

# **Geothermal Well Production Optimization: Exploration in the East African Region**

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## **Keywords**

*well performance, pressure decline, production optimization*

## **ABSTRACT**

Given the high geothermal gradient in the East African Rift Valley area, geothermal energy has increasingly become a resource of interest to alleviate the serious energy shortages in the region where on average 40% of the population has access to electricity (World Bank 2016). The interest is in part attributed to increased funding for renewable energy projects after the global drive at the COP21 in Paris in 2015 to reduce global warming to below 2° C.

The geothermal potential in the East African region exceeds 15,000MW (P. A. Omenda 2013), where generation is currently dominated by Kenya. New players include, among others, Rwanda, Djibouti and Ethiopia who have recently applied for Geothermal Risk Mitigation funding (GRMF) at the African Union for exploration studies.

One of the current challenges facing the new players is the shortage of in-country technical expertise to efficiently harness their geothermal potential. Most of the technology used in geothermal exploration and production projects has been adapted from the oil and gas industry with a very capital-intensive project model. Thus, to efficiently develop and optimize the resource's impact by the new and existing African players, it is of extreme importance to invest in production optimization practices of geothermal wells.

Topics worthwhile thinking about include:

*What are the current practices for doublet design and well monitoring?* Doublet design is an Enhanced Geothermal System application made up of an injector and producer well pair. It aims to maintain the reservoir pressure through re-injection of the produced fluid after heat extraction. It is largely still at the development stage and only economical in markets with very high electricity prices, that most households in East Africa may not be able to afford right now. Well monitoring is vital to prolonging a well's life; parameters to be monitored vary from one field to another, depending on its critical characteristics.

*Does the geothermal industry within East Africa have in place selection criteria to facilitate the choice of well casing and cement type? if yes, what criteria is it?* Casing sizes and materials are chosen following the same standards as in the oil and gas industry by considering the well temperature, fluid type and production rates. The African Union's Regional Geothermal Coordination Unit (Unit 2016) provides general criteria to be considered by casing services providers. To encourage a quick yet thorough technical driven

choice of casing in future drilling works, it will be advantageous to consider creation and use of standard work instructions as is the case in the oil and gas industry.

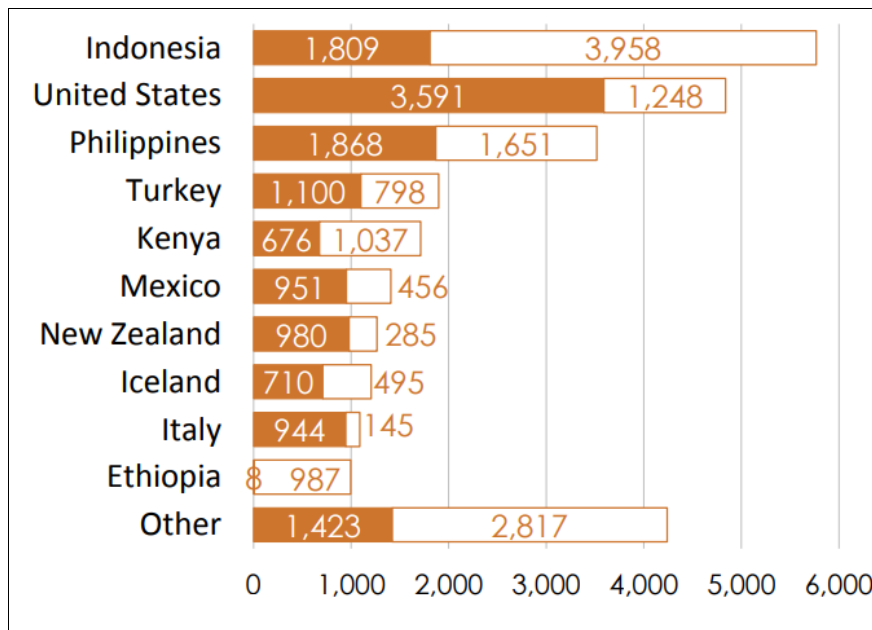
*What is the current effect of a changing well flow rate on the performance of a geothermal production unit?* Over time, due to reservoir depletion during production, geothermal wells will experience a decrease in flow rate due to pressure decline. When this happens in high enthalpy applications, it is common practice to drill new wells in untapped parts of the field or perform well stimulations to boost production, both of which tend to be expensive solutions that could be justified by the energy recovery factor. However, in medium to lower temperature wells where there is less heat energy, pumping systems can be utilized to increase well production as a more cost-effective solution.

This paper will focus on presenting pumping solutions (with focus on Electrical Submersible Pumps (ESP)) to tackle pressure decline problems taking into consideration equipment choice and operation to prolong the life of a geothermal production well including aspects such as, well monitoring. By borrowing from the already proven & tested oil & gas technology for similar applications, and through comparison to similar geothermal applications from different parts of the world, the outcome of the paper will be to establish the applicability and benefits of using ESPs for geothermal production in East Africa. The resultant target will be to create a work flow that can be consulted by in-country technical teams for pump selection in order to improve well performance and efficiency. These findings will lend deeper understanding to the current well production optimization practices regionally and how East African geothermal operators can obtain a positive knock on effect in increasing the amount of energy that is harnessed from their fields.

## **1. Introduction**

Geothermal energy is derived through heat transfer (by conduction or convection) from the earth's crust to water that has seeped into underground reservoirs. In instances of shallow reservoirs, the water may break through to the surface in the form of hot water, dry steam or more commonly a mixture of both. Extensive targeted well drilling into the earth is required to access the resource in the case of deep reservoirs, to supply large electricity generating plants. Energy available for work is fundamentally assessed by the temperature levels in the regions of interest. These exist in three categories; high ( $>180\text{ }^{\circ}\text{C}$ ), intermediate (between  $100\text{ }^{\circ}\text{C}$  and  $180\text{ }^{\circ}\text{C}$ ) and low (between  $30\text{ }^{\circ}\text{C}$  and  $100\text{ }^{\circ}\text{C}$ ). By harvesting the heat, geothermal steam is then used to drive steam turbines which power generators to produce electricity.

Considered a clean source of energy, geothermal energy production has the smallest land footprint of any major power source. One of the main advantages it has over other renewable energy sources such as wind and solar energy is that it is not subject to the same energy fluctuations as they are. Figure 1 below shows the top countries with installed geothermal capacity at present. Worldwide, geothermal applications are a mixture of high, moderate and low enthalpy applications. For instance, Denmark and France are low enthalpy regions while Indonesia has high enthalpy fluids. On the other hand, a mixture of medium-low enthalpy resources is found in Turkey.



**Figure 1: Geothermal Installed Capacity 2018 And Future Projects by 2020**(International Geothermal Association, (D. P. Omenda 2018)

Zooming in to Africa, Kenya and Eritrea's fields are high enthalpy regions whilst Ethiopia and Rwanda have medium to low temperature potential. Kenya has the highest installed geothermal capacity of 600 MW at Olkaria field and another 140 MW from Akira power plant is in the pipeline (World Energy Council 2016). Both high and low enthalpy geothermal potential exists in Ethiopia's main Rift Valley and Afar depression with currently 7.2 MW installed at Aluto Langano and a future 500 MW planned at Corbeti.

High enthalpy wells (above 180 °C) tend to be self-lifting with satisfactory production rates at existing reservoir pressures due to the high steam to water ratio, with the steam creating a gas lifting effect for the water. During the late stages (and the start, in commonly medium-low temperature wells) of production, there is decreased well deliverability. This is due to increased pressure drop at the producing wells interface because of increased fluid extraction rates. Decreased well deliverability leads to decreased power output and plant efficiency as there is less heat available to do work.

The challenge lies in how to handle this well performance issue of changing flow rates and its effect on the performance of the geothermal production unit, while keeping the project economically viable.

Drilling new wells in other parts of the reservoir may prove even more detrimental to the pressure loss effect through wells' interference (Lloyd D. Mann 1978). Historically, pumps have been used especially in medium-low temperature fields, commonly line shaft pumps in places like the USA. Today, with advancement in pump technology, there is increased use of ESPs in locations with enthalpy similar to East Africa such as Turkey due to increase in the number of moderate-temperature applications that are coming online. Countries such as Rwanda, Zambia and Uganda that are also medium-low temperature regions have hot spring temperatures ranging from 60 °C to 210 °C (P. A. Omenda 2013), ranges within which ESPs can operate efficiently. High temperature fields may also have regions where the temperatures are slightly lower making ESPs applicable to them too.

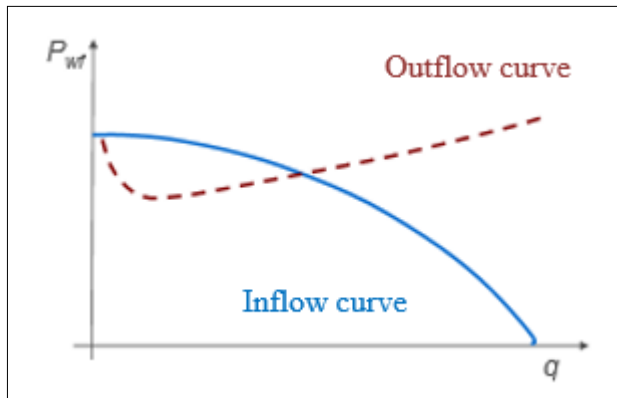
The next sections will focus on pump usage for declining pressure applications with an aim of introducing the technology, advantages and applications worldwide that can be implemented in East Africa.

## 2. Artificial Lift Pumping Solutions for Geothermal Wells

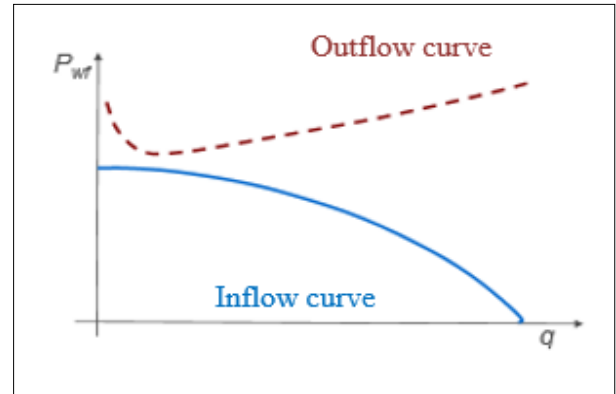
Surface production of a fluid from a reservoir depends on the ability of the energy from the reservoir system (expressed as pressure on an inflow curve) to match the pressure required to lift the fluid to the surface at the desired wellhead pressure (expressed as an outflow curve).

Wells flow naturally at the rate where the inflow curve intersects the outflow curve (see Figure 2). Inflow pressure losses occur due to reservoir depletion or frictional losses during fluid flow within the reservoir. There are also frictional losses in the production tubing and at the perforations in the case of a cased hole.

When the pressure losses or general fluid column weight are such that the outflow curve pressure demands exceed the inflow curve (see Figure 3), the well will not start and (or) flow naturally. Pressure losses can also lead to decreased flow rate over time where natural flow already existed.



**Figure 2: Well Flows Naturally**



**Figure 3: No Startup or Natural Flow**

Artificial Lift methods are utilized in such situations:

- Pumping methods are used to boost the system inflow pressure to induce well start up and (or) natural flow or to increase the existing well flow rate.
- Gas lifting is applied to lighten the fluid column thereby decreasing the outflow demands of the system.

Pumping systems are the appropriate choice for geothermal applications, the most common being line-shaft pumps and ESPs both of which are discussed in detail in the sections that follow. The following advantages are attributed to use of pumps in geothermal applications:

- They are utilized both downhole to get the fluid to the surface and at surface to increase the wellhead pressure to maintain pipeline flow.
- Inflow pressure from downhole pumps boosts well flow rates for increased energy recovery.
- Pump pressure boost also helps to keep the water pressurized. This increases the water's boiling point to keep single phase flow and additionally prevents gases such as carbon

dioxide (CO<sub>2</sub>) from coming out of solution. CO<sub>2</sub> has corrosive and scale forming effects on well casing and production tubing (Tevfik Kaya 2005).

## **2.1 Line-Shaft Pumps**

A downhole pump assembly is driven by a surface located motor whose torque is delivered via a vertical line shaft, which can operate up to 250°C. The main advantage of using this system is the high motor efficiency because it is operated in open air. This also eases troubleshooting and repair in case of motor failure.

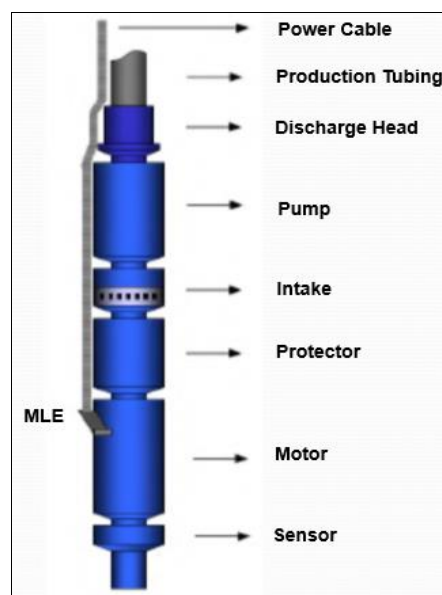
The greatest limitation of these pumps is the line shaft which is best suited for operation in vertical wells and this in turn limits their installation depth.

When considering the well trajectory, ESPs allows greater flexibility for the operator. They operate in both vertical and deviated wells because the entire system is submerged including the power motor (below the pump), which eliminates the need for a line shaft. The system generally passes through trajectories up to a maximum of 6 deg/100ft and operates within 1deg to 3deg/100ft. This means that ESPs also have greater margin with the installation depth. They additionally run up to 3500 rpm thus offering higher flow rates than line shaft pumps.

Given their versatility in comparison to line shaft pumps, greater detail will be offered about ESP systems and their geothermal applicability.

## **2.2 Electrical Submersible Pumps (ESP)**

ESP systems consist of a submersed centrifugal pump with an intake through which fluid enters. It is run by an electric motor installed below the pump as shown in Figure 4.



**Figure 4: Electrical Submersible Pump System**

Main components considered during ESP system selection are the pump, motor and cable, explained in detail in the next sections.

### 2.2.1 Pump

Standard ESP pump outside diameter (O.D.) sizes range from 3" to 11", pumping up to 153kg/s with efficiencies of 70% - 80% at the best efficiency point. They are cable of pumping both single and two-phase flow up to an average maximum of 25% gas volume fraction (GVF). With the use of gas separators and handlers, this fraction can be increased up to 75%.

The pump is made of several stages stacked on top of each other, each generating head whose sum determines the lift potential of the pump. A stage is made up of an impeller located in a diffuser which has an upper and lower thrust washer. A stage has either radial, axial or mixed flow. During operation, the impeller rotated by the shaft transfers kinetic energy to the fluid. The fluid is thrown against the diffuser's walls converting the kinetic energy to potential energy (the head developed by the pump).

In the floater pump configuration, an impeller is free to move up and down the shaft limited by the upper and lower part of the diffuser, with the thrust generated being handled by the thrust washers. Impellers are keyed to the shaft in compression pumps. To overcome the weight of the shaft and lift the impeller off the lower part of the diffuser in this configuration, shims are used to lift the shaft which allows the thrust from each stage to be transferred to the shaft. The shaft in turn transfers the thrust to the thrust bearing in the protector.

Each pump is designed with a specific recommended operating flow range (ROR) within which operating efficiencies can go as high as 78% at the best efficiency point. The pump will operate in up-thrust or down-thrust above and below this range respectively which will reduce its efficiency and run life.

Standard ESP pumps' run-life can be extended in aggressive well fluid environments by designing systems with carefully selected materials for the pump stages, bearing configuration and housing.

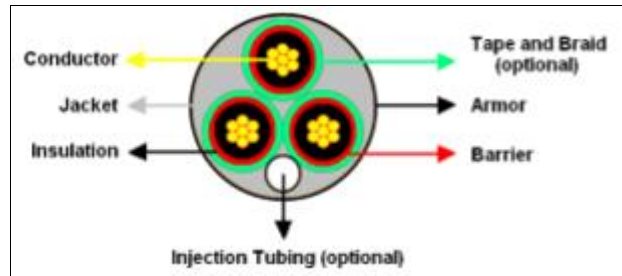
### 2.2.2 Motor

Standard ESP motors are 3-phase, 2-pole, squirrel cage induction motors (Luis Fernando Lobianco, Wahyu Wardani 2010). The motor converts three phase AC power into mechanical power to create torque which is transmitted to the pump via the motor shaft. The motor is composed of a stationary stator housing surrounding a rotor. Alternating current (up a maximum of 4000V) is applied to the stator winding via the motor pothead thereby creating a changing magnetic field which in turn induces an alternating current in the rotor winding. This current subsequently creates a rotor magnetic field. The rotor magnetic field is continually trying to synchronize with the changing stator magnetic field (albeit with slip) which causes the rotor to rotate and create the system's shaft torque to drive the pump.

Standard application motors options exist that can handle temperatures up to approximately 150°C, providing up to 1500 HP at 60Hz with a maximum O.D. size of 7.38". There also exists a plug-and-play family that has a maximum O.D. of 5.62" handling up to 177 °C, providing 900HP at 60Hz (Luis Fernando Lobianco, Wahyu Wardani 2010). Through technology advancements, there are high temperature series of equipment specific for applications such as geothermal, that have been installed (with recorded success) in downhole temperature conditions up to 218 °C providing up to 321HP.

### 2.2.3 Downhole Cable

Figure 5 shows a typical ESP cable design. For all applications, the cable components shown below are chosen taking into consideration the well temperature, reservoir fluid type, required current and gas presence.



**Figure 5: Typical Cable configuration (Luis Fernando Lobianco, Wahyu Wardani 2010)**

The armor provides protection against mechanical damage. In harsh environments, monel and stainless-steel armor are used to protect against other external damage such as corrosion. For geothermal applications, the insulation must be carefully selected to protect the ESP system against electrical failure. Oil companies such as Schlumberger utilize high temperature nitrile or EPDM (Ethylene Propylene Diene Methylene) known for their great performance in geothermal wells. Standard industry cables can handle up to 177 °C which can be extended to 220 °C if a lead layer is applied over the insulation. Lead also prolongs the life of the cable in aggressive environments by withstanding chemical attack and gas decompression in gassy wells.

### 2.2.4 Well Monitoring

It is recommended to install a sensor with the ESP system which will be used to transmit well parameters such as bottom-hole temperature, flowing bottom-hole pressure, intake and discharge pressure, motor voltage and current. Each parameter plays a role in giving an indication of the health status of the ESP. For instance, a sudden increase in motor current may be indicative of a stuck shaft. Increased gas production in the well can lead to symptoms such as decrease in motor current drawn.

Surface panels such as variable speed drives (VSD) are used to increase or decrease the pump flow rate by increasing or decreasing the system's operation frequency respectively. Gauge parameters can be retrieved from the surface panel (directly or remotely) for monitoring and troubleshooting purposes.

### 2.2.5 Worldwide Applications

There is long history of ESP use in geothermal wells in the USA (California and Utah). Their applications are growing in number especially in Turkey, where fields notably have similar medium temperature ranges like in some parts of East Africa.

A demonstration of one such successful installation is in the Aegean region of Turkey. The fluid is non-corrosive or abrasive and has a bottom hole temperature of 161°C. Technical well details are provided in Table 1.

**Table 1: Well details, Example from Germencik, Turkey**

Parameter	Value
Well depth	2071 m
Pump depth	600 m
Casing OD	9 5/8"
Tubing OD	6 5/8"

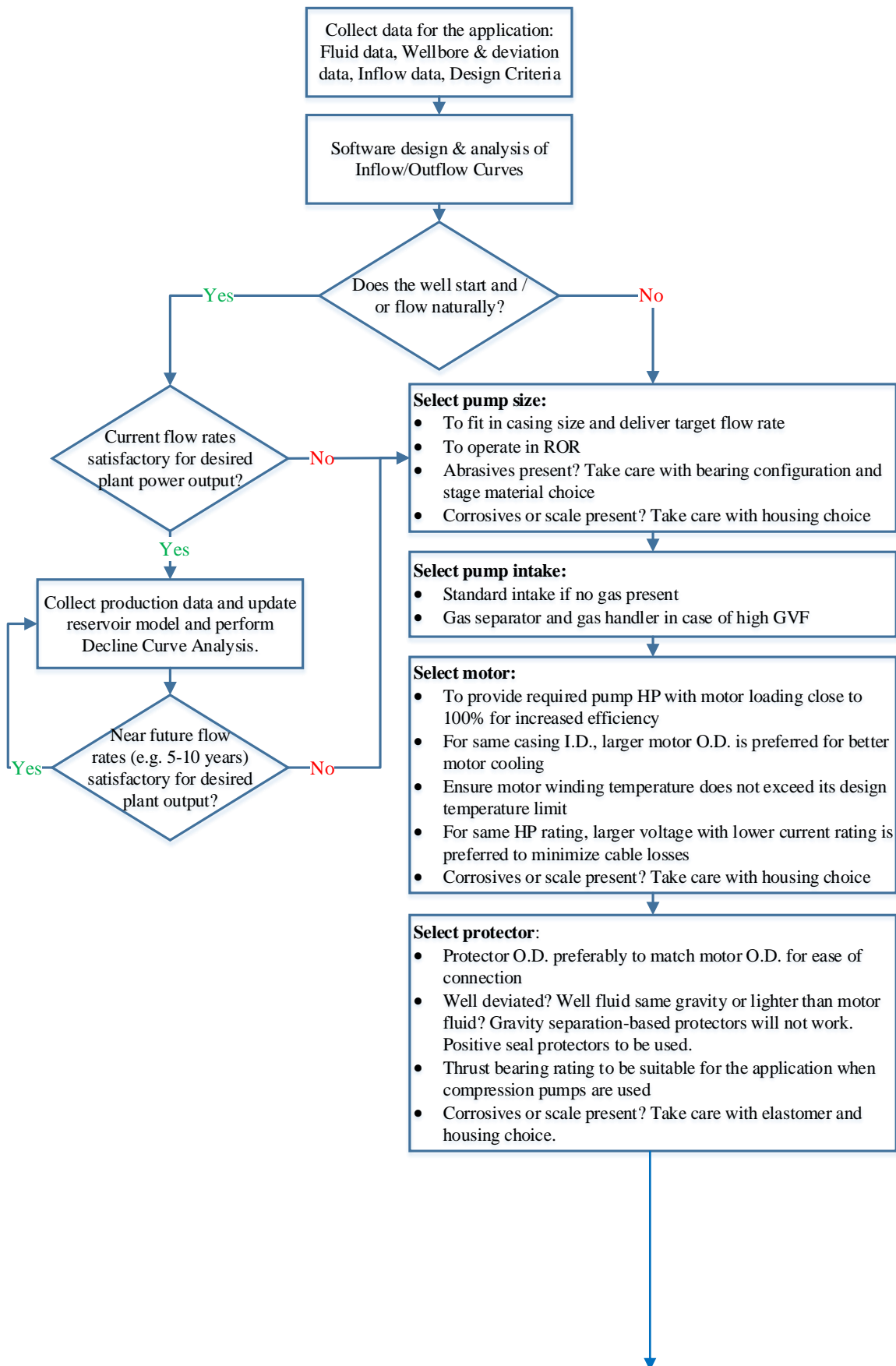
The well is being produced by a 7" pump and ran by a 1550KVA VSD combined with a 1000KVA step-down transformer (Technical data provided by Schlumberger, Turkey). The average motor winding temperature recorded over a 6-month running period is 168 °C which the ESP has been able to withstand. Data in Table 2 extracted from the gauge for well monitoring use, shows that flow rate stability is achieved by use of ESP.

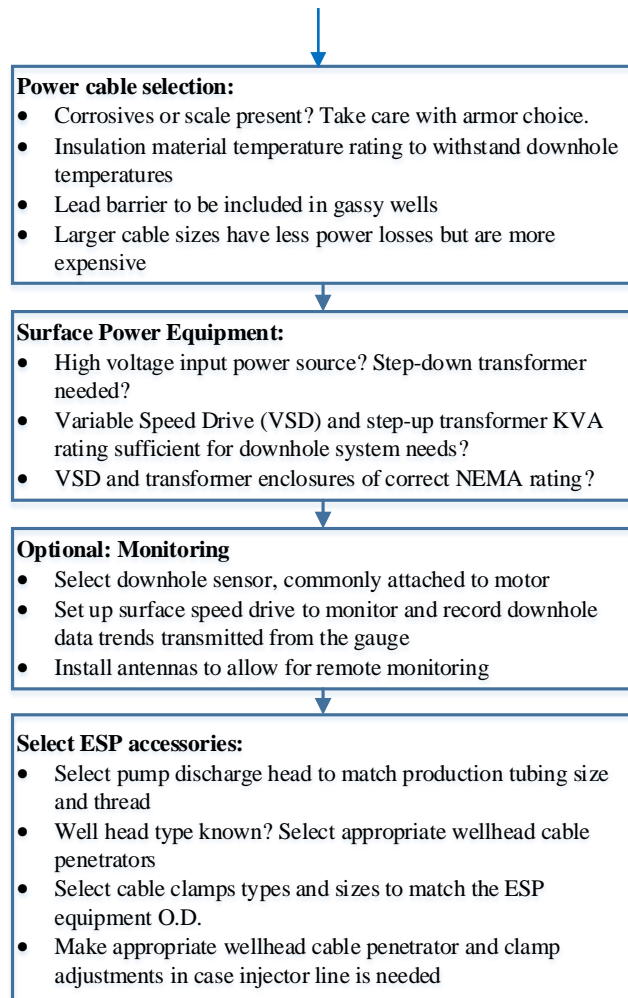
**Table 2: Well Monitored Data**

Time/Date	Pump Re quire d (kW)	Frequency (Hz)	Voltage (Volts)	Current (Amps)	Flow (m3/h)	Wellhead Pressure (Bar)	Wellhead Temperature (°C)	Steam Pressure (Bar)	Steam Temperature (°C)
19 July 2018 20:00	258.0	57	372	485	260	7.2	155.1	7.0	154.1
20 July 2018 20:00	258.9	57	372	489	278	7.4	155.8	7.0	154.4
21 July 2018 6:00	258.5	57	375	4879	276	7.0	155.4	6.5	154.2
21 July 2018 20:00	259.6	57	376	490	280	6.7	155.3	6.3	153.7
22 July 2018 6:00	258.8	57	374	487	284	6.7	155.1	6.2	152.7
22 July 2018 20:00	259.2	57	375	490	290	6.7	155.0	6.2	153.7
23 July 2018 6:00	258.4	57	376	489	288	6.7	155.1	6.2	153.8
23 July 2018 20:00	258.7	57	371	490	293	6.8	155.2	6.3	154.0
24 July 2018 6:00	258.4	57	372	488	283	6.8	155.2	6.3	154.0
24 July 2018 20:00	157.1	57	377	490.1	289	6.8	155.3	6.3	153.8
25 July 2018 6:00	252.9	57	377	490	294	6.8	155.3	6.3	154.0
25 July 2018 20:00	259.1	57	377	491	285	6.8	155.3	6.3	153.9
26 July 2018 6:00	258.2	57	375	490	292	6.8	155.5	6.3	154.0
26 July 2018 20:00	258.9	57	373	490	284	6.9	155.4	6.3	153.9
27 July 2018 6:00	258.2	57	375	489	311	6.6	157.0	6.3	151.9
27 July 2018 20:00	258.4	57	376	4899	300	6.8	155.5	6.3	153.9
28 July 2018 6:00	258.3	57	376	490	290	6.8	154.9	6.3	154.0
29 July 2018 6:00	258.5	57	376	490	281	6.8	155.6	6.3	154.1
30 July 2018 6:00	258.5	57	376	490	276	6.6	155.5	6.2	153.7

### 3. ESP Selection Criteria

Successful adaptation of ESP technology to a well is highly dependent on proper equipment sizing and material selection. The chart presented below demonstrates oil and gas industry recommended steps to be followed when designing an ESP system for a given application.





#### 4. Conclusion

In geothermal applications, well flow rate changes occur in the life of a producing field and have a direct impact on the plant power output. Low or declining rates due to declining reservoir pressure result in decreased plant power output.

Drilling new wells has previously been applied as one of the solutions to increase a field's production. Not only is it an expensive campaign especially in medium to low temperature fields but it may also lead to increased pressure losses through wells' interference. The faster and more cost-effective solution proposed and currently in use is to lift such wells artificially using pumps to boost downhole pressure to increase well flow. Due to the limited performance of line shaft pumps in deviated or very deep wells, this paper has focused on presenting use of ESPs in geothermal wells with the following selling points:

- Applicability in straight, deviated and deep well applications
- Large flow rate ranges
- Use of VSDs give the operator control of production (by regulating the well flow rate) which in turn gives a level of control in the power plant output.

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