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Oil Recovery by Artificial Lift Systems (ALS): A Review

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Abstract:- The main objective of Oil Recovery by Artificial Lifts Systems hinges on selecting the most suitable ALS in order to overcome or bring about a substantial reduction of the Bottom Hole Pressure (BHP) that would lead to a significant increase in differential pressure drawdown so as to maximize oil production rate in the face of the declining naturally Flowing Well Pressure (FWP) of the reservoir. In this paper, attempt was made to review the various ALS by trying to give a succinct but clear description of each method or system, its advantages, advantages as well as applications. Also, efforts were made to highlight the factors and criteria controlling proper selection of artificial lift methods to boost economic and efficient recovery of crude oil. It is a common practice that if factors such as well and reservoir indexes , location of the field, problems associated with well operations, Capital Expenditures (CAPEX) plus Operating Expenditures (OPEX) are given priority in selection of ALS, more oil could be recovered by these methods.

Keywords
- Artificial Lift Systems
- Oil recovery
- Selection criteria
- Bottom hole pressure(BHP)
- Drawdown
- Production rate
- Flowing well Pressure (FWP)

I. INTRODUCTION

Oil production demands huge amount of energy for lifting produced fluids from the subsurface to the surface. These energies are usually supplied naturally in form of pressures by reservoir pressure and formation gas to enable fluids lifting to the surface. But the declining natural reservoir pressure during the course of production necessities that the wells be supported by artificial lift systems optimum oil recovery.

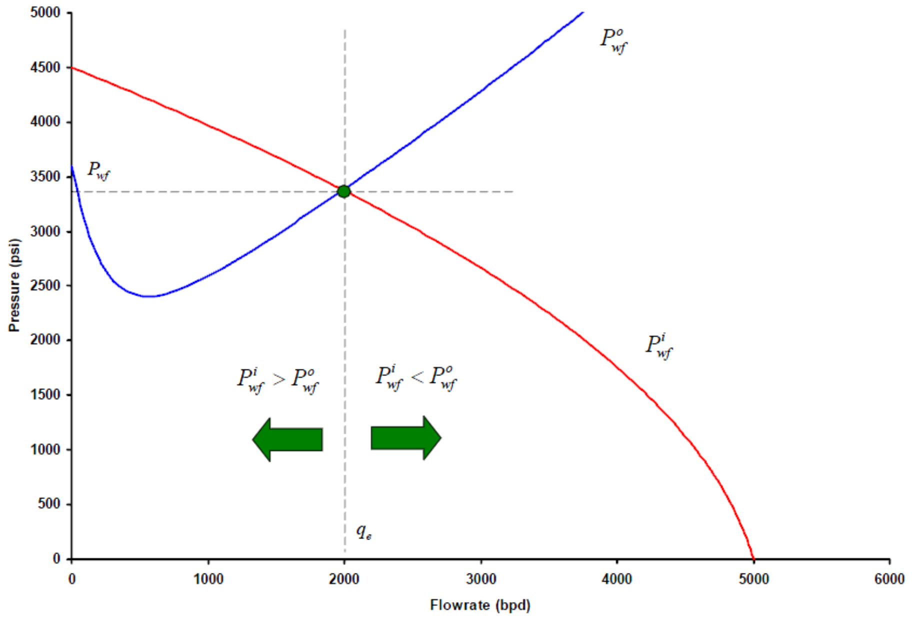

Fig 1:- Relationship between IPR and OPR, source [New Mexico Tech]

Artificial lift is a technique designed to bring about reduction in BHP to initiate flow in dead wells or increase flow rate through injecting pressurized gas into the reservoir fluid section to overcome hydrostatic pressure, or by using a subsurface pump to supply lift pressure capable transporting produced fluids to the surface. ALMs are the process of artificially adding pressure to the reservoir with the purpose of triggering economic recovery of oil from the well. Artificial Lift mechanism can be used in mature fields, as well as in young fields to recover more oil that should have been abandoned due to the declines in the natural reservoir pressures. ALMs account for more than 75% of oil wells worldwide (around 1million).

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Sylvester &Bibobra (2015) studied to find best artificial lift system to improve oil recovery. The main focus of every oil and gas operators is to minimize both CAPEX AND OPEX and essentially to optimize oil production while minimizing costs throughout the life of the well. This Study focuses on artificial lift techniques to install to enhance oil production and recovery.

The commonly used ALS includes:

- Sucker Rod Pump/Beam Pump System (SRP/BPS)
- Gas Lift System (GLS)
- Electrical Submersible Pump System (ESPS)
- Hydraulic Piston Pump System (HPPS)
- Hydraulic Jet Pump System (HJPS)
- Plunger Lift System (PLS)
- Progressing Cavity Pump System (PCPS)

Each of these artificial lift systems has its own advantages and disadvantages, and production profiles, reservoir nature, costs, working principle and a number of other variables, which determines its selection and application.

II. CATEGORY DESCRIPTIONS

A. *Sucker Rod Pump/Beam Pump System (SRP/BPS)*

Khamehchi et al (2014) posits that energy capable of driving oil from the subsurface reservoirs region to the surface for naturally flowing wells are derivable from five main drives mechanisms viz: water drive , solution gas drive, gas cap drive, gravity segregation and combination drive or combination of these mechanisms. When this natural energy drops considerably so that fluids are unable to flow to surface, this energy must be compensated by artificial lift systems.

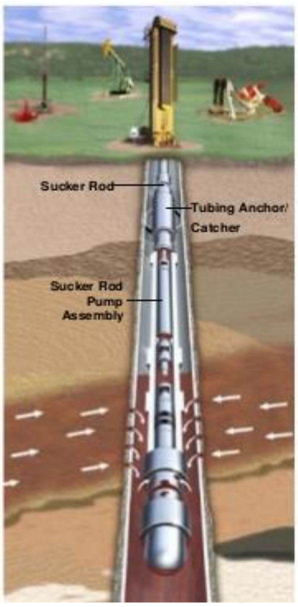
Sucker rod pump, one of the ALS, is a positive displacement pump which operates by transporting fluids from a suction chamber to a discharge unit. It uses a mechanical force in form of pistons, gears, bladders, diaphragms or plungers to discharge liquid through the pump and out of it.

Bimpong & Broni-Bediako (2012) studied displacement pump to increase oil production and recovery. Velocity of the sucker rod strings is usually associated with high frictional losses which hamper oil flow rate at lower reservoir pressures. They opine that positive displacement pump is a better option for producing fluids at low pressures.

SRP/BPS is the oldest and frequently used artificial lift system under different operating conditions to increase reservoir pressures for varying production rates to improve oil recovery and production rate. It consists of surface and subsurface components in design. The surface-pump unit controls the down-hole pump and is made up of a prime mover, a fixed beam usually called a walking beam at a pivotal post otherwise known as Sampson post. The arrangements trigger a process which pushes the beam to and fro thereby allowing it to move the subsurface components up and down. Other surface components include a gearbox with a crank mechanism on it, motor, horse head and V-shaped belt drives.

Rod pump systems can be applied in reduction BHP such that a high pressure differential (drawdown) capable of increasing production rates leading to improve oil recovery is created in the wellbore. They are flexible and relatively simple to design, operate, and maintain and adaptable to varying operating conditions.

Rod Lift System Application Considerations



	Typical Range	Maximum*
Operating Depth	100 - 11,000' TVD	16,000' TVD
Operating Volume	5 - 1500 BPD	5000 BPD
Operating Temperature	100° - 350° F	550° F
Wellbore Deviation	0 - 20° Landed Pump	0 - 90° Landed Pump - <15°/100' Build Angle
Corrosion Handling	Good to Excellent w/ Upgraded Materials	
Gas Handling	Fair to Good	
Solids Handling	Fair to Good	
Fluid Gravity	>8° API	
Servicing	Work over or Pulling Rig	
Prime Mover Type	Gas or Electric	
Offshore Application	Limited	
System Efficiency	45%-60%	

Fig 2:- Schematic of Electrical Submersible Pump System (courtesy of Schlumberger)

B. Gas Lift System (GLS)

Saepudin et al (2007) studied to optimize oil production by gas lift method. The main objective in oil production system using gas lift technique is to obtain the optimum gas injection rate which yields the maximum oil production rate.

Gas lift is the process by which pressurized gas is injected in between the tubing and casing (annulus) using different subsurface valves down to the depth of interest in order to decrease the density of the produced fluid column thereby lowering the BHP to pave way for reservoir fluids to flow easily, leading to increased flow rates and increased oil recovery.

Sheng and Chen (2014) studied use of gas injection as an improved oil recovery method and concluded that gas injection is more preferable to water injection because it has a higher pressure gradient for this reason water injection for water flooding an oil recovery technique is not mostly used in all reservoir conditions.

Two types of gas lift systems are:

- ***Continuous gas lift system:*** This type of gas lift is a steady-state system where pressurized gas is injected at a constant rate of flow in order to lower the density of the fluid column and the hydrostatic component of the flowing BHP thereby enabling the produced fluid (oil or gas) to easily flow to the surface, especially for wells with high BHP and high productivity index (PI).

Nishikiori et al (1995) established a method for finding the optimum gas injection rates for a group of continuous gas lift wells to maximize the total oil production rate and recovery.

- ***Intermittent gas lift system****:* This is unsteady state flow notable for a kind of a start-and-stop flow pattern from the subsurface to the surface. Usually a small pressurized gas is channeled into the tubing to lighten the fluid column, making it possible for the flowing BHP aided by the expansion of injection gas to transport the fluid to the surface and then interruption of gas injection occurs and the whole process is repeated each time. This method of gas lift is suitable for low BHP and PI wells.

Components of GLS include a gas compression, a tubing string with installations of unloading valves and operating valve, a subsurface chamber, and a gas injection manifold with injection chokes and time cycle surface controllers.

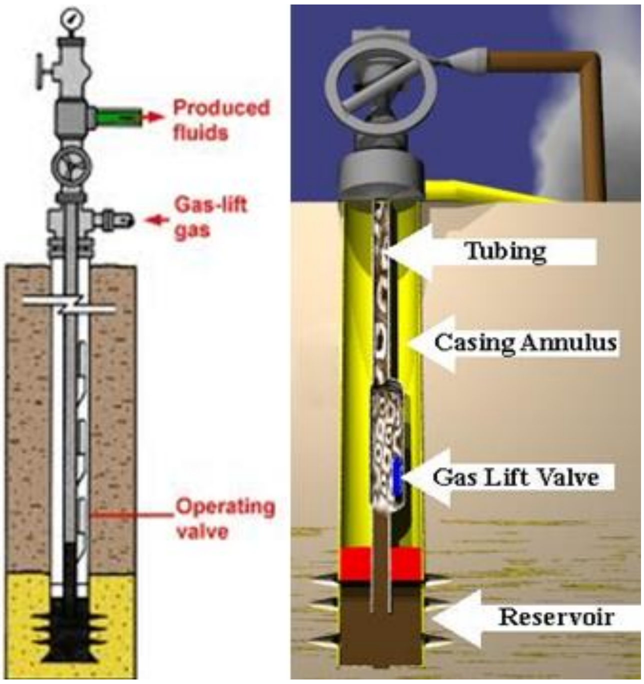


Fig 3:- Typical gas lift well, source [New Mexico Tech]

C. Electrical Submersible Pump System (ESPS)

ESPS are dynamic displacement and centrifugal pumps which operates by transporting fluids from inlet to outlet under the momentum created by it. In principle, it generates energy kinetic which is converted into pressure and then transferred to fluids. ESPS systems can be used in high-angle and horizontal wells when they are properly placed in straight or vertical sections of the well, and as the name implies it is submerged into the reservoir fluids and moves the fluid to the surface.

Chikwere et al (2015) investigated artificial lift systems and concluded that Gas lift system and Electrical submersible Pumps are one of the suitable artificial lift systems frequently and efficiently used to increase the producing life of oil or gas wells.

An ESPS is made up of subsurface and surface components which are subdivided as follows:

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Subsurface components:

• Pump system
• Motor system
• Seal electric cable chamber
• Gas separator chamber

Surface components:

• Motor controller (or variable speed controller) system
• Transformer zone
• Surface electric cable linkage

Electric submersible pumps are commonly used in high volume applications to recover over 1000 barrel of oil per day. This can be achieved when an electrical energy is conveyed to the subsurface electric motor with the aid of electric cables as sources of electrical energy which are attached to the production tubing. The pump is driven by the electric motor thereby generating hydraulic power and imparts energy to the produced fluid, which artificially lifts the fluid to the surface and leads to more oil recovery.

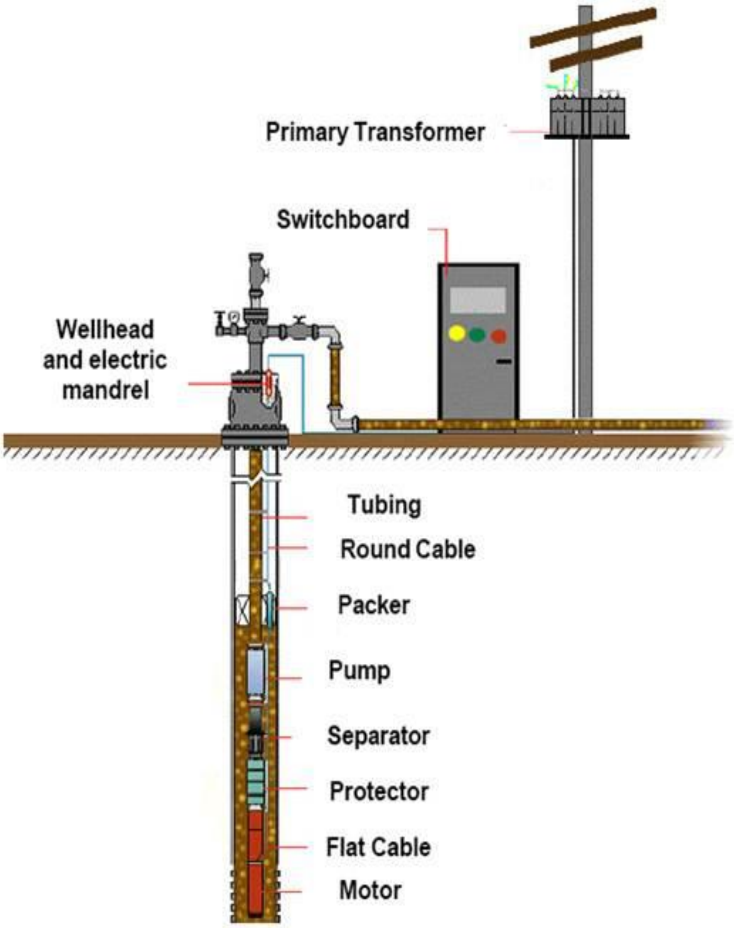


Fig 4:- Schematic of Electrical Submersible Pump System (courtesy of Schlumberger)

D. Hydraulic Piston Pump System (HPPS)

Hydraulic piston pump is a positive displacement pump which makes use of sets of pistons parallel to the input shaft for injecting fluids placed into a cylindrical block.

Well fluids are used in the system as the power fluid instead of hydraulic oil. The rotation of the shaft causes the piston and the cylindrical block to move round the shaft in a reciprocating manner.

HPPS is made up of an engine having a reciprocating piston which is driven by a power fluid connected by a short shaft to a piston in the pump end thereby making the injected power fluid operates a subsurface fluid engine and causing the piston to pump and transport formation fluids to the surface leading to recovery of more oil as it displaces the fluid up and down the strokes.

Hydraulic piston pumps operate in much the same way as the sucker pumps except that it function hydraulically rather than mechanically like sucker rod. It can be used to lift large volumes of oil from even from a great depth if wells are pumped down to relatively low pressures in line with **Bimpong& Broni-Bediako (2012)** conclusions in their studies on the use of displacement pumps to increase oil recovery.

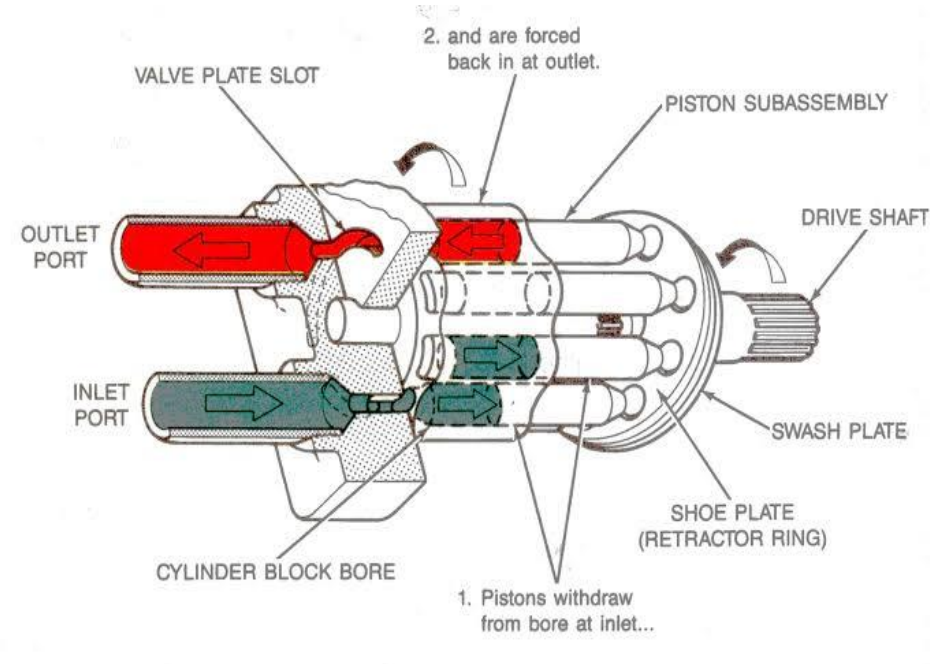
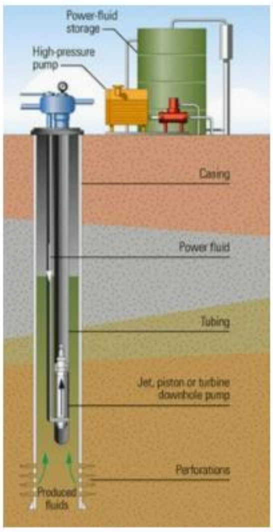


Fig 5:- Hydraulic piston pumps system, source [Canadian Oil Well Systems Ltd]

E. Hydraulic Jet Pump System (HJPS)

HJPS is a dynamic-displacement pump, which works by allowing fluids to flow from inlet to outlet chambers in much the same way as a centrifugal pump by self-induced momentum. The difference between a HPPS and HJPS is in the manner in which it (HJPS) enhances the pressure of the pumped fluid with the aid of a jet nozzle where the pressure energy is converted to kinetic energy in form of velocity head. The pump converts the energy from the injected power fluid to pressure that lifts production fluids to the surface thereby increasing oil recovery. Its main benefit is that it does not need much cleaning like piston pump. Also it has the ability to handle large volumes of fluids and no moving parts are involved.

However, a major drawback is that it is complex to design, very sensitive to a change in BHP and power oil systems suffers from being engulfed by hazardous fires **(Larry, 2006)**



	Typical Range	Maximum
Operating Depth	1000 - 3000 m TVD	6000 m TVD
Operating Volume	50 - 500 m3/day	4000 m3/day
Operating Temperature	30 - 120 C	260 C
Wellbore deviation	0-20deg hole angle	0-90deg hole angle (> 24deg / 30m DLS)
Corrosion Handling	Excellent	
Gas Handling	Good	
Solids Handling	Good	
Fluid Gravity	+/- 8° API	
Servicing	Hydraulic or Wireline	
Prime Mover Type	Multi-cylinder or electric	
Offshore Aplication	Excellent	
System Efficiency	10% to 30%	

Fig 6:- schematic of jet pump system (courtesy of weatherford)

F. Plunger Lift System (PLS)

A plunger lift system is an artificial lift method traditionally applied in oil wells to recover more oil from the reservoir but it is also used in de-liquefying(de-watering) a natural gas well. It is applicable in wells with high gas-liquid ratio. PLS systems are not expensive to install and they keep the tubing free from scale and paraffin.

The basic operation of PLS as an artificial lift method, is that when the flow rate is very high, the plunger rests at the top of the well but as the production declines liquids tends to gather at the bottom of the tubing making the well to start loading which causes the valve to close as the reservoir pressure decreases, then the plunger falls through the tubing. Pressure build-up occurs within the annulus while the well is shut in, after sometime; the valve opens and transports the plunger along with the fluids to the surface, making the well to flow freely as additional oil recovery occurs, usually less than 200BPD. A thorough explanation of operation of PL and its techniques can be found in **Listiak (2006)**

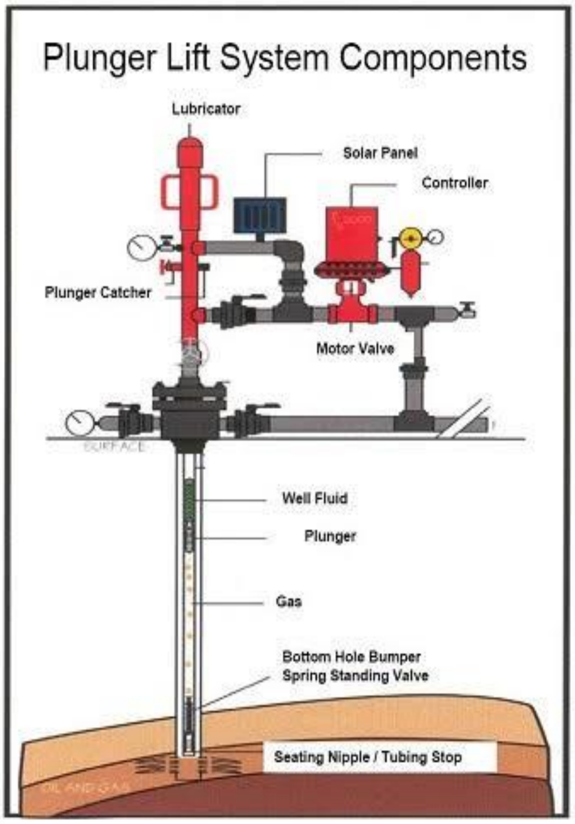


Fig 7:- schematic of plunger lifts system (courtesy of Petro Skills Systems)

G. Progressing Cavity Pump System (PCPS)

PCPS is also one of the positive displacement pumps consisting of a helical metal rotor designed to rotate inside an elastomeric, a double helical stator which is powered by subsurface electric motor or by means of rotating rods. . The stator is typically run into well on the bottom of production tubing, while the rotor is connected to the bottom of the sucker rod string. Rotation of the rod string by means of surface drive system causes the rotor to spin within the fixed stator, creating the pumping action necessary to produce fluid to the surface leading to improve oil recovery **(Michel, A. Daniel, 1994).**

The systems can be used for lifting heavy oils at various flow rates, coal bed methane, and handles large volume of water. It has the ability to handle Solids and free gas production efficiently. PCPS is designed to use in deviated and horizontal wells respectively. However, its main demerits is that PCPS has short operating life (2–5 years) and the fact that they are very expensive to procure but OPEX is reduced as the efficiency increases as a result of reduced energy requirements.

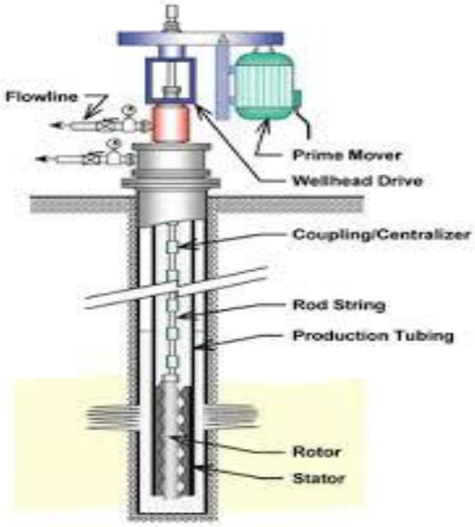


Fig 8:- schematic of progressive cavity pump system (courtesy of weatherford)

III. ADVANTAGES OF MAJOR ARTIFICIAL LIFT SYSTEMS

A. Rod Lift System

• It has high system efficiency
• It has optimization controls
•It is very economical to fix and service system failure
• Creation of strong drawdown
• Corrosion attacks and concerns is minimized
• It is Flexible and can adjust production's stroke length and speed
• It has a high salvage value for surface and subsurface equipment.

B. Gas lift System

• Provision for Wire-line maintenance system
• It is tolerant for solids and efficiently handles solids
• Suitable for large volumes in wells with high PI
• It is relatively simple and easy to maintain
• It can be used in areas with remote power source
• Effective in highly deviated wells/doglegs
• Suitable for high Gas Oil Ratio reservoir systems

C. Electrical Submersible Pump System

• It has high depth and volume capacity
• Its high efficiency makes it possible for over 1,000 BPD
• Cost of maintenance is relatively low
• It doesn't require much surface equipment
• It is highly resistant to corrosion attacks
• It is used in deviated wells /doglegs wells

D. Hydraulic Lift System

➢ *Jet Lift system*

• It has low pump maintenance system
• Moving parts are not available
• Handles high volume capability
• It allows "Free" pump system
• A single package can be used for multi-wells

➢ *Piston Lift system*

• It has "Free" or wire-line retrievable system
• It creates strong pressure differentials/drawdown
It has high volumetric efficiency
• It ensures good depth capability above 15,000 ft.

E. Progressive Cavity Pump System

• It has low surface profile for visual and height sensitive
• It requires low capital investment
• High operational system efficiency
• Power consumption is relatively low
• Capacity to pump oils ,waters and solids
• Capacity to Pump heavy viscous oils
• It doesn't have any internal valves to clog or gas lock
• It operates silently and quietly reducing noise
• It is simple to install with low maintenance costs
• It has portable, lightweight surface equipment

IV. DISADVANTAGES OF MAJOR ARTIFICIAL LIFT SYSTEMS

A. Rod Lift System

• It is heavy equipment for offshore use
• It produces less than 1,000 barrels per day.
• Exhibits high friction in crooked/holes
• Solids production such as sand, wax, etc. wears pumps
• Its liable to free gas minimizes pump efficiency
• It is a big obstruction in urban areas
• Difficult to handle down-hole corrosion

B. Gas lift System

• Unavailability of lifting gas is a problem
• Inability of casing to withstand lift gas pressure
• It is not suitable for heavy crude oil or emulsions
• Prone to gas freezing/hydrates at low temperatures

C. Electrical Submersible Pump System

• It is not suitable for shallow, low capacity wells
• It requires full work over operation to change pump
• Not tolerant to gas and solids
• It often required increased production casing size
• At high temperatures cable is worn out
• Cable is prone to damage during tubing installations
• Inability to pump sand efficiently

D. Hydraulic Lift System

• Inability to reach **a**bandonment pressure
• High surface pressures is a big challenge
• Highly hazardous Power oil systems
• Presence of free gas reduces system efficiency
• Very sensitive to change in surface flow-line pressure
• Minimum flowing BHP is high

E. Progressive Cavity Pump System

• At high BHP, gas dissolves in the elastomers
• Difficult to control Pump off
• Its lifting capabilities is just approximately 7,000 ft.
• Rods rotating problems increases with depth
• Its high starting torque is a big challenge

V. SELECTION OF ARTIFICIAL LIFT CRITERIA: FACTORS [NEW MEXICO TECH].

Key consideration factors for the selection of artificial lift systems include:

- Inflow performance relationship(IPR)
- Liquid production rate
- Water cut volumes
- Gas-liquid ratio/Gas oil ratio (GLR/GOR)
- Viscosity of the crude
- Formation volume factor
- Reservoir drive mechanism in place
- Formation Well depth
- Completion type in place
- Casing and tubing sizes applied
- Wellbore deviation factors
- Flow rates
- Fluid contaminants level
- Power sources availability
- Field location (onshore/ offshore)
- Long-range/ short-range recovery plans
- Pressure maintenance and operations issues
- Extent of Enhanced oil recovery projects
- Field automation projection

- Operating, service personnel and support services availability
- Economic and cost implications

A. General guidelines regarding the selection of Artificial Lift Systems

Selection of the artificial lift for a particular well must meet the physical parameters and constraints of the well system in question. Once a particular type of lift is selected for use, consideration should be given to the wellbore size and capacity required for obtaining the forecast production rate.

Lift Mechanism	Deviation Applicability	Lift Efficiency in Horizontal	Volume Lifted per Day (BFPD)	Solids Tolerance	Gas Tolerance	Comments
Beam lift (sucker rods & pump)	Vertical section	Not usually deviated	Limit around 1,000 bbl/d	Poor	Requires separation	Deviation limited by rod wear
Gas lift	Can be run to any position	Poor in horizontal	Varies with gas used	Excellent	Excellent	High gas rates required to lift
ESP (electric submersible pump)	Full horizontal	Excellent (if gas shielded)	>20,000 bbl/d	Poor	Requires separation	Req. const. flow & straight landing point
Jet pump	Full horizontal	Moderate	Tubular & depth limited	Moderate to poor	Limited	Requires flow path for power fluid
Plunger	To about 20°	Not used	10 to ≈50 bbl/d	Poor	Good	Low rate liquid removal
Progressing cavity	Full horizontal	Good, but rate limited	Varies, usually low	Excellent	Moderate	Req. straight landing point: protect bearings
Chamber lift	Best in vertical	Unknown	Low	Good	Good	Slugging flow

Table 1:- Source: [Weatherford 2005]

VI. CONCLUSIONS

ALS is used in mature fields, as well as young fields to recover more oil that should have been abandoned due to the declines in the natural reservoir pressures. ALS account for more than 75% of oil wells worldwide (around 1million).

Artificial lift methods becomes a good alternative to enhanced oil recovery (EOR) as it increases the drawdown by reducing the backpressure or BHP thereby generating additional reservoir pressure capable of lifting the formation fluids to the surface leading to more recovery of oil to meet rapidly increasing energy demands globally.

In this paper review, ALS has been analyzed as viable option to increase oil production to desired rate and its importance cannot be overemphasized as the continuously declining natural energy of the reservoir needs to be arrested by suitable selection and application of artificial lifts systems to boost oil production even from difficult unconventional reservoirs.

Common practice has shown that if factors such as well and reservoir indexes , location of the field, problems associated with operations, capital expenditures, operating Expenditures, etc. are given priority in selection of ALS, more oil could be recovered by these methods and project economics can be improved tremendously.

VII. RECOMMENDATIONS

- Artificial lifts should not only be used in mature wells as pressure booster but also in new and young wells.
- It should be employed early in the production life of the well.
- Wide selection criteria and factors should be considered before any method should be applied.
- Cause and effect analysis should done to ensure that each selected method meet the physical constraints of the well.
- One of the roles of petroleum production engineers should be to select artificial lift systems to increase oil production while minimizing operational costs.

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