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The Performance of Sucker Rod Pump Based Artificial Lift System in Oil Reservoirs: A Review

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Abstract

In many oil reservoirs worldwide, the downhole pressure may not be enough to lift the reservoir fluids up to the surface, especially with time progesses and the oil reservoir becomes more matured. In order to produce such reservoir fluids, pumps are often installed to artificially lift such oils; such techniques are called as artificial lift methods. More than 70% of all currently producing oil wells are being produced by artificial lift methods. Sucker rod pump is considered as one of the most used artificial lift techniques due to many reasons. Sucker rod pumps are easy to apply, quite common worldwide, and low in capital and operational costs. Moreover, many advancements in this technology have been applied to improve the performance and the applicability of sucker rod pumps.With such advancements, it is important to conduct an updated review and guide to optimize and better understanding the performance of the sucker rod pumps. This research provides an updated comprehensive review of sucker rod pump components, diagnostics methods, and the screening criteria for the application conditions. In addition, several field cases studies from oil wells worldwide are discussed in this research to highlight some of the key features of sucker rod pumps. Furthermore, the advantages and limitations of sucker rod pumps are investigated based on the updated review. The findings of this study can help in understanding the different types of sucker rod pumps, their properties, modeling and cost.

Introduction

Artificial lift systems are often used to increase the pressure drawdown inside the oil wells to enhance the hydrocarbon production. Most oil wells require an artificial lift technique at some point of their production life. The driving force which displaces oils from the reservoir to the bottom of the well is resulted from the natural energy of the reservoir. Such this natural energy actually causes the well to produce to the surface due to the enhancement in the pressure drawdown along the production paths. If the pressure drawdown between the reservoir and the surface producing facilities is great enough, the well will flow naturally to the surface using only the natural energy supplied by the reservoir. However, when the natural energy associated with oil production paths does not impose enough pressure drawdown between the reservoir and wellbore trajectory, such energy will not be sufficient to lift reservoir fluids to the surface and into surface facilities, or will not drive it into the surface in sufficient volume. Therefore, the reservoir energy should be supplemented by some form of artificial lift.

Artificial lift methods fall into two groups, those that use pumps and those that use gas. Common artificial lift methods used in the world are, sucker rod pumps (SRP) , electrical submersible pumps (ESP) , gas lift (GL) , plunger lift (PLNG) , hydraulic pumps (HP) , and progressive cavity pumps (PCP). In this research, we are focusing on sucker rod pumps because the operators found that such artificial lift techniques are so feasible to enhnce the oil production in many oil wells in southern region of Iraq. For many years of production for some oil fields in southern of Iraq, they suffer from declining in the reservoir pressure which make the oil rate to go down and settle down at low rates. Therefore, there is an urgent need to apply one of the artificial lift methods to enhance the oil production and keep the the oil wells alive. One of the most feasible artificial lift techniques which can be applied in southern oilfields of Iraq is sucker rod pumps.
The selection of sucker rod pumps among other artificial lift techniques is due to the compatibility beween the properties of Iraqi oil fields and the operating conditions of sucker rod pumps. We validated our approaches with the data obtained from the applicability of sucker rod pumps in Iraqi oil fields, the southern region in particular, where the first sucker rod pumps was installed and operated in Al-Zubair oil field in Basra Governorate on the well number ZB-171 where we got accurate production data about this case study. Also, we studied the pump design procedure and the operating paramers since we have all reservoir data and well production data before and after installation.

In this paper, we discuss the design, types, and development of sucker rod pump in oil fields. Moreover, we reviewed the operating conditions of sucker rod pumps and the screening criteria to conduct successful projects in the candidate oil wells [1].

SUCKER ROD PUMPS

Journal Sucker rod pumps include a wide range of artificial lift methods. With the advancement in this technology, the types of artificial lift methods that fall under the sucker rod classification have increased. Such artificial lift methods are used to increase oil recovery from low-rate wells that are producing moderate to heavy crude oils with a moderate level of gas and solid particles. Sucker rod pumps are widely used in the industry due to their multiple advantages including low-cost, well-established technology, availability, and wide applicability range [1].

Selection of Subsurface Rod Pumps

Pumps for sucker-rod lifted wells should be selected on the basis of numerous variables that are reflected via the well properties, the operating conditions, and the life of the pump. The main variables to consider are as follows:

- Well depth
- Bottom hole temperature
- Fluid viscosity
- Amount and size of particulates in the produced fluids
- Produced fluids corrosivity
- Required production rate vs. pump capacity
- Fluid-specific gravity
- Casing/tubing size
- Well-completion type
- Gas/liquid ratio (GLR)
- Pump-intake pressure vs. fluid bubble point
- Spare/surplus pumps and components
- New purchase and repair costs

Sucker Rod Pump Parts

The parts of sucker rod pump can be divided into two main types [2] [3]:

Surface equipment: includes the following parts which are illustrated in Fig. 1:
A. Prime Mover
B. Gear Reducer / Gear Box
C. Counterbalance
D. Horse Head
E. Polished Rod
F. Stuffing Box
G. Flowline

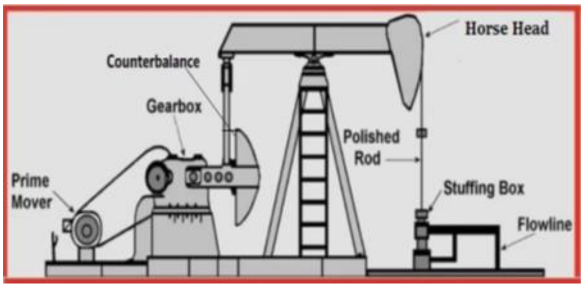

Figure 1: Surface equipment parts of sucker rod pump [4]

A. Prime mover
The prime mover converts the energy provided through electricity or a diesel engine into motion that is transmitted to the gear box. Early pumping units were powered by steam engines, and then the slow-speed gas engines became standard. The use of electric motors gained wide acceptance during the late 1940s, and nowadays the majority of pumping units is run by electricity [4].
• The investment cost of a gas engine is much higher than that of an electric motor
• Gas engines have a much longer service life.
• The energy costs where using electric motors have steadily increased during the last years due to increased power costs.
B. Gear reducer / gear box
The gear box is the main mechanism by which the surface component motion is controlled. The function of speed reducers, more commonly called gear reducers, is to reduce the high rotational speed of the prime mover to the pumping speed required. The usual speed reduction ratio is about 30:1, the maximum output speed is about 20 strokes per minute. Speed reducer sizes are standardized by the API in Spec. 11E, the rating relates to the maximum torque allowed on the reducer [4].
C. Counterbalance
The counterbalance works to balance the weight of the horse head as it moves up and down to allow for smooth and regulated operation and to reduce wear of the surface components.
D. Horse head
The horse head is the surface pumping unit that move up and down to allow the downhole pump components to operate. It carries the weight of the string.
E.Polished rod
The polished rod is the topmost sucker rod. It is usually designed from more durable material compared to the other sucker rods since it is carrying the entire weight of the string.
F. Stuffing box
Its main function is to prevent leakage of fluid by providing a seal among the components.
G. Flowline The produced fluids flow into the flowline in the surface in order to be transported to the refinery.
Downhole Parts: The pump plunger, the moving part of a usual sucker rod pump, is directly connected to the rod string. It houses a ball valve which is called the traveling valve. Fig. 2 explains the downhole parts of the sucker rod pump. The downhole pump is composed of several components including the traveling valve and the standing valves. During the upstroke, the traveling valve closes and the fluid above the plunger is lifted. This allows the barrel to fill up with fluid through the standing valve. During the down stroke, the standing valve closes, and the fluid is compressed thus allowing the fluid to move through the traveling valve [4]. The downhole parts could include the following parts:

A- Rod string
B- Downhole pump
- Barrels
- Plungers
- Traveling valves
- Standing valves
- Valve balls and seats

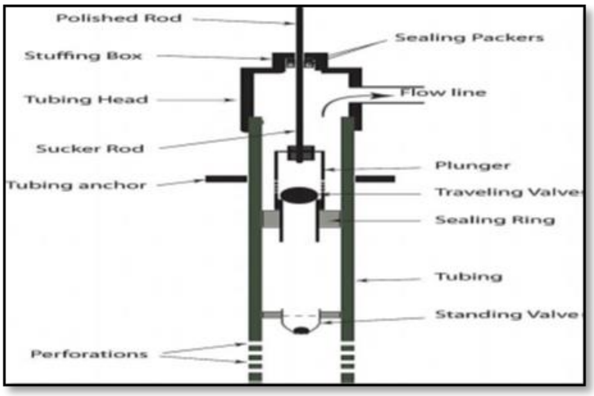

Figure 2: Downhole equipment parts of sucker rod pump

A-Rod string:
The sucker rods make up the main length of the string. They are specially shaped in order to accommodate the fluids and work with the overall design. The rod string, composed of sucker rods, run inside the tubing string of the well. The rod string provides the mechanical link between the surface drive and the subsurface pump.

B-Downhole pump:
The pump plunger, the moving part of a usual sucker rod pump, is directly connected to the rod string. It houses a ball valve, called traveling valve. The downhole pump is composed of several components such as the traveling valve and the standing valves. During the upstroke, the traveling valve closes and the fluid above the plunger is lifted. This allows the barrel to fill up with fluid through the standing valve. During the down stroke, the standing valve closes, and the fluid is compressed thus allowing the fluid to move through the traveling valve [4].

How sucker rod sump works
Prime movers are the main source of the energy to initiate the the transmission then pass it to a pair of cranks, usually with counterweights. After that, it convents the energy to motion up and down the arm pit. Then, the mechanical motion will be forwarded to the walking beam where the horse head located at the end of the walking beam. At the bottom of the horse's head, there is a cable (bridle), which is typically made of steel or fiberglass. Bridle is connected to the polished rod, then the polished rod is fastened to the piston rod that passes through tubing (a pipe that extends to the bottom of the well through the fluid is sucked).

How downhole pump works
The downhole pump is the component that moves the fluid up the tubing. It consists of a pump chamber, a plunger with a traveling valve (riding valve) and a standing valve as shown in the Fig. 3. As the plunger travels down the pump chamber, the traveling valve is open while the standing valve is closed, allowing fluid to flow above the plunger. When the plunger is traveling back up the pump chamber, the standing valve opens, and the traveling valve closes, drawing in more fluid from the reservoir. The pump assembly acts like a check valve. It allows fluid to flow up through ball checks but not back into the reservoir [4].

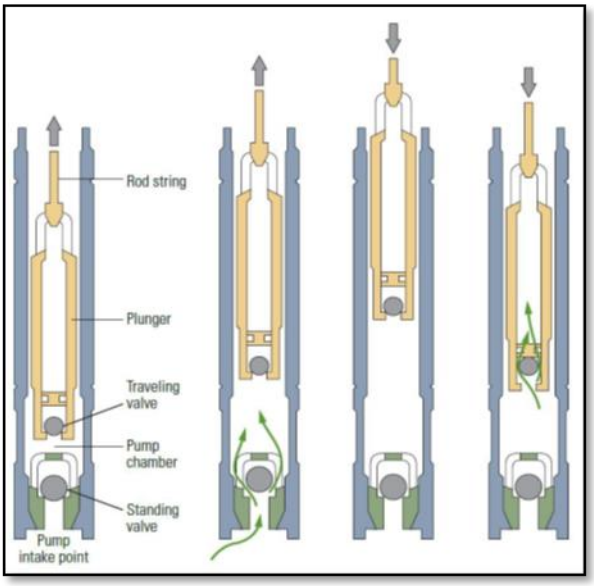

Figure 3: Principle of work sucker rod pump and lowering pressure of bottom well

Advantage of sucker rod pump

A-Rod pumping works similar to positive displacement pump; it can reduce the bottom hole pressure to a very low level and hence deplete the reservoir better as shown in Fig. 4. This is done through the rise of the plunger to the top and by opening the standing valve, thus entering the fluids into the barrel and contributing to reducing the pressure at the bottom of the well. As a result, achieving a high pressure drop would deplete the target reservoir.

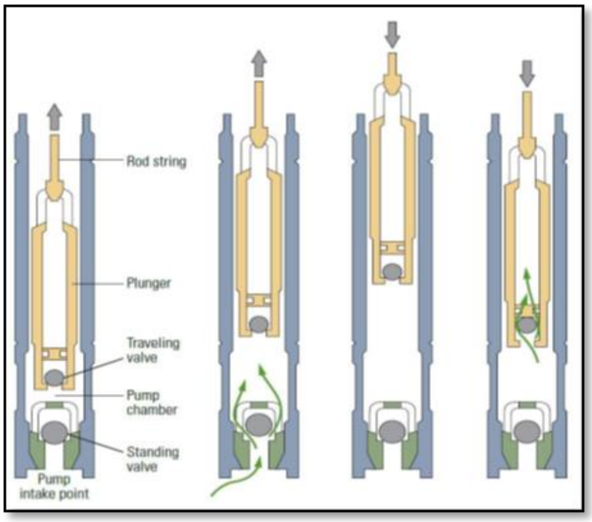

Figure 4: Principle of work sucker rod pump and lowering pressure of bottom well

Table 1: Operating conditions of artificial lift type [6]

Form of Lift	Rod Lift	Progressing Cavity Pumping	Gas Lift	Hydraulic Lift	Electric Submersible Pumping
Maximum operating depth TVD (ft)	16000	12000	18000	17000	15000
Maximum operating volume (BFPD)	6,000	4,500	50,000	8,000	60,000
Maximum operating temperature (F°)	550	250	450	550	400
Corrosion handling	Good to excellent	Fair	Good to excellent	Good	Good
Gas handling	Fair to good	Good	Excellent	Fair	Fair
Solids handling	Fair to good	Excellent	Good	Fair	Fair
servicing	Workover or pulling rig	Workover or pulling rig	Wireline or workover rig	Hydraulic or wireline	Workover or pulling rig
Prime mover	Gas or electric	Gas or electric	compressor	Multicylinder or electric	Electric motor
Offshore application	limited	limited	excellent	Good	excellent
System efficiency	40 to 60%	50 to 75%	10 to 30%	45 to 55%	35 to 60%

B-Rod pump systems are simple in their design, operation, and maintenance. Therefore, they are quite understood by the industry in terms of design and operation. Sucker rod pumps consist of surface and subsurface equipment as shown in Figure.5. The surface equipment is responsible for converting the rotational movement of the main engines into reciprocating movements, while the subsurface equipment is responsible for the principle of suction and displacement of the reservoir fluids.The Sucker rod pump is started up by the prime mover which provides the power needed for the operation. This energy is transmitted through the gear reducer assembly to the crank. Gear reducer is used to reduce the high rotational speed of the motor to be suitable for the pump. The crank, pitman and walking beam combination are used to convert the rotary motion into the reciprocating motion.

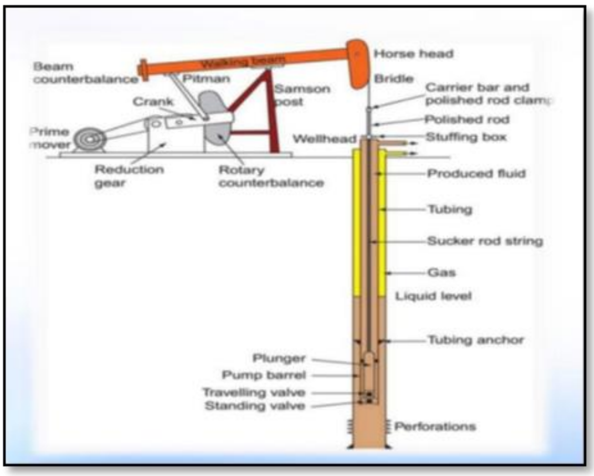

Figure 5: Essential parts of sucker rod pump: surface and subsurface equipment

C- Rod pump systems are the most common lift methods which their replacement parts are widely available, compatible, and interchangeable. The operating cost is quite competitive in comparing to other lift methods. Fig. 6 presents the certain model of sucker rod pump or pump jack.

Figure 6: Certain model of sucker rod pump or pump jack

D- High temperature and viscous fluid can be lifted by sucker rod pumps. Because the parts of the subsurface pump consist entirely of metal parts and steel ball valves (there are no rubber parts in the pump) it is able to withstand the high and different temperatures inside the well. Table 1 illustrates some operating conditions of different artificial lift types [6].

E- Easy corrosion and scale inhibition treatment where the removal of wax can be done by hot oil /solvent circulation. The injection of a scale inhibitor into the formation is also possible.

Figure 7: Dynamometer device and sensors

F- Pump monitoring can be easily done by using surface and downhole dynamometer cards as shown in Fig. 7. Therefore, detecting any damage, malfunction in plunger, valve failure, or any shoratage in the subsurface pump equipment can be easily determined. In addition, the equations and fundamental mathematical models of sucker rod pump technique are well established and can be easily modeled by using many softwares which are readily available [3].

G- Ease of maintenance of the pump, that is, when a malfunction occurs in the subsurface units such as the plunger or one of the valves, then the sucker rod string is easily pulled to the surface through a winch of normal weight and get repaired quite easily.

Disadvantages of sucker rod pump

A-Sucker rod pump is not suitable for deviated or inclined wells. The mechanical friction between rod string and production tubing in high and deviated wells may cause rod / coupling failures. In addition, the system requires more surface power to operate due to such friction.
Centralizers of the sucker rods may require centralizers or protectors in deviated wells to reduce wear on the tubing and rods as shown in Fig.8. This requirement becomes more extreme in crooked or highly deviated wells. In some cases, the rod pumps cannot be used in such critical conditions.

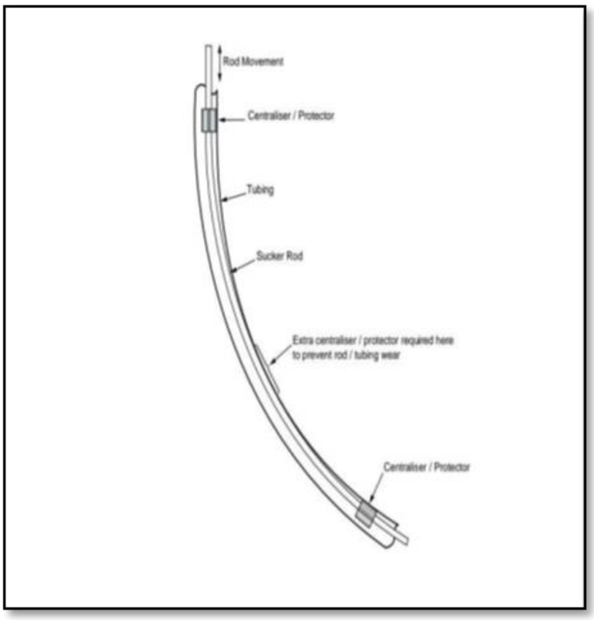

Figure 8: Centralizing rod reduces friction and wear [5]

If we do not solve such problems or don’t consider the sucker rod pumps centralizers during the production process, the downhole string of the sucker rod may collide with the tubing string. The resulted friction may cause an erosion and/or wear the tubing and/or the sucker rods. This could eventually lead to severe leak ages and breakage of both components. Fig. 9 shows tubing failure example.

Figure 9: Tubing failure example [4]

B- Rod pump systems are only applicable for wells with shallow and medium depths because the pump depth is normally limited by the strength of the rod string and coupling materials. The effective depth range of sucker rod system is from 7500 ft to 15000 ft. In deeper wells, peak stress at the top of the rod string can be above the maximum permissible working stress of the rods being used. In a situation like this, severe damage can occur in the rod string. As well as sucker-rod systems should be considered for lifting moderate volumes from shallow depths and small volumes from intermediate depths. It is possible to lift up to 1,000 B/D from approximately 7,000 ft and 200 bbl from approximately

14,000 ft. Special rods may be required, and lower rates may result depending on different conditions. In addition, the greater the depth goes, the higher the weight of the oil column becomes so the sucker rod string cannot lift this large load of oil inside the deep wells, especially the sucker rod string which is near to the surface. Such loads can cause damage or cutting the rod string. Therefore, we run such artificial lift pumps at specific depths based on the capacity of the sucker rod pump to bear the weight of the oil column[4] [5].

C- Like any positive displacement pumps, rod pump systems do not operate well with the presence of gas, solids and wax. These problems can be presented as following:

• Gas problem

A high volume of gas can reduce the overall efficiency of the pump by up to 40 %. This reduction in efficiency is due to the late opening of the traveling valve in the down stroke due to the compression of gas beneath the plunger as illustrated in Fig.10.

One of the ways to manage gas production with sucker rod pumps is to place the intake beneath the producing zone. This allows the tubing - casing annulus to function in a separated way and since the gas has a lower density, it will rise to the top. The intake, being beneath the production zone, will be submerged in the higher density liquid, and thus a minimum gas volume will be present in the pump. In horizontal wells, the pump cannot be placed below the producing zone, and thus a downhole gas separator is needed. At the intake of the separator, an annulus is created between the dip tube and the mud anchor body. This allows the heavier liquids to move down the dip tube while the lighter gas bubbles rise out of the separator. Fig.11 presents an illustration of a conventional downhole gas separator. The two main types of gas separators include the centrifugal separator and the gravity separator. It uses the difference in density of the water and oil and the difference in centrifugal force in the cyclone generated. Centrifugal separator is usually the preferred method due to its speed; however, its efficiency is lower in wells that contain gas. The gravity separator relies on gravity separation based on density difference. This method is slower than the cyclone and has less efficiency. [4]

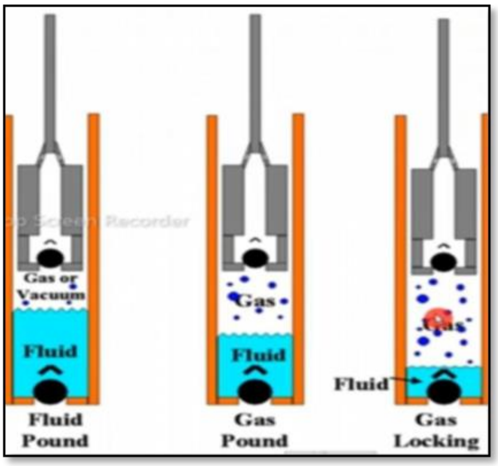

Figure 10: Effect of gas compressibility on valve failure

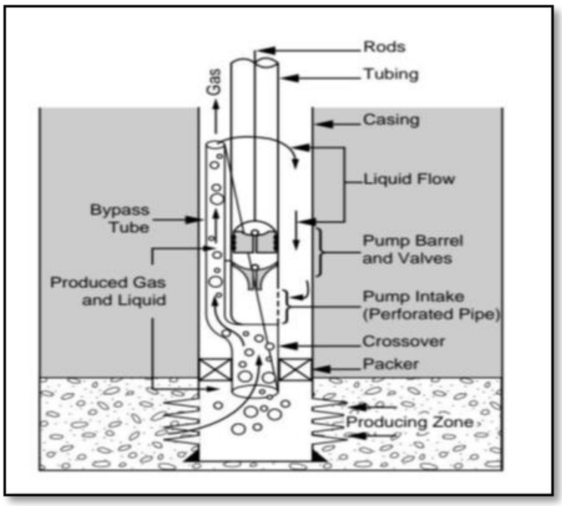

Figure 11: Conventional downhole gas

• Erosion / sand problems

An excessive volume of sand can lead to two problems. Firstly, it can cause severe erosion of the sucker rods and the pump which may eventually lead to failures. Secondly, it can accumulate in some of the components such as the plunger, as shown in Fig. 12. This can cause plugging problems that are very difficult to mitigate. The three main methods by which sand production in sucker rod can be mitigated as following[4]:

- Cope with the sand production by altering the production equipment to withstand sand.
- Stabilize the formation producing sand using chemicals.
- Install gravel pack, sand screen, and downhole demanders.

Figure 12: sand accumulation in the downhole plunger [4]

• Wax and inorganic scale deposition:

Wax and inorganic scale deposition interferes with efficient rod pump operation. Continuous injection of an inhibitor below the pump to ensure protection of the complete downhole equipment is complicated unless there is a (normally unacceptable) complication of the completion design. Removal of wax by hot oil / solvent circulation or injection of a scale inhibitor into the formation is also possible.

D- Sucker rod pump is not applicable in offshore wells due to its high surface space requirement while rod pump system is applicable for onshore wells as shown in Fig. 13.

Figure 13: Offshore work platform

E- Need for workover operation to service downhole equipment as shown in Fig.14. Because the possible malfunctions of the pump are in the lower parts of the pump, often at the bottom of the well.

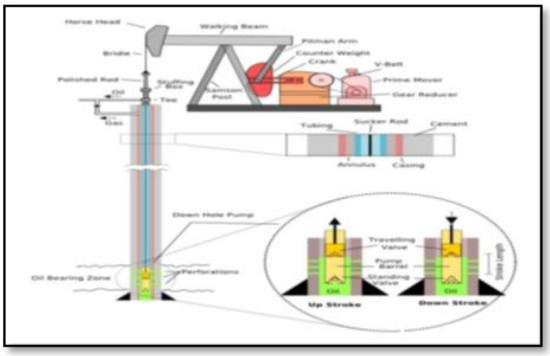

Figure 14: Malfunction of subsurface parts of SRP

F- The polished rod stuffing box, if not properly maintained, may present an environmental hazard by leaking well fluids to the atmosphere. The polished rod and stuffing box are combined to prevent fluid from leaking to the surface as shown in Fig.15. Therefore, such leaks could cause environment problems thus to force the fluid to flow into the T connection just below the stuffing box.

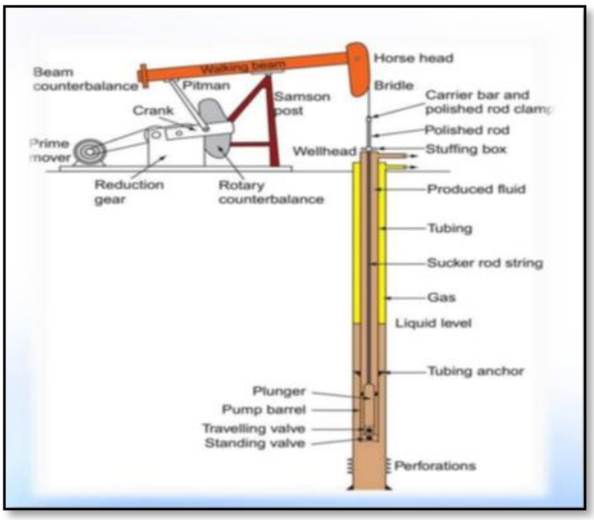

Figure 15: Essential Part of sucker rod pump

Data collected from fields

The data presented in Table 2 are gathered from applying sucker rod pumps in two wells, ZB-176 and ZB-177, in Al-Zubair Oil Field.

Table 2: Design data of artificial-lift system in ZB-176 and ZB-177

Well name	ZB-177 Case 1	ZB-177 Case 1	ZB-176
Inputs			
Pump Intake Pressure, psi	1500-Worst Case	1500-Worst Case	1500-Worst Case
Tubing Pressure, psi	332	332	332
Tubing Size	3 1/2"	3 1/2"	3 1/2"
Pump Setting Depth, FT	2450m (8039 ft)	2450m (8039 ft)	2450m(8039 ft)
API	33	33	33
Water Cut	70%	70%	80%
Water Specific	1.15	1.15	1.15

Equipment selection

Table 3: presents the artificial-lift system equipment selection for ZB-177

Unit Size	CG-1280D-427-192
Motor Size	125 HP –400 V /50 HZ
VSD	125 HP VSD –400 V /50 HZ
Wellhead	Stuffing Box, BOP, Pumping Tee –3.5” Flanged Connection
Flow Line Connection	Tee, 3"LPX1"LP Connection
Sucker Rods	Tapered (API 87) –Grade: MMS (High Strength)
Downhole Pump	30-175-RHBC-20-6-4-4 With Pump Setting Nipple Brass Nickel Carbide
Gas Shield	3-1/2" X 5-1/2" SLOTTED GAS SHIELD

Sucker rod string

Table 4: presents design structure of the artificial-lift system used in Zubair Oil Field

Item No	No. of Joints	Description of Item	Length (FT)	Depth To Top
1	1	Pony rod MMS AISI4138 1"x2'	2.00	0.00
2	1	Polished Rod 1.1/2" X 30 FT w/coupling	30.00	2.00
3	3	Pony rod MMS AISI4138 1"x6'	18.00	32.00
4	118	SUCKER ROD 1"x25' MMS GRADE	2950.00	50.00
5	216	SUCKER RODS 7/8" X 25' MMS (4138)	5400.00	3000.00
6	6	SINKER BAR, 1 1/2' X 25', TYPE K, 3/4'	150.00	8400
7	1	Stabilizer Bar 1" - Pin 3/4" KD (4320) 04 ft T (8630) FS PPA-BM-3	T 4.00	8550
8	1	D.H.P (30-175-RHBC-20-6-4-4)	28.00	8554
9		String END		8582

History of the well

ZB-177 is an oil well located in Al-Zubair Oil Field in southwest of Basra Governorate, nearby Iraq Kuwait border.
It has been observed that this well and other wells to have decline in the wellhead pressure and production rate till the well ceased and not flowing anymore. A sucker rod pump was suggested to be installed in this particular well as shown in figure.16.

Figure 16: SRP installed in ZB-177

Production data after installation of sucker rod pump

It has been noticed that there is an improvement in the production performance of ZB-177 after installation of sucker rod pump as showing in the following reported data:

- Wellhead pressure 360 psi
- Production rate 355.6 bbl./day
- Oil production rate 337.8 bbl./day
- Water production rate 17.7 bbl./day
- Pump depth 8582 ft
- Oil specific gravity 0.845 g/cm
- API gravity 35.85

CONCLUSIONS

In this paper, we illustrated artificial methods and concentrated on sucker rod pump by explaining its main parts, application conditions, the advantages, and the disadvantages. The sucker rod pump technique has proved its success in the oil industry as its advantages are more than its disadvantages. If we touched on some of the defects and problems that exist in this technique, we would find that the solutions to these problems are extremely easy and can be treated in a quite uncomplicated way. As a result, we can say that this technology is a wonderful qualitative movement in the field of petroleum engineering. The main conclusions of this study can be drawn as following:

- Sucker rod pumping is the most commonly used artificial lift technique in onshore fields of United States.
- Sucker rod pumps can be designed for the oil reservoirs at shollow depths with moderate production rates or intermediate-depth reservoirs with small flowrate so it is possibly applied to lift up to 1,000 B / D from approximately 7,000 ft and 200 bbl from approximately 14,000 ft.
- Sucker rod pumping systems should be considered for new, lower volume stripper wells because they have proved to be cost effective over time. In addition, operating personnel usually are familiar with these mechanically simple systems and can operate them efficiently.
- It is usually applied in the wells are vertical moderate to shallow wells which usually do not suffer high temperatures.
- The gas compressibility problem that affects the work of the valves and their failure is the most prominent problem in the pump. However, through the use of a traditional gas venting separator, it can reduce the effect of gas on the pump, and thus it works normally.

- If the pump contains some aggregates of sand, limescale, corrosion, and wax components that all cause the pump to stop its normal operation. However, by injecting some solvents and some hot compounds into the bottom of the pump, it works to remove all these sediments and corrosion, and thus the pump works normally.
- It was concluded that this technique of artificial lift does not work in wells with severe deviation, and this problem was solved through the use of insulators or centraliser that are placed between the pump string and the pipe. Therefore, it can be used in any types of wells, but not in wells with severe deviation

Conflicts of interests

There are no known conflicts of interest related to this research. Also, we would like to confirm that there is no significant financial support provided to get this work done.

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