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Operating Parameters of Electrical Submersible Pump Simulation Using Excel®

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ABSTRACT: Artificial lifting methods are implemented in oil wells whose energy from the reservoir is insufficient to lift the fluids to the surface. Artificial lift equipment is responsible for transmitting energy to the fluid at the bottom of the well. Among the lifting methods, the electrical submersible pump has been increasingly used in onshore or offshore oil wells. In this type of lifting method, energy is transmitted from the surface to the bottom of the well by an electric cable which is connected to a subsurface motor. The motor is connected to a centrifugal pump that implements the pressure differential in the bottom of the well, resulting in elevation. To implement electrical submersible pump in an oil well, it is fundamental to determine the required parameters pump to be used. This work aimed at present the calculation procedure necessary to determine the operational parameters of the pump. The equations found in the literature were implemented in a spreadsheet developed in Excel®, which calculates in an agile way the variables required for pump selection. The results obtained by the spreadsheet were similar to those available in the literature.

I. INTRODUCTION

Electrical submersible pump (ESP) is used in wells that haven't enough bottom pressure to lift the fluids to the surface naturally. The use of the ESP was indicated for wells that produce with high flows, that present water inflow and low values gas oil ratio. However, with the advancement reseaches about ESP, new applications have emerged for its use. Nowadays, ESP is also used in wells with gas-oil ratio considerables values, which gas separators are used in the bottom of the well [1,2].

The operation of the electrical submersible pump consists of the transformation of electrical energy into mechanical energy. The electrical energy is transmitted through an electrical cable from the surface to the engine installed in the bottom of the well. The motor is connected to a multi-stage centrifugal pump, which provides differential pressure resulting in fluid lifting. The costs for installing ESP in an oil well are considered high, so its implementation must be analyzed carefully [2,3].

With the advancement of technology in the oil industry, computational resources have become the object of research by several scholars. The computational tools developed are fundamental in simulation, analysis or control in wells with artificial elevation methods. Researchers such as [4,5,6,7] implemented the empirical equations in a computational program with the purpose of simulating the conditions of a well and, consequently, analyzing the data obtained. While [8] developed an algorithm to control the electrical submersible pump.

Before the ESP is implemented in an oil well, it is essential that the pump operational parameters be selected correctly. To do so, it is necessary to have knowledge of the relative data of the well, the reservoir, the production and the performance chart of a preselected pump. The proper selection of pump parameters is to maximize production and minimize equipment costs [9].

According to [9], actually there are three programs capable of dimensioning the ESP: a commercial program, a program that is available in the literature and a model proposed by him. In this context, it has been found that access to these programs is limited due to the user's cost or accessibility such programs. The development of an easily accessible and free program would bring a scientific contribution of a didactic and industrial nature [9].

In view of this context, this work aimed to develop an Excel® spreadsheet capable of determining the operating parameters of the electrical submersible pump.

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II. METHODS

This topic contains the equations required in determining the operating parameters of a electrical submersible pump.

A. Equations required for pump selection

The equations needed to select the pump were implemented in the cells of an Excel® spreadsheet. The procedure for selecting a pump was divided into seven steps to better understand each step.

Step 1 - Calculation of the pressure and flow rate at the bottom of the well

To select the centrifugal pump it is necessary to know the pressure and the flow obtained by the centrifugal pump. The calculation of the bottom flow of the well is described by Equation 1.

$$q_{wf} = B_o q_s \quad (1)$$

Where:

q_{wf} :Flow rate at the bottom of the well, bbl/d.

B_o: Formation volume factor, bbl/stb.

q_s: Required liquid throughput at pump, bbl/d.

The flow pressure at the bottom of the well is obtained by means of the Inflow Perfomance Relationship (IPR) correlation of the Vogel model, as shown in Equation 2.

$$P_{wf} = 0,125\, P_{res}\,[-1\sqrt{81-80\left(\frac{q_s}{q_{max}}\right)}] \quad (2)$$

Where:

P_{wf}: Flowing bottom-hole pressure, psia

P_{res}: Resevoir pressure, psia.

q_{max} : Maximum oil flow, stb/d.

Step 2- Calculation of the minimum depth of the pump

According to [1], to determine minimum depth it is assumed that the casing pressure is zero and that there is no gas in the annulus of the well. In this way, the calculation can be defined through Equation 3.

$$H_{min,b} = H - \frac{P_{wf} - P_{suc}}{0,433\,\gamma_L} \quad (3)$$

Where:

$H_{min,b}$: Minimum pump depth, ft.

H: Depth of production interval, ft.

P_{suc} :Required suction pressure of pump, psia

γ_L: Specific gravity of production fluid

The pump can be installed at any depth that operates below the minimum depth. However, [10] suggests that a pump installed at a depth of 200 feet above the depth of the production interval.

Step 3 - Calculation of the suction pressure of the pump for the chosen depth of settlement.

The calculation of the suction pressure of the pump at the set depth of the pump is given by Equation 4.

$$P_{suc,b} = P_{wf} - 0,433\,\gamma_L\,(H - H_b) \quad (4)$$

Where:

$P_{suc,b}$: Pump suction pressure, psia.

H_b: Depth that pump is set, ft.

Step 4 - Calculating the pressure differential required by the pump

The pressure differential required by the pump is determined by Equation 5.

$$\Delta_P = P_D - P_{suc,b} \quad (5)$$

Where:

ISSN: 2350-0328
International Journal of Advanced Research in Science, Engineering and Technology
Vol. 4, Issue 5 , May 2017

Δ_P: Required pump pressure differential, psia.
P_D: Discharge pressure, psia.

The pump discharge pressure is calculated by Equation 6.

$$P_D = P_{cp} + \Delta P \quad (6)$$

Where:
P_{cp} =Well head pressure, psia.
ΔP = Pressure variation due to hydrostatic and friction forces, psia.

The pressure variation due to hydrostatic and friction forces is calculated by Equation 7.

$$\Delta P = \Delta P_{PE} + \Delta P_F \quad (7)$$

Where:
ΔP_{PE} = Pressure drop in tubing, psia
ΔP_F= Pressure variaton due friction forces, psia.

Equation 8 determines a pressure variation due to a hydrostatic force of the fluid.

$$\Delta P_{PE} = 0{,}433\, \gamma_L H_b \quad (8)$$

Equation 9 determines the pressure variation that occurs due to the frictional force.

$$\Delta P_F = \frac{124{,}8\, f_F\, \gamma_L\, v^2 H_b}{386{,}04\, d_i} \quad (9)$$

Where:
f_F =Fanning's friction factor.
v = Flow rate of the fluid, ft/s.
d_i =Tubing inner diameter, in.

The Fanning friction factor is determined by Equation 10.

$$f_F = \frac{\left[\frac{1}{1{,}74 - 2\log(2\epsilon)}\right]^2}{4} (10)$$

Where:
ϵ = Roughness.

The flow velocity of the fluid is calculated by Equation 11.

$$v = \frac{q_{wf}}{\frac{\pi}{4} D_i{}^2} \quad (11)$$

Where:
Di = Tubing inner diameter, ft.

Step 5 - Pump Head Calculation
The head of the pump is calculated by Equation 12.

$$h = \frac{\Delta_p}{0{,}433\gamma_L} \quad (12)$$

Where:
h:Potential for pump lift, ft.

ISSN: 2350-0328
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Vol. 4, Issue 5 , May 2017

Step 6- Calculation of the required number of stages
For calculation of the number of stages of the pump it is necessary to initially obtain the performance chart of the pump determined by the manufacturer. The performance chart shows the corresponding head value for the flow rate at the bottom of the well. The value found must be divided by the number of pump stages shown in the performance chart.The number of stages of the pump is given by Equation 13.

$$NE = \frac{head}{n} \quad (13)$$

Where:
NE: Required number of stages
n: head for each stage pump, ft/stage.

Step 7 - Calculation of the power required
To determine the power required by the pump, the performance chart of the pump is used. By means of the value of the oil flow that will pass through the pump, the head curve is the power necessary to raise the fluids for each stage of the pump. Thus, it is necessary to divide the found value of power by the number of stages described by the chart, thus obtaining the power required by stages of the pump.
The power required by the pump is calculated by Equation 14.

$$P_{r,b} = NE\ P_{reb} \quad (14)$$

Where:
$P_{r,b}$: Required power, hp.
P_{reb}: Required power for each stage of the pump, hp/stage.

The equations 1 to 14 were implemented in an Excel® spreadsheet in order to determine the operational parameters of a electrical submersible pump in an agile and practical way.

B. Case study

Aiming to demonstrate the use of the spreadsheet that was elaborated, selected data from [1,10], which depicts a well that will be equipped with ESP.The data are presented in Table 1.

Table 1: Characteristics of the production system

Variable	Value	Unit
Depth of production interval (H)	10000	ft
Degree API	32	
Gas Oil Ratio	50	scf/std
Tubing inner diameter (di)	2,992	in
Formation volume factor (Bo)	1,25	bbl/stb
Oil viscosity (μo)	5	cp
Production fluid gravity (γl)	0,865	
Surface temperature (Ts)	70	ºF
Bottom-hole temperature (Tf)	170	ºF
Resevoir pressure (Pres)	4350	psia
Maximum rate (qmax)	15000	std/d
Desired production rate (qs)	8000	stb/d
Well head pressure (Pcp)	100	psia
Required pump suction pressure (Psuc)	200	psia

Font: Adapted[1,10]

The data of the case study were implemented in the spreadsheet developed for its validation and the results found were discussed.

ISSN: 2350-0328
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Vol. 4, Issue 5 , May 2017

III. RESULTS AND DISCUSSIONS

Figure 1 shows the developed worksheet duly filled in with the case study data.

CALCULATION OF ELECTRICAL SUBMERSIBLE PUMP SETTINGS

Objective: To determine the specifications required of a electrical submersivel pump quickly and effectively . The variables must be entered in the American System.

Input data

	Value	Unit
Resevoir depth (H)	10000	ft
Desired surface rate (q_s)	8000	STB/d
Resevoir pressure (P_{res})	4350	psia
Well head pressure (P_{cp})	100	psia
Tubing inner diameter (d_i)	2,992	in
Oil viscosity (μ_o)	5	cp
Roughness (ε)	0,001	-
Required pump suction pressure (P_{suc})	200	psia
Formation volume factor oil (B_o)	1,25	bbl/stb
Pump setting depth (H_b)	9800	ft
Maximum rate (q_{max})	15000	bbl/stb
Production fluid gravity (γl)	0,865	

Figure 1: Simulator with data

Input variables are requested only once, so the user is free to fill only the cells needed to obtain the required result. If you want to get all the results it is essential to fill all the variables in the worksheet. It is worth mentioning that the variables must be supplied in the requested units.

After completing all the data, the worksheet automatically calculates the results, as shown in Figure 2.

ISSN: 2350-0328
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Vol. 4, Issue 5 , May 2017

Solution		
Step 1 - Calculation of the pressure and flow rate at the bottom of the well		
Pwf	2823	psia
qwf	10000	bbl/d
Step 2- Calculation of the minimum depth of the pump		
Hmin,b	2997	ft
Step 3 - Calculation of the suction pressure of the pump for the chosen depth of settlement		
Psuc,b	2748	psia
Step 4 - Calculating the pressure differential required by the pump		
fFaning	0,005	
v	13,33	ft³/s
ΔpPe	3673	psia
ΔPf	798	psia
Δp	4471	psia
PD	4571	psia
Δpb	1823	psia
Step 5 - Pump Head Calculation		
head	4868	ft
Step 6 - Calculation of the required number of stages		
Analyze pump performance chart and input pumping head		
Hbomb.	6000	ft
Required number of estages		
NE	81	stage
Step 7 - Calculation of the power required		
Input power required for the flow through analysis of pump performance curve		
Preb	600	hp
Required power		
Pr,b	487	hp

Figure 2: Solutions

As can be verified by Figure 2, the solutions were divided into stages, whose equations were presented in the methodology of this work.

In the first step, the oil flow at the bottom of the well and the flow pressure at the bottom of the well are calculated. By disposing of the oil flow rate at the bottom of the well and the inside diameter of the coating it is possible to determine a centrifugal pump having compatible dimensions to be inserted into the well. The choice of pump is correct when analyzing the value of the oil flow at the bottom of the well its value is located in the central region of the flow range determined by the manufacturer.

In the second step of the solutions, the minimum depth of settlement of the pump was calculated. Given that the depth chosen for settlement of the pump should be greater than the minimum depth and [1]

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Vol. 4, Issue 5 , May 2017

recommend that the pump be seated 200 ft above the depth of the productive range, it was adopted 9800 ft as a point of the centrifugal pump.

The third step presented the calculation of the suction pressure of the pump to the chosen depth of settlement. The value found (2748 psia) is higher than the minimum pressure required by the pump (200 psia). Therefore, the pump can be installed at the chosen depth without any problem.

In the fourth step the pressure differential determined by the pump was obtained. To do so, it was necessary first to calculate the discharge pressure of the pump. The discharge pressure of the pump was calculated by well head pressure and pressure variation due to hydrostatic and friction forces.

For the calculation of the sixth and seventh steps, knowledge of the performance curve of the pump was fundamental and should be requested from the pump manufacturer. The performance curve used in this case study is presented in Figure 3.

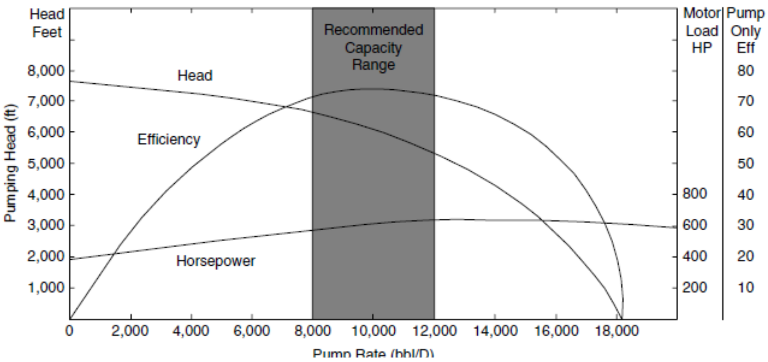

Figure 3: A characteristic chart for 100-stage ESP [1]

The results showed that the pump to be installed should have a 4868 ft head with 81 stages and the engine should provide 487 horsepower for the pump.

IV. CONCLUSION

This work resulted in the development of a spreadsheet in Excel® to determine the operating parameters of a submerged centrifugal pump.

The worksheet has been divided into two parts: the first one requests the input data, and the second the solutions are obtained. In this way, the spreadsheet allowed all the necessary equations to be solved in an agile and practical way.

The validation of the spreadsheet was performed through the implementation of a case study from the literature. The results obtained by the developed simulator were similar to those available in the literature, allowing the successful validation of the spreadsheet.

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