Published by :
http://www.ijert.org
International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

Design and Simulation of an Electrical Submersible Pump

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Abstract - **Artificial lift methods are used for the enhancement of productivity from oil wells. This study has been conducted on the electric submersible pump (ESP), an analysis of production system that is used to identify the potential of any well, a description of ESP components and installation, a comparison of different productive wells and a discussion of a cases study of oil wells for a design ESP throughout the different parameters. These methods use artificial means to increase well production and ultimately oil recovery. One of these artificial lift methods is the use of ESP that has an efficiency and consistency for wells with a moderate to high production. PROSPER is a well performance, design and optimization computer software for modelling most types of well configurations. This study major focuses on the design and simulation of an ESP system for wells having different productivity index using the PROSPER software.**

***Keywords:** Artificial lift methods, Electrical submersible pump, PROSPER software, Well performance.*

I. INTRODUCTION

The artificial lift system of a well resembles the human heart which pumps the high volumes of reservoir fluids to the surface in low producing wells. These methods are employed in oil wells whose energy from the reservoir is insufficient to lift the fluids to the surface. Most of the producing wells in the world nearly 90 % are presently working on the artificial lift system from early stages. Among the available artificial lift methods, the electrical submersible pump (ESP) system is very effective in wells with low bottom hole pressure, low gas to oil ratio, low bubble point pressure, high water cut, and deviated wells [1].

Electrical Submersible Pump System

History and origin:

A Russian engineer named Armais Arutunoff in 1911 invented an electric motor that can be worked on the water. By the addition of a drill and centrifugal pump to the motor, he invented an electrical submersible pump. Later he improves the system and invented the Russian Electrical Dynamo of Arutunoff for which Schlumberger is currently acting as a service provider [1].

Some of the ESP System Service Providers are listed:
Schlumberger- REDA, Weatherford, Baker Hughes-Centrilift, Wood Group ESP, ALNAS.

Components:

The components of an ESP System can be categorized into surface and downhole components are listed [2]: a). Surface Components: Transformers, Motor controllers, Junction box, Well Head. b). Downhole Components: Electrical Cable, Cable Protectors, Pumps, Gas Separator, Seal section, Motor, Pump intake, Drain valve, Check valve. The ESP System along with its components labelled is shown in Fig.1.0.

Working Principle of ESP System:

Electrical Submersible Pumps are the vertical alignment of centrifugal pumps in the borehole which accelerates the velocity of fluids by impellers. The kinetic energy produced by the impellers is converted into pressure energy by the diffuser and pumps the fluid. An Electrical Submersible Pump is a multi-stage stacked centrifugal pump whose stages are determined by bottom hole pressure and desired flow rate. The arrangement of each stage of an ESP System consists of an impeller and diffuser. When the fluid enters the impeller of the first stage, it centrifuges the liquid radially outward and increases the velocity of the fluid. Now the fluid enters the diffuser from the sharp edges of the impeller where the kinetic energy of the fluid is converted into pressure energy. The pressure gained by the fluid in the first stage and enters the next stage where the pressure is increased slightly than the first stage. As the stages are increase, the pressures are gaining incrementally in each stage to desired discharge pressure and designed head of the pump [1].

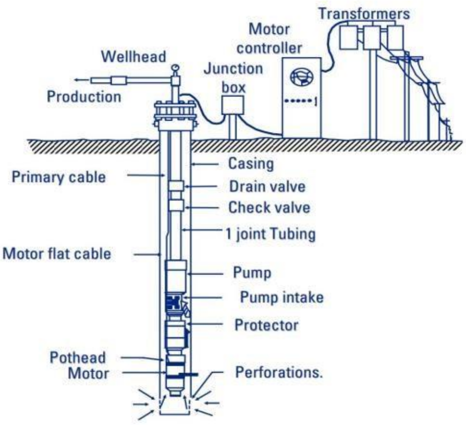

Figure 1.0: ESP System and its components

Advantages, Disadvantages, and Industrial applications of ESP system:

The major advantages of an ESP system [3,4,5]:

- Capable of pumping high viscous crude oils to the surface.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
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- It can be applied to well having low bottom hole pressure.
- ESP System has a low tendency of scale forming operating conditions.
- It has a capacity to produce high volumes of fluids up to 18,000 barrels/day to surface.
- High efficiency and low operating costs.

The major disadvantages of an ESP system [3,4]:

- It can take high repair and maintenance costs.
- It is not applicable to high GOR producing wells.
- The efficiency of the motor is reduced in sand producing wells and sand producing wells will cause mechanical repairs to wells.
- ESP System installation is very critical in highly deviated and dogleg severity wells.
- Special equipment is needed for the repair of the ESP system in deviated wells.
- It is not applicable to the high temperature and deep wells.

The Industrial applications of an ESP system [3, 4, 5]:

- High productive index wells.
- Offshore wells.
- Mostly deviated and horizontal wells.
- ESP is also used for the dewatering purpose of the wells.

Economic analysis of an ESP system:

The better economic evaluation of an ESP System is carried out through the PROSPER software and production can be forecasted in different scenarios for 5-6 years. ESP generates higher gross profits because it produces high potentials of reservoir fluids. On other hand it can also have high operating expenses due to high water cuts and the replacement of failed pumps.

II. DESIGN AND SIMULATION STUDIES ON ESP SYSTEM USING THE PROSPER SOFTWARE

PROSPER is a production optimization software used to models the well completions configuration and design artificial lift methods. It predicts the reservoir fluid properties as a function of temperature and pressure. It simulates the optimized results for the particular artificial lift method based on input data. PROSPER distinctive matching options that tune PVT, multi-phase flow correlations and IPR to match measured field information. It is accustomed style and optimize well completions as well as multi-lateral, multi-layer and horizontal wells, conduit and pipeline sizes [6,7,8].

Stepwise Procedure for Design of ESP System Using PROSPER Software

- First click on file option and select the new file.
- Now in the system summary, water and oil with Black Oil model options are chosen for fluid description and choose Electrical Submersible Pump for artificial lift method.
- Enter the PVT parameters in the PVT input data window and match data with correlations to get the least deviation.
- After matching PVT data, input reservoir operating parameters in the IPR window to develop the inflow performance relation (IPR) curve and determine the absolute open flow.
- Enter deviation survey data, downhole equipment data, surface equipment data, (if available) and geothermal gradient data in their respective windows.
- Enter desirable design parameters and calculate the output design parameters and generate a plot based on output design parameters.
- From the plot generated, choose the optimum operating design of ESP System.

We consider two wells having different productivity index wells (i.e. High and Low) for the design of the ESP System.

Design of ESP System for low productivity index of a well:

The following table 1 delineates the reservoir and fluid input data for the PROSPER software to design the ESP System for the low productivity index of a well.

Table 1: Reservoir and Fluid Input Data

Reservoir and Fluid Input Data	
Reservoir pressure	4000 psi
Bubble point pressure	2500 psi
Reservoir Temperature	200^0F
GOR	400 scf/stb
Water cut	0 %
Oil API	30^0API
Gas specific gravity	0.75
Water salinity	80000 ppm
Oil FVF	1.2 bbl/stb
Oil viscosity	0.31 cp
Productivity index	2 stb/day. psi

After giving the reservoir and fluid input data to the software, inflow performance relation (IPR) curve is generated and the absolute open flow (AOF) of the well is determined. The Fig. 2.0. Illustrates the IPR curve for low productivity index well with AOF.

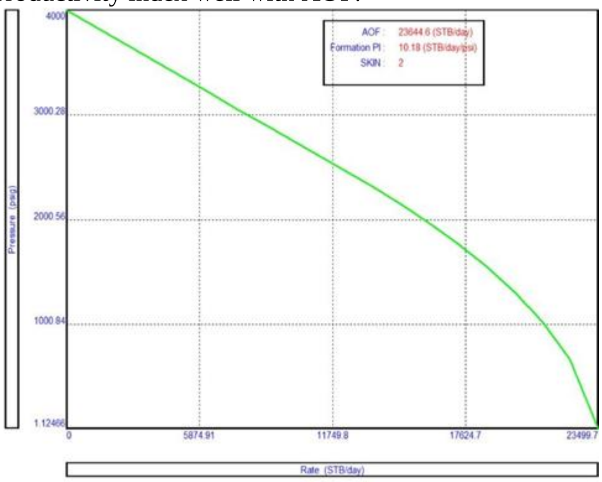

Figure 2.0: IPR curve of a low productivity index well

According to the absolute open flow rate, give the desirable design parameters to software as shown in table 2 and generate calculated output design of ESP System as shown in table 3.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

Table 2: Input Design Data

Input data	
Pump depth(measured)	7000 ft
Operating frequency	60 Hz
Maximum pump outside diameter	6 in
Length of cable	7000 ft
Design rate	11000 stb/day
Water cut	0%
Top node pressure	250 psig

Table 3: Calculated Design Data

Calculated Design Data	
Pump Intake Pressure	2088.75 psig
Pump Intake Rate	12935.9 Rb/Day
Free GOR Entering Pump	67.5125 scf/STB
Pump Discharge Pressure	3206.38 psig
Pump Discharge Rate	12756.5 Rb/Day
Total GOR Above Pump	400 scf/STB
Average Downhole Rate	12808.7 Rb/Day
Head Required	2669.17 ft
Pump Inlet Temperature	199.18^{0}F

On the basis calculated design data, select the better downhole equipment like pump, motor and electrical cable for well having low productivity index (PI = 2) available in the software. For the selected equipment generate optimum output results are presented in table 4 and the design plot of a ESP system as shown in Fig. 3. 0. From the plot generated the best efficiency and better operating conditions of system.

Table 4: Results for selected Equipment

Results	
Number of Stages	65
Power Required	393.76 HP
Pump Efficiency	62.3434 %
Pump Outlet Temperature	203.03 ^{0}F
Current Used	94.614 amps
Motor Efficiency	88.0176 %
Power Generated	393.76 HP
Motor Speed	3512.01 rpm
Voltage Drop along Cable	210.999 volts
Voltage Required at Surface	2671 volts

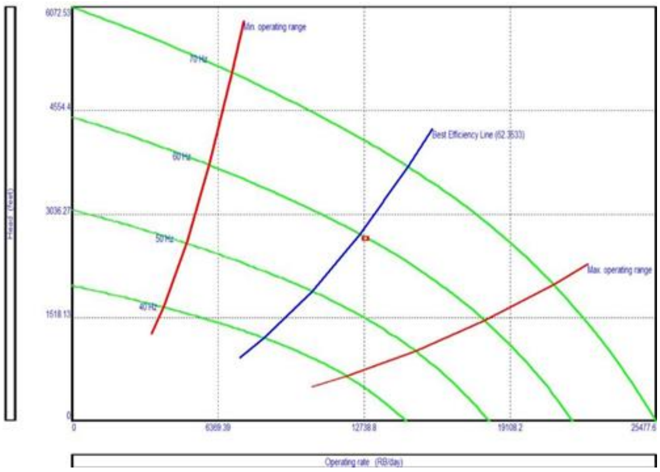

Figure 4: ESP Design plot for low productivity index well

Design of ESP System for high productivity index of a well:

The following table 5 below represents the reservoir and fluid input data for the PROSPER software to design ESP System for low productivity index of a well**.**

Table 5: Reservoir and Fluid Input Data

Reservoir and Fluid Input Data	
Reservoir pressure	4490 psig
Bubble point pressure	1958 psi
Reservoir Temperature	219^{0}F
GOR	507 scf/stb
Water cut	16 %
Oil API	34.2 API
Gas specific gravity	0.92
Water salinity	220000 ppm
Oil FVF	1.42 bbl/stb
Oil viscosity	0.5 cp
Productivity index	6.5 stb/day. psi

After giving the reservoir and fluid input data to the software, an inflow performance relation (IPR) curve is generated and the absolute open flow (AOF) of the well is determined. The figure 4 delineates the IPR curve for the high productivity index well with AOF.

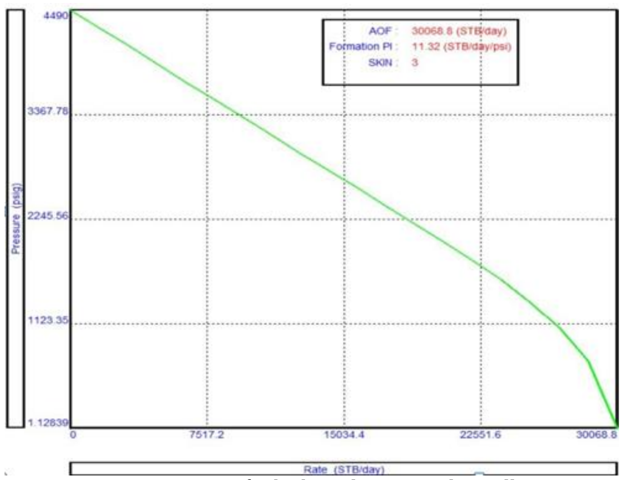

Figure 4: IPR Curve for high productivity index well

Based on the absolute open flow rate, give the desirable design parameters to software as shown in table 6 and generate calculated output design of ESP System as show in table 7.

Table 6: Input Design Data

Input data	
Pump depth(measured)	10330 ft
Operating frequency	60 Hz
Maximum pump outside diameter	6.18 in
Length of cable	10430 ft
Design rate	12000 stb/day
Water cut	16 %
Top node pressure	350 psig

Table 7: Calculated Design Data

Calculated Design Data	
Pump Intake Pressure	2880.93 psig
Pump Intake Rate	14061.8 Rb/Day
Free GOR Entering Pump	52.73 scf/STB
Pump Discharge Pressure	4857.03 psig
Pump Discharge Rate	13934.4 Rb/Day
Total GOR Above Pump	507 scf/STB
Average Downhole Rate	13993.9 Rb/Day
Head Required	5866.49 ft
Pump Inlet Temperature	209.399^{0}F

Based on calculated design data, select the better downhole equipment like the pump, motor, and electrical cable for well having high productivity index (PI = 6.5) available in the software. For the selected equipment generate optimum output results are shown in table 8 and the ESP Design plot as depicts in figure 5. From the plot generated the efficiency and better operating conditions are determined.

Table 8: Results for selected Equipment

Results	
Number of Stages	120
Power Required	776.196 HP
Pump Efficiency	66.9641 %
Pump Outlet Temperature	217.366 ^{0}F
Current Used	112.42 amps
Motor Efficiency	82.83 %
Power Generated	508.79 HP
Motor Speed	3441.53 rpm
Voltage Drop along Cable	509.07 volts
Voltage Required at Surface	3344.07 volts

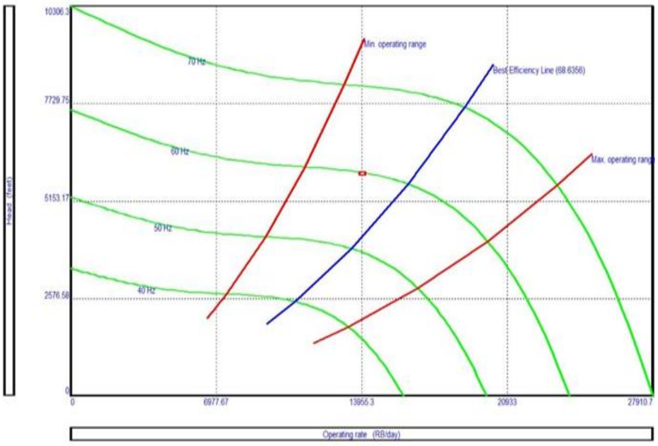

Figure 5: ESP Design plot for high productivity index well

Comparison between the High Productivity and Low Productivity Index of Wells:

The following table 9 represents comparison of results of low productivity index well and high productivity index well which are taken as case studies.

Table 9: Comparison of results of two wells

Parameters	Low Productivity Index Well	High Productivity Index Well
Pump setting depth	**Low**	**High**
Design Rate	Low (11000 STB/Day)	High (12000 STB/Day)
Water cut	High (0 %)	Low (16%)
Pump Intake Pressure	Low	High
Pump Intake Rate	Low	High
Pump discharge Rate	Low	High
Head Required	Low	High
Number of Stages	Low	High
Pump efficiency	Low	High
Voltage Drop along Cable	High	Low

III. CONCULSION

From the Design of ESP Systems of two wells, we studied that a greater number of stages of pumping and high head is required for low productive well, due to these factors the pump efficiency is decreased. More over Pump intake pressure and Pump discharge pressure are decreased because of its low producing rates. The same conditions are vice versa for high productive wells.

IV. ACKNOWLEDGMENT

I would prefer to specific my profound sense of feeling to guide Mr, Ajmeera Ramesh, Asst. Professor, Department of Petroleum Engineering and Petrochemical Engineering, JNTUK, Kakinada, for his or her skillful steerage, timely suggestions and encouragement in finishing this paper.

International Journal of Engineering Research & Technology (IJERT)
ISSN: 2278-0181
Vol. 11 Issue 03, March-2022

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