЫЧИ

Аннотация. *В данной статье рассматриваются основные эксплуатационные осложнения, возникающие в нефтяных скважинах, оборудованных штанговыми скважинными насосными установками (ШСНУ). В исследовании систематизированы ключевые механические, гидродинамические, геологические и физико-химические факторы, снижающие эффективность работы насосов, увеличивающие износ оборудования и сокращающие межремонтный период скважин. Анализ базируется на принципе работы ШСНУ, структуре их основных узлов и причинах отказов в осложненных условиях эксплуатации. Результаты показывают, что эксплуатационные осложнения приводят к падению дебита, неполному наполнению насоса, повышенному энергопотреблению, ускоренному износу штанг, НКТ, плунжеров и клапанов, а также к увеличению частоты ремонтов. Сделан вывод, что снижение потерь от осложнений требует комплексного мониторинга, правильного подбора оборудования, оптимизации режимов работы и своевременного проведения профилактических мероприятий.*

Ключевые слова: *штанговая скважинная насосная установка, эксплуатация нефтяных скважин, эксплуатационные осложнения, износ штанговой колонны, газовое влияние, парафиноотложение, коррозия, эффективность добычи.*

Introduction

Sucker rod pumping systems are among the most widely used artificial lift methods in the oil industry. They are especially common in low-rate wells and mature fields where natural reservoir pressure is insufficient to lift fluid to the surface. Under such conditions, sucker rod pumps provide a reliable and economically efficient way to sustain production.

The practical value of these systems lies in their relatively simple design and adaptability to different operating environments. A typical sucker rod pumping installation includes surface equipment, a rod string, tubing, and a downhole pump. The surface drive converts rotary motion into reciprocating motion and transmits it through the rod string to the plunger, which lifts fluid from the well to the surface.

Despite their simplicity and broad applicability, sucker rod pumping systems are highly sensitive to production conditions. Their performance depends not only on equipment design, but also on well trajectory, fluid properties, gas content, solids production, corrosion activity, and the selected operating regime. In actual field practice, these factors often lead to complications that reduce pump efficiency, increase dynamic loading, accelerate wear, and raise operating costs.

Operational complications are significant because they affect the technical, technological, and economic performance of the well stock. They reduce liquid production, shorten the run life of downhole equipment, increase energy consumption, and lead to more frequent repairs. In many cases, complications do not arise separately but interact with one another. For example, gas interference may reduce pump filling, unstable operation may increase dynamic loads, and these loads may then accelerate rod fatigue and plunger wear.

The purpose of this article is to classify the main complications occurring during the operation of wells equipped with sucker rod pumping systems, analyze their causes, and assess their impact on production efficiency.

Materials and Methods

The study is based on analytical systematization of the material related to the operation of wells equipped with sucker rod pumping systems. The research approach combines technical description of the pumping process with classification of the factors that cause operational complications.

The operating principle of the sucker rod pump is based on reciprocating plunger motion transmitted from the surface unit through the rod string. The pump operates in two alternating stages: suction and discharge. During the upward movement of the plunger, the pressure below it decreases, the standing valve opens, and formation fluid enters the pump chamber. During the downward movement, the standing valve closes, the traveling valve opens, and the fluid is displaced above the plunger and then lifted through the tubing.

The theoretical pump rate is determined by the following expression:

$$Q_T = (\pi \cdot D^2 \cdot S \cdot n) / 4 \tag{1}$$

where Q_T is the theoretical pump rate, m^3/s; D is the plunger diameter, m; S is the plunger stroke length, m; and n is the number of double strokes per second.

Under real operating conditions, actual production differs from theoretical production because of leakage, gas content, viscosity, abrasive particles, incomplete pump filling, and other losses. The actual pump rate is expressed as:

$$Q_f = Q_T \cdot \eta_V = (\pi \cdot D^2 \cdot S \cdot n \cdot \eta_V) / 4 \tag{2}$$

where Q_f is the actual pump rate, m^3/s, and η_V is the volumetric efficiency of the pump.

The overall efficiency of the installation, taking into account mechanical losses caused by friction, wear, and leakage, can be represented as:

$$\eta_{total} = \eta_V \cdot \eta_{\mathrm{mech}} \tag{3}$$

where η_{mech} is the mechanical efficiency of the installation.

The load on the rod string is described by the following expression:

$$F = \rho \cdot g \cdot H + P \tag{4}$$

where ρ is the fluid density, kg/m^3; g is gravitational acceleration, m/s^2; H is well depth, m; and P is the pressure acting on the plunger, Pa.

Pump discharge under selected operating conditions can also be described as:

$$Q = n \cdot V_{plunger} \cdot \eta \tag{5}$$

where Q is pump discharge, m^3/day; n is pumping frequency; $V_{plunger}$ is the fluid volume per plunger stroke; and η is pump efficiency.

To assess actual pump performance, the following efficiency ratio is used:

$$\eta = (Q_{actual} / Q_{theoretical}) \cdot 100\% \quad (6)$$

If $Q_{actual} = 5.8$ m^3/day and $Q_{theoretical} = 6.12$ m^3/day, then:

$$\eta = (5.8 / 6.12) \cdot 100\% \approx 94.8\% \quad (7)$$

These analytical expressions make it possible to compare ideal and actual pump operation and to identify the effect of operational complications on performance.

Results

Structure and operation of sucker rod pumping systems

A sucker rod pumping system consists of surface and downhole equipment. The surface part includes the pumping unit, reducer, crank mechanism, walking beam, polished rod, motor, belt drive, frame, and control unit. The downhole part includes the rod string, tubing string, and the downhole pump itself. Depending on operating conditions, gas anchors or sand anchors may also be installed below the pump.

The downhole pump generally consists of a barrel, a plunger, a standing valve, and a traveling valve. Their coordinated operation ensures cyclic filling and emptying of the pump chamber and gradual lifting of the produced fluid to the surface..

The stable operation of the system depends on the correct interaction of all these elements. Surface equipment transmits motion, the rod string delivers this motion to the pump, the tubing string serves as the flow channel, and additional downhole devices reduce the negative effect of free gas or solid particles.

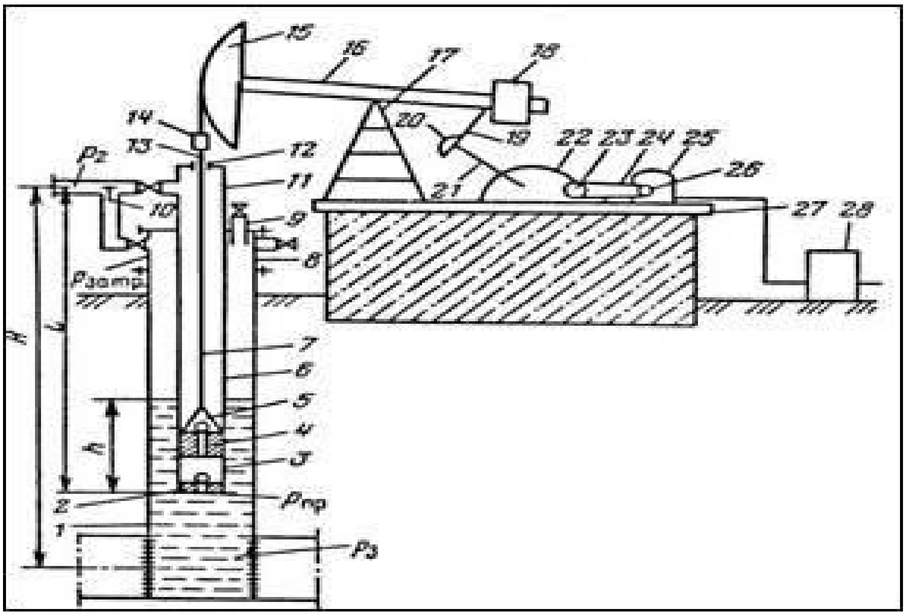

Figure 1. Schematic structure of a sucker rod pumping installation

Operating technology of wells equipped with sucker rod pumps

The operation of a well equipped with a sucker rod pump is a multistage technological process. Before startup, the technical condition of the pumping unit, drive, rod string, tubing string, valves, and threaded connections must be checked. At this stage, the pump setting depth and the expected operating regime are also selected.

The initial startup includes filling the tubing string with fluid, eliminating gas pockets, and gradually increasing the pumping frequency. During normal operation, the selected pumping regime depends on production rate, fluid viscosity, gas factor, and pump setting depth. Stroke length and pumping frequency are regulated to optimize loading on the rod string and downhole pump.

Continuous monitoring of pressure, temperature, fluid level, and rod load allows operators to identify rod wear, valve wear, plunger slippage, gas accumulation in the pump, and production decline. Preventive maintenance includes inspection of the plunger, replacement of worn rods and valves, checking leak tightness, and, when necessary, major repair.

In difficult operating conditions, such as high gas content, water influx, or deviated wellbores, special pump and rod designs may be required. Gas separation methods, liquid rate regulation, and operating mode optimization are used to maintain stable production.

Classification of operational complications

The analysis shows that complications in wells equipped with sucker rod pumps may be classified according to origin, location, and consequences. In practical terms, the main categories are mechanical, hydrodynamic, and geological complications. In addition, many failures are caused by a combination of several factors acting simultaneously.

Mechanical complications

Mechanical complications are among the most common problems in sucker rod pump operation. One of the main issues is rod string damage, including bending, cracking, breakage, and complete rod failure. These problems are caused by side loading and rod-to-tubing friction in deviated wells, cyclic loading, corrosion, abrasive wear, installation errors, and incorrect selection of rod dimensions or strength.

Another important problem is damage to the pump barrel, plunger, and valve assembly. Abrasive particles such as sand intensify wear of sealing surfaces, reduce tightness, and may cause sticking of the pump elements. Paraffin and other deposits also worsen the performance of the plunger-barrel pair and increase resistance to movement. In addition, high gas content may disrupt valve operation and cause unstable pump performance.

Tubing wear is another major form of mechanical deterioration. It may be associated with corrosion, abrasive erosion, deformation in curved well intervals, loss of tightness, and local damage in contact zones. Dynamic loads further intensify wear. These loads include liquid impact, gas impact during plunger movement, and resonance vibrations.

A separate group within mechanical complications is related to friction. In deviated wells, rod centralization becomes especially important because side forces and constant contact between rods and tubing reduce equipment life and increase power consumption. The absence of rod guides, incorrect balancing, and poor string centralization intensify this problem.

Mechanical complications may also arise because of plugging and the accumulation of deposits. Sand, sludge, paraffin, and salt deposits increase friction, disturb pump operation, and lower system efficiency. Incorrect equipment selection, overload, and insufficient load-diagram analysis further increase the risk of failure.

In practice, these factors often act together. Sand entry into the pump combined with free gas may lead to gas locking, valve sticking, cylinder wear, and loss of production.

Figure 2. Sand accumulation in the sub-packer plunger.

Hydrodynamic complications

Hydrodynamic complications arise when the stable movement of produced fluids inside the wellbore is disturbed. These complications reduce production efficiency, shorten equipment run life, and increase operating costs.

One of the most widespread hydrodynamic problems is gas interference. When pressure decreases, dissolved gas is released from oil and accumulates in the free state. As a result, gas plugs form near the pump intake, worsen fluid intake, disturb pump operation, and create dynamic overloads. In severe cases, gas locking may stop liquid lifting completely.

To reduce gas-related complications, gas separators and gas anchors are used. Their effect may also be limited by changing pump setting depth and by adjusting the pumping frequency.

Another important hydrodynamic complication is emulsification. Intensive mixing of oil and water may lead to the formation of stable emulsions. This increases apparent viscosity, raises hydraulic resistance, and increases energy consumption. Emulsions may also contribute to internal tubing corrosion. Paraffin and salt deposition have a strong hydrodynamic impact as well. As produced fluid moves upward through the tubing, cooling causes paraffin crystallization and the gradual narrowing of the flow channel. Salt precipitation occurs because changes in pressure and temperature force dissolved minerals out of solution. These deposits form near the pump intake and on tubing walls, reducing flow area and, in extreme cases, completely blocking the system.

Hydraulic shocks caused by sudden changes in flow velocity are another hydrodynamic problem. Strong shocks and oscillations may damage pump components, tubing, and associated structural elements.

Geological complications

Geological complications are linked to the geological environment in which the well operates. These include unstable rocks, loose water-saturated formations, tectonic fault zones, suffosion, karst processes, and breakthrough of groundwater horizons.

Weak and unstable formations are especially dangerous because they may deform or collapse, changing wellbore geometry and increasing contact loads on downhole equipment. Tectonic zones are often characterized by low rock strength and a high density of microfractures, which may lead to structural instability and altered fluid flow.

Hydrogeological factors may also create serious difficulties. Groundwater may loosen the rock mass, increase pore pressure, and activate suffosion processes. The presence of soluble rocks such as gypsum, dolomite, and limestone may lead to karst development, the formation of cavities, and structural instability.

Although geological complications may initially appear unrelated to the pump itself, they directly influence the long-term reliability of sucker rod pump operation because they change the mechanical and hydrodynamic conditions inside the well.

Causes of operational complications

The analysis makes it possible to identify several main groups of causes leading to complications in sucker rod pumped wells.

The first group includes geological and physical causes. The presence of abrasive particles, especially sand, in the produced fluid leads to rapid wear of the barrel and plunger. Sand creates an abrasive medium, damages internal surfaces, reduces sealing quality, and may cause pump sticking. Excessive sand production also leads to erosion of rods and other components and may cause plugging in the plunger zone.

The second group includes physicochemical causes. Heavy hydrocarbons in crude oil may crystallize during lifting because of temperature decline, forming paraffin deposits. Over time, these deposits grow into plugs that reduce tubing capacity, increase hydraulic resistance, and overload the rod string and surface drive. A similar problem occurs with salt precipitation when changes in pressure and temperature force dissolved salts out of solution.

The third group includes design and technological causes. Improper selection of pump parameters, rod dimensions, and installation geometry increases the probability of overload, metal fatigue, sticking, and production loss. Inaccurate centralization and unsuitable pump clearances may also worsen operating conditions.

A major cause of pump inefficiency is incomplete filling caused by free gas. Although sucker rod pumps can handle some gas, excessive gas content significantly lowers performance because gas compression beneath the plunger delays valve opening and reduces liquid intake. In some cases, efficiency losses may reach 40%. To reduce this effect, the pump intake may be placed below the productive interval so that the annulus acts as a natural gas separator. In horizontal wells, where this is not possible, downhole gas separators are required.

Corrosion is another major cause of failure. Carbon dioxide, hydrogen sulfide, acidic waters, and saline media gradually destroy metal components. Carbon dioxide contributes to carbonic acid formation and micro-pitting, whereas hydrogen sulfide may cause sulfide cracking. Under cyclic loads, even small defects may develop into fatigue damage. Since corrosion often remains hidden until a serious failure occurs, early detection is especially important.

Figure 3. Corrosion damage to downhole components of a sucker rod pump.

Operational and organizational factors also play a significant role. Excessive pumping frequency, incorrect operating mode, insufficient diagnostics, and delayed preventive maintenance all increase the probability of failure. Repeated hydraulic shocks, incomplete pump filling, ignored early signs of corrosion, and overlooked fatigue damage reduce the reliability of the installation and may ultimately lead to shutdown.

Discussion

The analysis shows that operational complications in sucker rod pumped wells are not isolated defects but interconnected processes. Mechanical, hydrodynamic, geological, and physicochemical factors reinforce one another and together determine the actual performance of the pumping system.

A key conclusion is that the same complication often belongs to several categories at once. Sand production is a geological issue, but it also creates hydrodynamic resistance and severe mechanical wear. Gas interference is a hydrodynamic problem, yet it also causes dynamic loading and unstable valve operation. Corrosion is physicochemical in origin, but under cyclic stress it becomes a mechanical reliability problem.

Another important observation is the gap between theoretical and actual pump performance. Theoretical production depends on pump geometry and stroke parameters, whereas actual production depends on volumetric efficiency, mechanical losses, gas content, viscosity, deposits, wear, and fluid composition. Therefore, the difference between theoretical and actual pump output can be treated as a practical indicator of complication severity.

The source material also makes clear that complication control requires more than routine repair. Effective prevention depends on proper equipment selection, timely monitoring of operating parameters, correction of stroke length and pumping frequency, chemical protection against deposits and corrosion, and the use of gas and sand separation devices. Real-time monitoring systems and frequency-controlled drives are particularly important because they allow earlier detection of unstable operation and make it possible to adjust the regime before serious failure occurs.

Conclusion

Operational complications in wells equipped with sucker rod pumping systems are a major factor limiting the technical and economic efficiency of oil production. These complications develop under the combined influence of mechanical loading, unstable multiphase flow, geological heterogeneity, corrosive media, solids production, and deviations from the optimal operating regime.

The main mechanical complications include rod string wear and failure, pump-plunger damage, valve malfunction, tubing deterioration, friction-related failures, and plugging by deposits. Hydrodynamic complications include gas locking, emulsification, paraffin and salt deposition, hydraulic shocks, unstable pump filling, and production decline. Geological complications include unstable formations, tectonic disturbance zones, groundwater influence, suffosion, karst processes, and formation deformation. In practice, these complications usually occur in combination.

The source material indicates that complications may reduce production rate by 15-40%, lower the operating coefficient of wells to 0.65-0.75 instead of 0.9 and above, shorten run life by 1.5 to 3 times, and increase energy consumption by 20-35%. As a result, complication development leads to higher repair frequency, greater energy use, lower production volume, and reduced economic efficiency.

The most effective way to reduce these losses is an integrated preventive approach. This approach should include correct pump and rod design, optimization of operating regimes, use of gas and sand separation devices, regular monitoring of load and fluid level, protection against corrosion and deposits, and timely maintenance. Such measures improve equipment reliability, extend run life, and increase the overall efficiency of sucker rod pump operation.

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