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DETAILED DESIGN OF AN ESP INSTALLATION FOR A GEOTHERMAL WELL

GÁBOR TAKÁCS
Petroleum Engineering Department
University of Miskolc
gtakacs@kfgi.uni-miskolc.hu

ABSTRACT

Electrical submersible pump installations are the prime candidates for application in water producing and/or geothermal wells because of the many beneficial features of this artificial lift method long used in the oil field. ESP units are ideally suited to produce large and extremely large volumes of liquids from wells and the very efficient cooling of the ESP motor provided by water flow permits a long operating life.

The paper introduces the basic design of an ESP installation for geothermal water production and details the selection and application of the system's different components. Being the heart of the system, the selection of the submersible pump provides the basis for the design of the total system. Pump type, the necessary number of stages are properly selected and checked for operating conditions. After the required electric motor is selected, the cable selection is one of the important steps which involves not only technical but economic considerations as well. The design procedure detailed in the paper can directly be used in selecting and operating ESP systems utilized for geothermal well production.

1. INTRODUCTION

In case of application in geothermal wells operating conditions are ideal for ESP units because of the following features:

- The well usually produces single-phase liquid, water only.
- The amount of free gas at the pump suction, if any, is very low so that it can be removed easily by a simple reverse-flow gas separator. Therefore, no deterioration of submersible pump performance takes place.
- The viscosity of the produced water is low, so that no correction of the standard pump performance curves is necessary.
- The ESP unit is fed with an AC current with a constant frequency.

Such flow conditions are ideal for the operation of the centrifugal pump and allow the application of a very straightforward design procedure [1–6] the main phases of which are detailed in the following sections.

2. DATA REQUIREMENTS

For a proper design of the ESP installation, the knowledge of many different data is necessary. Perhaps the most important among them is the reliable information on the well's productivity so that the desired liquid rate from the well can be established. The liquid rate is always an input parameter in the design of ESP installations because the selection of the submersible pump (the heart of the system) can only be accomplished in the knowledge of the desired rate. Just remember that different pumps have different recommended application ranges.

Necessary input data can be grouped as given here.

1. **Well Physical Data.**
   - Casing and liner sizes, weights, and setting depths.
   - Tubing size, type, weight, and thread.
   - Total well depth.
   - Depth of perforations or open hole interval.
   - Well inclination data.
2. **Well Performance Data.**
   - Tubinghead pressure at the desired rate.
   - Casinghead pressure.
   - Desired liquid production rate.
   - Static bottomhole pressure or static liquid level.
   - Flowing bottomhole pressure or dynamic liquid level.
   - Productivity data.
   - Producing gas-water ratio.
   - Bottomhole temperature at desired water rate.
3. **Fluid Properties.**
   - Specific gravity of water.
   - Specific gravity of produced gas.
   - Bubble point pressure.
4. **Surface Power Supply Parameters.**
   - Primary voltage available at the wellsite.
   - Frequency of the power supply.
   - Available power supply capacity.
5. **Unusual Operating Conditions.**
   - Production of abrasives, especially sand.
   - Type and severity of corrosion.
   - Extremely high well temperatures.

3. WELL INFLOW CALCULATIONS

The basic requirement for a proper installation design is the exact information on the well's inflow performance because the selection of the ESP pump cannot be made without the knowledge of the liquid rate and the corresponding dynamic liquid level. These parameters are interrelated and can be calculated from the well's Inflow Performance Curve and usually the constant Productivity Index (*PI*) model is applied, depending on whether free gas is present at the perforations or not.

The well's flowing bottomhole pressure (*FBHP*) is easily calculated from the previous data and the next formula has to be used if the constant PI equation describes the well inflow:

$$FBHP = SBHP - \frac{q}{PI} \tag{1}$$

Based on the flowing bottomhole pressure (*FBHP*) at the perforations the pressure at the pump's **suction** (Pump Intake Pressure, *PIP*) is found from the following formula, using the fluid gradient valid in the annulus below the pump setting depth:

$$PIP = FBHP - \left(L_{perf} - L_{set}\right) grad_l \tag{2}$$

Finally, the “in-situ” **liquid volumetric rate** to be handled by the ESP pump is found from the water flow rate:

$$q_l' = q_w\ B_w \tag{3}$$

In addition to these calculations and based on the actual inflow performance data the well’s maximum possible flow rate can also be established. This enables one to investigate the possibility of other producing scenarios.

4. TDH CALCULATIONS

In order to determine the required number of pump stages in a later phase of the design procedure, the total head to be overcome by the ESP pump has to be determined. This is called the Total Dynamic Head, *TDH*, and is the sum of the following components, all expressed in length units:

- the wellhead pressure at the given liquid production rate,
- the net hydrostatic pressure acting on the pump, and
- the frictional pressure drop that occurs in the tubing string at the given liquid rate.

The second term equals the true vertical depth (TVD) of the dynamic liquid level, the depth where the water level in the casing annulus stabilizes while producing the desired liquid rate. It is easily found from the value of the pump intake pressure, *PIP*, as given here:

$$L_{dyn} = \frac{L_{set}\ grad_w + CHP - PIP}{grad_w - grad_g} \tag{4}$$

It should be noted here that the pump is usually set below this depth in order to provide the necessary submergence required for proper pump operation. A rule of thumb value is at least 500 ft of fluid over the pump (FOP), the other limit being the depth of the sandface (perforations). The reason is that in conventional installations the motor must be set above the depth of the sandface to ensure the liquid velocity required for proper cooling.

The frictional head loss in the tubing string, Δh_{fr}, can be estimated from charts or the widely used Hazen–Williams formula can be employed.

The total frictional head loss in the tubing string is found as:

$$\Delta H_{fr} = \Delta h_{fr}\ \frac{L_t}{1{,}000} \tag{5}$$

If not done before the start of the installation design, the size of the existing or predicted tubing string should be checked for extensive frictional pressure drop. The generally accepted practice in the ESP industry is to limit the frictional head loss in the tubing string to a value of 100 ft / 1,000 ft. When the head loss found at the desired water production rate is greater than this value, selection of a bigger tubing size is recommended. If this rule is followed, the frictional energy loss in the tubing string consumes less than 10% of the total energy requirement of the ESP system [7, 8], and this ensures an economic installation design.

Now, the *TDH* is calculated in head (ft) units as follows:

$$TDH = \frac{2.31}{\gamma_l} WHP + L_{dyn} + \Delta H_{fr} \tag{6}$$

5. SELECTION OF THE PUMP

The selection of the proper ESP pump for operating in a given well involves:

- the determination of the pump series (outside diameter) to be used,
- the selection of the required pump type,
- the calculation of the required number of stages, as well as
- the checking of the mechanical strength of the selected pump.

5.1. Pump Series

As with all ESP components, the most important selection criteria is that the chosen pump should fit in the casing string of the well. Centrifugal pumps are manufactured in different outside diameters, their series numbers usually represent their outside diameters, e.g. a 338 Series pump's OD is 3.38 in, 400 Series means 4.00 in OD, etc.

When selecting the pump series to be used, economic considerations command the choice of pumps with the largest OD that can be run in the given casing size. This is because ESP components (pumps, motors, etc.) with identical technical parameters but different ODs, due to manufacturing complications, are less expensive if they have a larger OD.

5.2. Pump Type

After the pump series has been determined, the proper type is selected from the available options. Pump types differ in the design of the stages such as the shape and number of vanes, the height, angle, and length of vanes, etc. All these factors have an impact on the liquid flow rate and the head developed by a pump stage.

Pump type selection is based on the comparison of the well's desired water production rate and the recommended liquid capacity ranges of the pump types available. The ESP pump type selected should have

- the required water rate within its optimum capacity range, and
- the rate belonging to its best efficiency point (BEP) to fall close to the desired rate.

If several pump types meet these requirements the final selection may be based on the following considerations.

- Compare the horsepower requirements and choose the pump that needs a smaller motor.
- If the accuracy of the well's inflow parameters is unreliable, choose a pump with a "steep" Q–H (head capacity) curve. Such pumps will produce a water rate near the desired volume even if the actual *TDH* differs from the design rate.

5.3. Number of Stages

The individual stages in a multistage centrifugal pump develop identical heads which are additive so a pump with a given number of stages develops a total head equal to the sum of the heads of all stages. This allows the determination of the necessary number of stages for a given case where the total head represented by the *TDH* is known.

Since at this step of the design process the pump type is already known, one has to use the performance curves of the selected type, made available by the manufacturer. Pump performance curves contain, in the function of the pumping rate, the following measured operational parameters:

- the head developed,
- the efficiency, and
- the power required, all for a given number (usually one) of stages.

In order to determine the required number of stages, one has to read the head developed by one stage at the desired liquid production rate and use the following formula:

$$\boldsymbol{Stages} = \frac{\boldsymbol{TDH}}{\textbf{head/stage}} \tag{7}$$

Since it would be too costly to fabricate ESP pumps with every possible number of stages, pumps are manufactured in different housings containing discrete numbers of stages. This is the reason why one should select the pump with the next available greater number of stages than the number calculated from **Eq. 7**.

5.4. Checking the Pump's Mechanical Strength

The pump selected by the previous procedure must be checked for mechanical strength of the pump shaft and the pump housing to ensure that the loading on the shaft and/or the housing do not exceed the limits specified by the manufacturer.

The strength of the pump shafts is given by the manufacturer by specifying the maximum allowed power the shaft can transmit at a frequency of 60 Hz. The actual power required by the selected ESP pump is found from the pump performance curves, where the power needed to drive a given number of stages (usually one) is plotted in the function of the pumping rate. After reading at the desired liquid rate the necessary power per stage from the performance curve, one finds the total power needed:

$$\boldsymbol{BHP_{pump}} = \frac{\boldsymbol{BHP}}{\boldsymbol{stage}}\ \boldsymbol{Stages}\ \boldsymbol{\gamma_l} \tag{8}$$

The total required power, BHP_{pump}, must be less than the maximum allowed power on the pump shaft, BHP_{shaft}, found from the manufacturer's technical specifications.

Manufacturers specify the mechanical strength of pump housings by publishing the allowed internal burst pressure for their pumps. This pressure should be compared to the maximum possible internal pressure which occurs when the pump develops the maximum head. Some manufacturers use the "shut-in" head valid at zero flow rate, others use the highest head found in the recommended rate range. Again, the performance curves of the selected pump have to be used to find the maximum head per stage value, from which the maximum internal pressure is found as follows:

$$\boldsymbol{p}_{\max} = \left(\frac{\boldsymbol{head}}{\boldsymbol{stage}}\right)_{\max} \boldsymbol{Stages}\ \ \boldsymbol{grad_l} \tag{9}$$

For safe operation, the calculated maximum pressure must be less than the burst pressure rating of the pump housing.

6. SELECTION OF THE PROTECTOR

The protector or seal section of the ESP unit performs several vital functions for the proper operation of the installation the most important of them being absorbing the axial thrust developed in the pump. This is the reason why protectors are selected primarily on the basis of the calculated thrust load developed by the pump.

In addition to thrust load capacity, several other features have to be considered when selecting the proper protector for a particular application:

- the right size (series) is to be chosen,
- the protector shaft should be capable to transfer the required power, and
- the protector's oil expansion capacity should be sufficient.

The available sizes of protectors are compatible with motor and pump series and the proper outside diameter is selected to match the ODs of the selected motor and the pump.

Most ESP pumps belong to the floating impeller class where all axial forces developing in the stages are absorbed by the thrust washers of the stages. The only thrust occurring in such pumps is the downthrust on the pump shaft due to the shaft being exposed to a large pressure differential. Since this load is directly transferred to the protector, the load on the protector's thrust bearing is found by multiplying the cross sectional area of the pump shaft by the maximum pressure developing inside the pump, found from **Eq. 9**:

$$\boldsymbol{F_{TB}} = 0.785\ \boldsymbol{p}_{\max}\ \boldsymbol{d}^2 \tag{10}$$

In fixed impeller pumps (a.k.a. compression pumps), in contrast to those with floating impellers, high axial loads develop in the pump stages because the impellers are axially fixed to the shaft. Thrust forces developing on the impellers, therefore, are directly transferred to the protector's thrust bearing. The calculation of these forces, however, requires that measured thrust values for the given stage be available. To increase the safety of installation design for compression pumps, manufacturers usually publish thrust values at shut-in conditions in lb/stage units.

The capacity of the protector's thrust bearing relies on the operating temperature because the viscosity of motor oil decreases at elevated temperatures making the oil film on the bearing surfaces to become thinner. Therefore, performance diagrams have to be used and a protector with a load capacity greater than the load just calculated is selected.

The shafts of different protectors have different mechanical strengths, and manufacturers usually specify the maximum allowed power on their shafts. Therefore, the protector selected on the basis of thrust bearing load must be checked by comparing its shaft rating to the power needed to drive the pump. For proper operation, a protector with a greater shaft rating than the pump power calculated from **Eq. 8** has to be chosen.

In order to increase the protection of motors in hostile environments, to save on pulling costs, or to increase the run time of the ESP system, tandem protectors i.e. two or more sections stacked in series can be used. Such protectors may contain both bag-, and labyrinth-type chambers.

The protector's operation consumes a definite power which should be provided by the ESP motor. Most ESP equipment manufacturers (except Centrilift) include this power in the pump horsepower requirement of their published pump performance curves. For such cases the total horsepower needed to drive the ESP unit equals the pump power calculated from **Eq. 8**.

7. MOTOR SELECTION

When selecting the submersible motor to match the ESP pump already chosen, one has to determine

- the proper motor series (outside diameter),
- the required motor power, and
- the right combination of motor voltage and amperage.

Motor series denotes, just like with the pump, the OD of the motor. Again, the motor series with the largest OD that can be run in the well casing should be preferred. Many times, motors with outside diameters different from the ESP pump are used, mainly because larger diameter motors are less expensive.

ESP motors are cooled by well fluids flowing past the motor's outside surface and the recommended minimum flow velocity required for proper cooling is 1 ft/s. To prevent the erosion of the housing, however, velocities have to be limited to 12 ft/s for clean fluids, and to 7 ft/s for fluids containing abrasives. The formula given in the following allows the calculation of flow velocities in the annulus formed by the casing string and the ESP pump:

$$v_l = 0.0119 \frac{q_l'}{ID_c^2 - OD_m^2} \tag{11}$$

The criterion for selecting the motor with the proper power capacity is the total power requirement of the ESP system, BHP_{system}, that consists of the powers needed to run (a) the pump, (b) the protector, and (c) the gas separator (if used). If no rotary gas separator is used, like in the design for geothermal wells, and the power to drive the protector is included in the pump horsepower, the ESP system's total power demand equals the pump power, BHP_{pump}, calculated from **Eq. 8**. Since ESP motors in every series are manufactured with several discrete power ratings, one should choose a motor with a nameplate rating just above the required system power, BHP_{system}.

The actual current demand of the motor is calculated from the nameplate data of the selected motor and the system's power requirement as follows:

$$I = I_{np} \frac{BHP_{system}}{HP_{np}} \tag{12}$$

Most ESP motors of a given power rating come in several versions differing from each other by the combination of their required voltage and amperage. Since electric power is defined as the product of voltage and amperage, motors with higher voltage values require less current, and vice versa. This feature gives the designer a great flexibility to achieve an optimum selection of motors for various conditions with the objective of maximizing the economy of fluid lifting.

The prime factor in selecting the motor voltage is the running depth of the ESP unit because it heavily affects the voltage drop in the electric cable. Deeper installations require longer cables and involve higher voltage drops across the cable; this leads to greater amounts of wasted electrical energy and lower system efficiencies. In such conditions, selecting a motor with a higher voltage rating means that a much lower current flows through the cable causing a lower voltage drop; consequently the amount of wasted power is reduced. Also, the use of higher voltages is advantageous in geothermal wells with high downhole temperatures because higher voltage motors need less current to develop the same horsepower, thus the operating temperature of the electric cable is reduced, and cable life is increased.

Based on the considerations just discussed and an analysis of the power flow in the ESP system, Powers [8] concludes that in most situations the motor with the highest voltage requirement is the proper choice. This not only reduces the total power consumption but many times allows the use of a smaller and less expensive power cable.

8. SELECTION OF THE POWER CABLE

The electric power cable is a vital part of the ESP system and its proper selection is not only a technical task but requires, as it will be shown later, economic considerations as well. Cable for the ESP industry is manufactured in a wide variety of types, sizes, etc.

When designing an ESP installation the right cable is selected by determining its required (a) length, (b) type, and (c) size, with proper considerations of all operational conditions.

8.1. Cable Length

The length of the power cable is determined from the running depth of the motor to which a sufficient length needed for the safe connection of surface equipment (about 100 ft) is added. The main cable (usually a round configuration) should reach down to the top of the ESP unit from where a motor lead extension (usually a flat cable section) runs to the pothead of the motor.

8.2. Cable Type

ESP cables are manufactured in a wide variety of types i.e. with different insulating and conductor materials, constructions, and armors. The proper choice primarily depends on well conditions, most importantly on well temperature, and the composition, gas content, and corrosiveness of the well fluid. The main considerations [9, 10] on the proper selection of the individual parts of the cable can be summed up as follows:

- The material of choice for cable conductors is copper, especially in deeper wells since aluminum has a lower conductivity.
- The two most common materials used for the insulation of the individual conductors are polypropylene and EPDM (ethylene propylene diene monomer), their temperature limits are 205 ºF and 400 ºF, respectively. Polypropylene is susceptible to degradation by light hydrocarbons, CO_2, and hydrocarbon gases. EPDM materials have a much wider temperature range and are less sensitive to gases.
- Jackets are made from Nitril or EPDM materials, the latter being used at higher temperatures.
- Braids or tapes provide additional strength and protection to cable components.
- Metal armor provides mechanical protection to the cable during running and pulling and the choices are galvanized or stainless steel and Monel.

8.3. Cable Size

The main considerations for selecting the size of the power cable are: (a) the physical dimensions, and (b) the voltage drop along the cable. The physical size should be chosen so that the cable fits in the annulus between the casing string and the ESP unit. The voltage drop occurring in the cable is a function of the conductor size and the motor current, and is a direct indicator of the energy losses occurring along the cable.

If the effect of conductor size on the operation of the whole ESP system is investigated, it is easy to see that smaller conductors mean greater energy losses and proportionally greater operational costs. But, at the same time, cable investment cost is lower than for a bigger conductor size. Bigger cable sizes, on the other hand, result in lower operating expenses but higher investment costs. Therefore, the selection of the optimum cable size should involve not only technical but economic considerations as well.

Optimization procedures [11, 12] are based on finding the least value of total operating costs over the expected life of the cable. The total operating cost is the sum of the capital and operating expenses and these, as described previously, vary with cable size. Since an increase of the conductor size involves increased capital costs but decreased operating costs, a cable providing the minimum of total costs can surely be found. It is easy to see that, contrary to the rules previously used, the smallest possible size may not be the best selection. Calculation of the cost items is described in the following.

The monthly payment necessary to pay back the capital outlay for the cable over its expected life, considering the time value of money, is found from the formula used for calculating partial payments of loans. In the following formula the multiplier of the investment cost is the Capital Recovery Factor (CRF) that defines the variation of the capital cost's contribution to the total cost:

$$PB = CI \frac{(1+p)^N}{(1+p)^N - 1} \, p \tag{13}$$

In the formula, the monthly interest rate, p, is calculated as:

$$p = \frac{P}{1200} \tag{14}$$

The monthly operating expenses are equal to the cost of the electric power wasted along the cable. The calculation model of Vandevier [11] is detailed in the following, who used the next simplifications when calculating this cost item:

- Instead of using an average along the cable length, cable temperature is taken to be equal to the well's bottomhole temperature.
- The cable's inductive reactance is neglected because of its low value for any ESP cable.

First the total resistance of the cable (in Ohms) at well temperature is calculated from:

$$R_T = \frac{L_c \, r}{1{,}000} \left[1 + 0.00214 \left(BHT - 77\right)\right] \tag{15}$$

The power loss in the cable (in kW units) is calculated from the cable resistance and the motor current:

$$\Delta P_c = \frac{3 \, I^2 \, R_T}{1{,}000} \tag{16}$$

Finally, the monthly cost of this power loss ($/month) is found as:

$$C_{cl} = 720 \, \Delta P_c \frac{c_e}{100} \tag{17}$$

When using the calculation model described previously, the steps of the cable size selection are the following:

1. Based on the ampacity chart of the selected cable type the allowed amperage values of each available size are determined at the well's bottomhole temperature.
2. Cable sizes with allowed currents greater than the required motor current are selected for further economic analysis.
3. After performing the calculation of total costs for each candidate, the cable with the minimum of monthly costs is chosen.

8.4. Checking Motor Startup

It should be noted that the cable size selected affects the operating conditions of the motor especially immediately after startup. At system startup ESP motors draw more than five times greater instantaneous currents than their nameplate current. Due to the increased current a high voltage drop develops across the cable and the voltage reaching the ESP motor may be insufficient to start the motor. Normal starts require about 50% of the motor's nameplate voltage to be available at the motor's terminals.

The following simple formula, although being an estimate only, permits a rapid check on the cooperation of the cable and the motor at startup conditions. The ratio of startup and nameplate voltages is found from:

$$\frac{U_{start}}{U_{np}} = \frac{U_{np} - 4\, I\, R_T}{U_{np}} \tag{18}$$

The selected cable size is satisfactory if this ratio is greater than 0.5, because in those conditions more than 50% of the nameplate voltage reaches the motor's terminals and no startup problems will occur.

9. SWITCHBOARD AND TRANSFORMER SELECTION

When specifying switchboards and transformers, the most important information is the maximum power of the ESP system required at the surface. This can be found from the necessary surface voltage and the motor current. Surface voltage is composed of the motor's required terminal (nameplate) voltage plus the voltage drop across the power cable. Since at this phase of the installation design the nameplate voltage has already been selected, and the cable voltage drop equals the product of cable resistance and the motor current, the installation's surface voltage requirement is found as:

$$U_{surf} = U_{np} + 1.732\, R_T\, I \tag{19}$$

From the available models, a switchboard with a rated voltage above this value is selected. The power rating of the switchboard (in kVA units) is found from the formula used to find three-phase electric power:

$$P_{surf} = \frac{\sqrt{3}\, U_{surf}\, I}{1{,}000} = 0.001732\, U_{surf}\, I \tag{20}$$

The necessary 3-phase step-up or step-down transformer should have the same kVA rating as the switchboard.

10. MISCELLANEOUS EQUIPMENT

At this point of the design procedure, all important parts of the ESP installation are selected and a detailed order can be placed to the manufacturer. The only remaining pieces of equipment can easily be chosen from the manufacturer's catalog and only a listing with the most important considerations is given in the following.

Downhole Equipment

- Motor lead extension is a flat cable section whose length should be about 6 ft longer than the combined length of the gas separator, pump, and protector.
- Flat cable guards should be installed along the ESP unit and the necessary number of 18 in sections is chosen.
- Cable bands on the power cable are spaced every 15 ft along the tubing string; and 2 ft apart along the flat cable.
- Check and drain valves are selected to be compatible with the tubing size.

Surface Equipment

- Up-to-date wellheads use power feed-through connections and are to be chosen to be compatible with the well's casinghead, tubing, and power cable sizes.
- A junction box is needed to provide a connection point for the power and surface cables and is selected from available models.
- Surface cable should have sufficient length to reach from the junction box to the switchboard and must be at least the same size as the power cable.
- Service equipment includes cable reels, reel supports, and cable guide wheels; they should match the selected cable sizes.

11. CONCLUSIONS

The paper introduces the design of ESP installations capable of producing geothermal water wells. Basic design principles and practical recommendations are discussed for the selection of the components of the electrical submersible pumping system. Conclusions related to system design can be summarized as follows.

- ESP installations are ideally suited for producing water from geothermal wells.
- Design of the installation is based on the proper selection of the submersible pump.
- The proper selection of the electrical cable involves an economic study to find the cable size that provides the least amount of total cost over the life of the equipment.

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LIST OF SYMBOLS

B_w	water volume factor at pump suction pressure	bbl/STB
$BHP/stage$	the power needed to drive one pump stage	HP/stage
BHP_{system}	power requirement of the ESP system	HP
BHT	bottomhole temperature	ºF
c_e	cost of electric power	c/kWh
CHP	casinghead pressure	psi
CI	capital investment for cable	$
d	pump shaft diameter	in
$grad_l$	fluid gradient in the annulus	psi/ft
$grad_w$, $grad_g$	water and gas gradients in the annulus	psi/ft
HP_{np}	nameplate power of the motor	HP
$head/stage$	head developed by one stage of the selected pump	ft
$(head/stage)_{max}$	shut-in head developed by one pump stage	ft
I	required motor current	Amps
I_{np}	nameplate current of the motor	Amps
ID_c	inside diameter of the casing string	in
L_c	cable length	ft
L_{dyn}	TVD of the dynamic liquid level	ft
L_{perf}	TVD of perforations	ft
L_{set}	TVD of pump setting	ft
L_t	measured tubing length to the pump setting depth	ft

N	expected life of the cable	months
OD_m	outside diameter of the motor	in
p_{max}	maximum internal pressure in the pump	psi
P	prime interest rate	%/year
PI	productivity index	STB/d/psi
PIP	pump intake pressure	psi
q	liquid rate	STB/d
q_l''	"in-situ" water flow rate	bpd
q_w	water volumetric rate	STB/d
r	resistance of conductor at 77ºF	Ohm/1,000 ft
R_T	cable resistance	Ohms
$Stages$	the selected number of pump stages	-
$SBHP$	static bottomhole pressure	psi
U_{np}	motor nameplate voltage	Volts
U_{surf}	required surface voltage	Volts
WHP	producing wellhead pressure	psi
ΔH_{fr}	frictional head loss in the tubing string	ft
γ_l	specific gravity of the produced liquid	-

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