Analysis of workover operations over a ten-year period in an oil and gas field with sucker rod pump production

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Abstract: *At the start of exploitation of any hydrocarbon or geothermal water reservoir, production of reservoir fluids is driven by natural energy in the form of reservoir pressure. Therefore, the primary task for production engineers is to maintain this reservoir pressure for as long as possible, ensuring long-term economic production. Unfortunately, sooner or later it becomes necessary to introduce mechanical methods of fluid lifting. Today, there are numerous solutions on the market for mechanical lifting of reservoir fluids (progressing cavity pumps-PCP, electric submersible pumps-ESP), and one of the oldest mechanical methods for producing reservoir fluids is the sucker rod pump. In the Republic of Croatia, sucker rod pumps are among the most commonly used mechanical methods for lifting reservoir fluids. Although Croatian production engineers have significant experience working with sucker rod pumps, operational problems are common and are accompanied by additional expenses related to workover operations. This paper presents an analysis of workover operations over a ten-year period (from 2011 to 2022) in an oil and gas field in the Republic of Croatia. Based on the collected data, an analysis was conducted to determine the volume of fluid not produced during equipment maintenance and repair, the waiting time for repairs, the duration of equipment maintenance as well as the cost-effectiveness of the repairs. Special attention is given to the analysis of the causes of problems in using sucker rod pumps and the identification of problematic wells.*

Keywords*: SUCKER ROD PUMP, PROBLEMATIC WELLS, WORKOVER OPERATIONS, FAILURES OF DOWNHOLE EQUIPMENT, CAUSES OF EQUIPMENT FAILURES*

1. Introduction

At the start of the exploiting of any hydrocarbon or geothermal water reservoir, production of reservoir fluids is driven by natural energy in the form of reservoir pressure. This reservoir pressure, depending on the location of the reservoirs (depth, density of overburden layers, regional tectonics), may be normal, overpressure or underpressure. Under normal circumstances, it is about normal reservoir pressure which corresponds to the pressure of the column of formation water from sea level to the depth of the reservoir. Unfortunately, starting production of the reservoir fluid (oil, gas, or geothermal water) inevitably causes a decline in reservoir pressure. These trends in reservoir pressure decline can be mitigated through reservoir management strategies, and one of the most commonly strategies is reinjection of the produced water in water-driven reservoirs or gas in gas-cap driven reservoirs.

Therefore, the primary task for production engineers is to maintain reservoir pressure for as long as possible, ensuring long-term economic production. However, sooner or later it becomes necessary to introduce some form of artificial fluid lifting. According to Perrin (1999), at the end of the 1990s artificial lift was used in 75% of the world's production wells (excluding the USA) or even more (90%) if data relating to the USA is included. Artificial method for reservoir fluid lifting can be divided into two groups [1]:

- mechanical lifting by pumping, and
- reduction of reservoir fluid density by mixing the reservoir fluid with gas (natural gas, carbon dioxide) injected into lower part of the production string.

Today, there are numerous solutions on the market for mechanical lifting of reservoir fluids (progressing cavity pumps-PCP, electric submersible pumps-ESP), but one of the oldest and most widely used mechanical methods for producing reservoir fluids is the sucker rod pump. The most important part of the sucker rod pumping system is the positive-displacement pump driven from the surface by rod strings. Despite availability of different and modern solutions for reservoir fluid pumping, the sucker rod pumping system still occupies a large share of the market today. For example, according to data published in 2012, in China there were 118000 wells equipped with sucker rod pumping system, representing 96% of all producing wells [2]. Also, according to data from Matanović i Moslavac (2011), at the beginning of 2000 in the Republic of Croatia were 1,133 active wells, of which 484 were equipped with sucker rod pumping systems while 310 were equipped with gas lift systems [3]. The reason for this probably lies in the fact that it is the oldest artificial system, with extensive technical and engineering experience in its operation.

2. Sucker rod pumping system

As mentioned earlier, the sucker rod pumping system is probably the oldest and most widely used mechanical system for pumping reservoir fluid. The sucker rod pumping system, shown in **Fig. 1**, consists of surface pumping units (usually mechanical or hydraulic propulsion systems) powered by an electric motor or engine (gas or diesel) as well as a pumping head, and a subsurface part which includes the rod string, tubing, and a positive-displacement pump at the bottom.

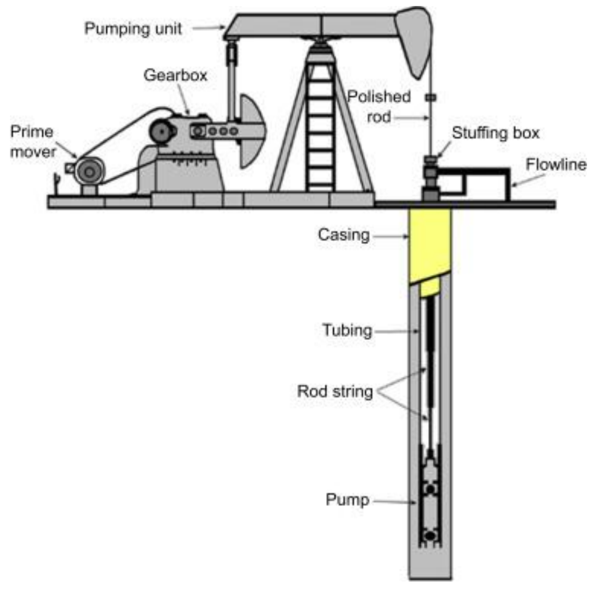

Fig. 1 *Sucker rod pumping system* [4]

Despite technological improvements over the years, the basic working principles of positive-displacement pumping remain unchanged. The core of the system is a positive-displacement pump composed of a cylinder (pump barrel) with a standing valve at the bottom and a hollow plunger with a travelling valve. The hollow plunger is connected to the surface system by a steel rod string, and fluid pumping is achieved by the reciprocating motion of the hollow plunger and the alternating operation of the valves mentioned above. Depending on their installation method, sucker rod pumps can be classified as rod pumps (R pumps) and tubing pumps (T pumps), each with specific advantages and disadvantages (**Fig. 2**).

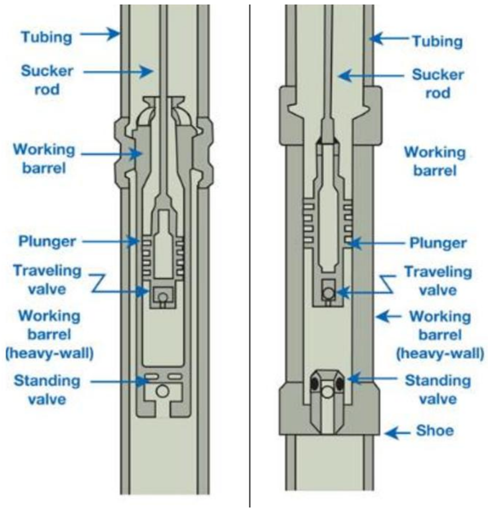

Fig. 2 *Rod pump (left) and Tubing pump (right)* [5]

The pumping unit is installed on the surface and, using electric motors or various types of engines, ensures continuous reciprocating movement of the rod string in opposite direction, enabling the pumping of reservoir fluids accumulated within the wellbore. In additional to the power source for driving the pumping unit, the methods of converting rotational motion from the power unit into linear motion of the rod string is also important. The oldest system, still relevant today, is the mechanical walking beam (**Fig. 3**), balanced with a mechanical counterweight or compressed air. Beside this, there are also hydraulic types of pumping units, as well as various derivatives of these two basic types, such as the linear rod pumping unit (LRP) and other commercial solutions.

Fig. 3 *Mechanical walking beam balanced with counterweight*

The design of the sucker rod pumping system and the selection of the appropriate pump and pumping unit are specific to each location and depend on various parameters, such as the depth of the reservoir, production index, static level of the reservoir fluid column within the wellbore, inside diameter of the installed production casing, pressure required to lift the reservoir fluid and transport it to surface facilities, and the amount of gas within the reservoir fluid, etc.

3. Sucker rod pumping system

As mentioned earlier, the sucker rod pumping system is the oldest method of artificial lifting of reservoir fluid. Given the extensive engineering experience accumulated over 150 years of practical application, the sucker rod pumping system represents a long-term production solution with low operating costs and significant potential for process automation [6]. Despite these advantages, the sucker rod system is accompanied by numerous problems, which can lead to operational halts and associated production losses. Outages in the sucker rod system result in two distinct costs: the first is related to the workover operation required to resolve the cause of the outage, and the second, equally important, is the cost of fluid production interruption (unrealized production of reservoir fluid). Accordingly, from the production engineer's perspective, it is very important to schedule workover operations at specific locations, as reducing the time between problem detection and taking corrective action lowers the costs associated with lost production. This is especially important for large fields with several hundred sucker rod pumping systems installed and possibly only a small number of workover units available in the area.

The sucker rod system outage is most often caused by mechanical wear and material fatigue but can also result from corrosion or their combined effects. The first issue mentioned relates to well construction and system operating principles. Unfortunately, some wells, even those designed as vertical, contain wellbore sections with unwanted changes in inclination and azimuth. Ideally, any contact between the moving rod string and the fixed tubing string within the wellbore should be avoided, but this is practically impossible. According to Hart (2003), between 10% and 20% of the inside surface of the tubing comes into contact with rod couplings [7]. This contact causes excessive wear of the rod couplings and creates a groove on the inner side of the tubing along the length corresponding to the pump stroke. This wear leads to tubing leakage and system downtime, necessitating the removal of the damaged tubing joint from the production string, even though more than 80% of the tubing surface area remains untouched (**Fig. 4)**.

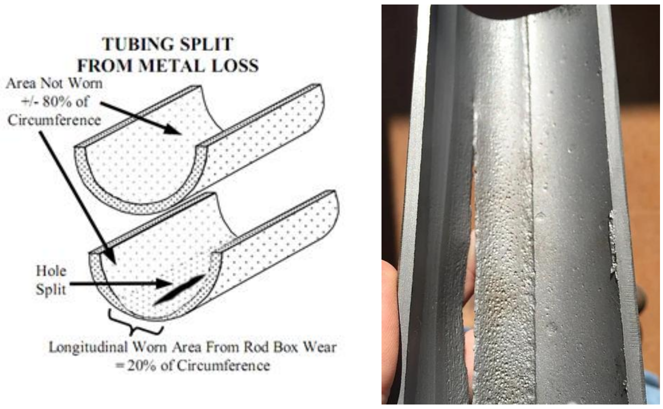

Fig. 4 *Mechanical wear of the tubing* [8]

Apart from mechanical wear, problems also arise from corrosion, especially when the produced fluid contains various admixtures such as carbon dioxide, hydrogen sulfide, or a high proportion of reservoir water. The subsurface components of the sucker rod pump production system, damaged by mechanical action, are particularly susceptible to these processes. Specifically, movement of the rod string inside the tubing removes both the corrosion product and corrosion inhibitors from the inner surface of the tubing, allowing these processes to continue [9]. The chemical effect of the reservoir fluid on the inner surface of the tubing is shown in **Fig. 5**.

Fig. 5 *Pitting corrosion of the tubing* [10]

Considering all the above, it is very important to detect the primary mechanism of tubing and rod wear as soon as possible. The initial assessment can be made based on chemical analysis of the produced reservoir fluid. In the case of mechanical wear, the produced fluid will contain only metal shavings, whereas in the case of corrosion, the produced fluid will contain products of steel corrosion such as FeS, FeCO3, or iron oxide [7].

4. Analysis of workover operations in an oil and gas field over a ten-year period – Case study from Republic of Croatia

The Republic of Croatia has a long tradition of exploiting hydrocarbon reservoirs both onshore and offshore, as well as geothermal water reservoirs. The oil-gas field under consideration is located in the continental part of the country. Of the 195 wells drilled in this field, only 30 are currently active (less than 15%), of which 29 are production wells and one is an injection well. There are also 43 observation wells (**Tab. 1**) [11].

Table 1. Status of the wells in the oil-gas field under consideration.

Well status			Well number
Active	Oil wells	Sucker Rod Pumps	26
		Electrical Submersible Pumps (ESP)	1
		Natural flowing wells	2
	Injection wells		1
Inactive	Oil wells		39
	Gas wells		2
	Injection wells		6
Observation wells			43
Abandoned wells			75

During the period under consideration, 292 workover operations were conducted on 60 wells. According to the available information, of the 60 wells where workover operations were carried out, one was horizontal, 44 were vertical, and for 15 wells (or 25% of workover operations) there was no information about the type of well (**Fig. 6**) [11].

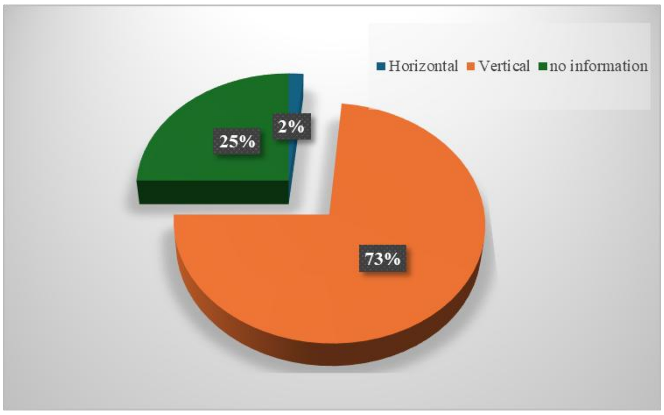

Fig. 6 *Type of wells under workover operation in the period from 2011 to 2022*

Of the 292 workover operations mentioned above, 263 (90%) were conducted in vertical wells, 3 (1%) in horizontal wells, while for 26 operations (9%) there was no information about the type of well construction. Furthermore, 94% of all workover operations during the period from 2011 to 2022 were carried out in wells with a sucker rod pump production system (**Fig. 7**). In addition, 273 workover operations were conducted on rod-type pumps, while information about the type of installed pump was missing for only two operations.

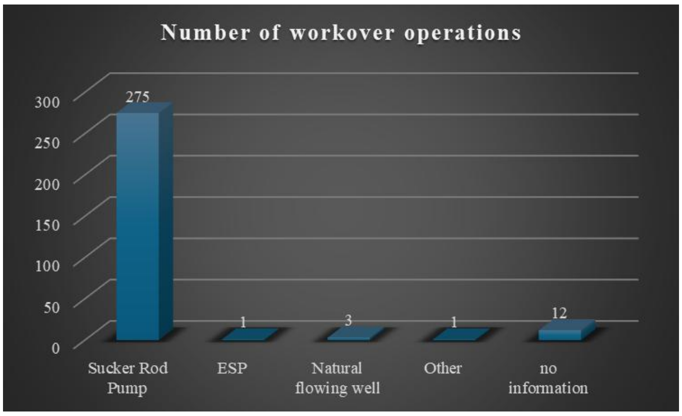

Fig. 7 *Number of workover operation during the period from 2011 to 2022 by production system*

It is particularly interesting to examine the reasons for stopping production and conducting workover operations. Most workover operations (43%) are caused by tubing failure, followed by sucker rod pump failure at 20% and rod string failure at 11% (**Fig. 8**). In 95% of tubing string failures, leakage was the cause, while 87% of rod string failures were due to breakage. Unfortunately, a large number of workover operations lack accurate information about the cause of production stoppage and the need for workover operations. This lack of accurate information makes analysis of the problem more difficult, and in some cases, impossible.

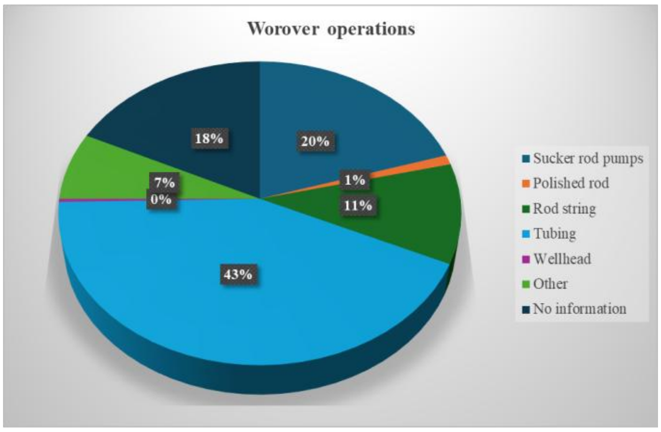

***Fig. 8** Workover operations during the period from 2011 to 2022 in relation to the part of the production system in failure*

In addition to identifying the problematic part of the installed production system, determining the failure type is equally important for a thorough analysis. According to the available information, of the 123 workover operations conducted between 2011 and 2022, 42% were related to leakage, 11% (32 operations) to breakage, and 66 operations to other types of failure. For a large number of workover operations (71), accurate information about the failure type is missing. The cause of problems related to the sucker rod pump is particularly unclear. Based on the available data, in 47 (80%) of the workover operations attributed to the sucker rod pump, the specific cause of the problem remains unknown. The exact cause of the pump-related problem is stated for only 20% of these workover operations (for example, paraffin or formation sand) (**Fig. 9).**

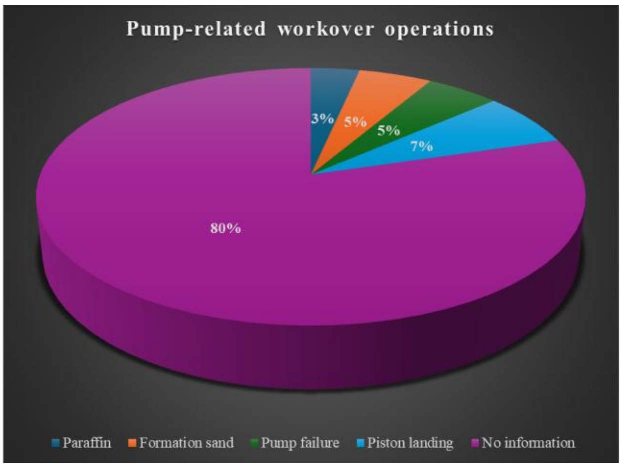

***Fig. 9** Workover operations during the period from 2011 to 2022 related to problems with sucker rod pumps*

Also, the cost of the workover operation varies considerably between operations, ranging from €3,500 per operation to more than €450,000 per workover operation and well. Half of the workover operations cost between €11,000 and €20,000 (**Fig. 10**). The data in Fig. 10 show that 15 workover operations cost between €40,000 and €450,000, while for 57 workover operations, information about the cost is missing [11].

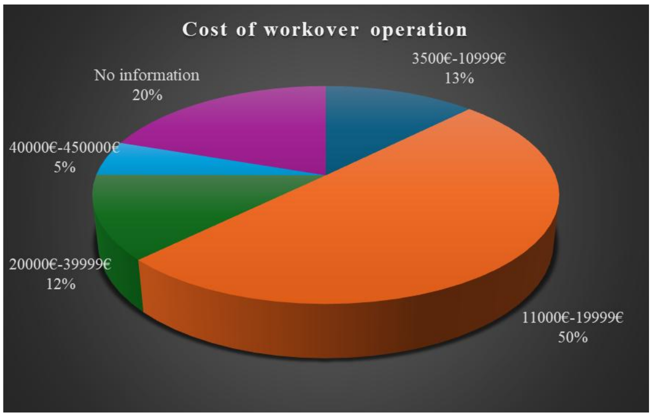

***Fig. 10** Cost of workover operations during the period from 2011 to 2022*

5. Conclusions

Despite being a well-established technology with over 150 years of global use, the sucker rod pumping system experiences problems related to its mode of operation. As expected, most issues with installed sucker rod pumping systems in the oil-gas field studied were associated with the subsurface equipment, primarily the tubing, but also the rod string and the pump itself. The analysis presented in the paper highlighted issues with the consistent collection of all relevant data and the absence of important information. Unfortunately, without all relevant information, identifying problematic wells and implementing preventive actions is significantly more difficult.

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