

# Electrical Submersible Pumps for Geothermal Applications

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## ABSTRACT

The use of sustainable energy has considerably increased during the last decades and it will continue growing as a consequence of the governmental incentives focusing on a low-carbon society.

One of the most promising sources of renewable energy is geothermal. This source of energy is currently used in 24 countries to produce electricity and in more than 72 countries geothermal energy is directly applied for heating, bathing, etc.

In a geothermal project, pumping is often necessary in order to lift the hot brine to the surface, to increase the fluid pressure or simply to move the fluid from one place to another in the surface.

The proper design and selection of the pumping technology is an important step to ensure a long run life of the geothermal system and to reach the economical objectives of a geothermal project.

Electrical Submersible Pump (ESP) is one of the artificial lift technologies that can lift geothermal hot brine. In this paper, the current and future status of this technology, its advantages and limitations are introduced and explained.

## Introduction

Currently the world puts a strong focus on stimulating “green energy” to decrease our dependence on fossil fuels and to cope with the global warming by decreasing greenhouse gas emissions.

*“Climate change concerns coupled with high oil prices, peak oil and increasing government support are driving increasing renewable energy legislation, incentives and commercialization.”*

(from United Nations Environment Programme).

The main forms of renewable energy forms are wind power, hydroelectricity, bio fuel (bio fuel/mass/gas), solar power, tidal power, waste water (chemical process) and geothermal heat. The focus of this paper is on geothermal energy considering it is among the cheapest options.

By looking at the geothermal map of Europe (fig.1), it can be realized that there are a lot of potential areas that can be used as a source of geothermal energy which can be translated either into heat or electric generation though EGS (Enhance Geothermal System) or ORC (Organic Rankine Cycle).

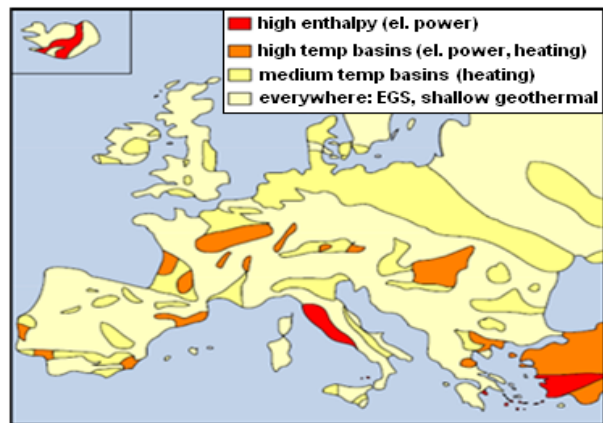


Fig. 1 - Geothermal map of Europe

The definition of geothermal energy is the energy contained as heat in the Earth's interior. In order to use this energy, production wells are drilled in specific areas on the earth where geothermal brine flows naturally and/or they can be lifted by using an artificial method i.e. pump.

Pumping is often necessary in order to get geothermal fluid to surface. Pumping is sometime required to increase pressure or move the fluids from one place to another place once they are on the surface. Line shaft pump and electrical submersible pump are the two common technologies that are widely used in geothermal application.

## Electrical Submersible Pump

An electrical submersible pump (ESP) system consists of a multistage down hole centrifugal pump, a down

hole motor, a protector section (also called seal) between the pump and motor and an electrical cable extending from the motor to the surface power supply. A variable speed drive can be used to regulate the flow rate and ensure that the electrical submersible pump is running within its recommended operating range. However, the standard electrical submersible system is limited to a bottom hole fluid temperature of 150 deg C and the *hotline 550* family can withstand a bottomhole fluid temperature up to 218 deg C, while above this temperature, the ESP can't longer be used as the steam will be produced instead of hot water/liquid.

One of the important factors that defines the accelerated investment in geothermal will depend on the development of a pump technology that is able to provide a high flowrate at high temperatures.

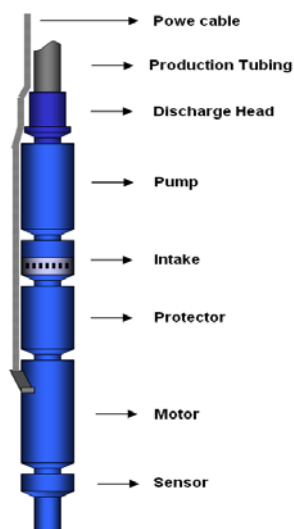


Fig. 2 – Typical ESP string

## Pump

An electrical submersible pump is built from several stages stacked together in a housing. Each stage consists of an impeller which rotates together with the shaft, and a diffuser which contains the impeller and converts the kinetic energy from the impeller into potential energy, creating the head/pressure that allows the fluid to be lifted.

The stages can be constructed in floater and in compression types. In the floater configuration, in no flow condition, the impeller sits on top of diffuser while in operating condition the impeller has the ability to move freely in the diffuser, depending on the thrust acting on them. Although they have a simpler construction, floater pumps have a defined operating range and can wear the downthrust washers when operated out with this operating range in low flow conditions. In the compression configuration, the impellers are all stacked together so they move as one and the shaft on which they are keyed too is shimmed

to the protector so that all the impellers are lifted slightly and all the down thrust loading is taken on the thrust bearing which is located within the protector housing. Hence, this configuration can safely operate far below the recommended operating range. However we need to ensure sufficient flow to assist motor cooling.

Schlumberger portfolio has pumps which can produce up to 14000 m<sup>3</sup>/day or approximately 160 l/s. They are available in several configurations to provide the flexibility and certain features to accommodate a variety of applications.



Fig. 3 –Illustration of an ESP radial flow stage

The standard housing metallurgy is carbon steel with possibility to be coated. For extreme corrosive environments, housing metallurgy is 9Cr-1Mo with head and base made of 316 stainless steel or 22Cr duplex stainless steel. The material of the stages can be the standard Ni Resist or 5530 material, the latter with improved performance in erosive conditions.

The bearings and sleeves selection process is normally a compromise between the hardness, that helps to prevent erosion from fines and debris, and brittleness, which tends to break bearings. In case of sand presence, then the bearing material should be chosen to be resistant to sand abrasion.

There are many possible materials for bearing and sleeves. Standard abrasion resistant pumps use zirconia bearings and sleeves. However harder materials such as silicon carbide and tungsten carbide will be use as required. The bearings can be located only in the head and in the base of the pump for wells with no abrasion problems, spaced at every certain number of stages throughout the pump or at every stage in a full bearing housing for extreme cases.

## Protector

The main functions of the protector are (1) to act as an insulator keeping the well fluid out of the motor; (2) to carry the downthrust from the pump; (3) to couple the torque developed in the motor to the pump and finally (4) to equalize the pressure between the wellbore and the motor.

There are three main types of protectors chambers: the labyrinth, the positive seal or bag and the metal bellows.

The labyrinth design uses the difference in density of the motor oil and the fluid in the well to keep them apart even if they are in direct contact with each other. The well fluid is normally immiscible with the motor oil so, although there is direct contact, there is no tendency to contaminate the motor oil. It is important to notice that the motor oil is always selected taking the well fluid specific gravity in consideration. In case of the well fluid is lighter than the motor oil, then this kind of protector can not be used. Labyrinth protectors provide excellent results in water wells, are cheaper to manufacture and can be reused. However, it is not recommended for wells with a deviation higher than 45 degrees.

The positive seal design use bags made of high performance elastomer (chemraz, aflas, vitton, HSN) that are able to withstand the extreme downhole environments typically encountered. The bag keeps the well fluid on the outside and the clean motor oil on the inside and it expands or contracts to accommodate the change in volume. In this kind of protector, there is no contact between the motor oil and the well fluid, hence there is no restriction in the well fluid specific gravity and it is suitable for both vertical and high deviated wells. However, high temperatures and high contents of H<sub>2</sub>S can attack the elastomer.

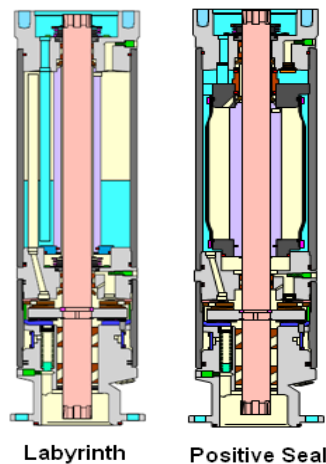


Fig. 4 – Types of protectors

The third type of protector is called metal bellow. It operates using the same principle as a positive seal, however, instead of using a bag made of elastomer, metal bellows replaces the elastomer. This extends the maximum operating temperature limit far beyond the elastomer bag type with the advantage that metal bellows can withstand chemical attacks.

The *hotline 550* advance protector has metal bellows as optional. The advance protector is equipped with a check valve that allows well fluid to get in the bellows if the oil contraction exceeds the protector oil capacity. The check valve is likely to operate while pulling out of the well.

Practically all the protectors nowadays are modular. In this case, the protector is made by adding up labyrinth

or/and positive seals or metal bellow chambers to provide redundancy in case one of the chambers fails. Labyrinth chambers can be added in series and bags or metal bellow chambers can be added in series or parallel. For example a protector type LSBPB means labyrinth series bag parallel bag. It is also common for high horse power motors to use dual protectors, for example, two LSBPB in tandem which increase the area for expansion and which has a larger oil volume. As a result there will be an increase in the reliability of the system.

## Motor

The electrical motors for use with electrical submersible pumps are typically Alternating Current (AC), 3 phase, two poles, squirrel cage induction motor. A motor consists of one or more sets of stator and rotors assembly. For each stator a wire is carefully hand wound around the stator laminations in three phases. Each rotor within the rotor assembly is also made of laminations that create the iron core. Inside each lamination slot there are copper bars with supporting copper end rings. When energized, the stator will generate a magnetic field that interacts with the rotor magnetic field bringing the rotor almost into synchronization with the stator's field.

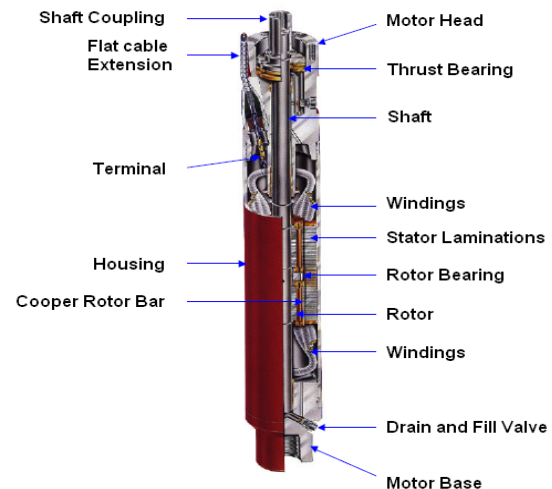


Fig 5 –ESP Motor components

The applied voltage varies linearly according to the running frequency. Because of that the same motor can have different nameplates (voltage, current, horse power) at 50 Hz or 60 Hz, however the voltage to hertz relation is always constant. At the top of the motor there is a thrust bearing whose purpose is to hold the weight of the entire rotor string. The interior of the motor is filled with non conductive dielectric oil.

Typically, the voltage in an electrical submersible pump motor can vary from some hundreds of volts for small motors up to around 4000 V, which is currently the limit for the insulation at the pothead region. Higher voltage motors are preferred to reduce the amperage,

the recommended cable cross-section and the cable voltage drop.

The motor cooling is performed by the well fluid running along the motor housing. In this case, the motor heat is transferred to the fluid cooling the motor. Therefore, an electrical submersible pump must be placed above the well perforations or region of inflow. If this is not the case, then a shroud must cover the motor to assure that the well fluid will cool the motor housing before reaching the intake.

The standard motor available in today portfolio, called *dominator*, can withstand bottomhole temperatures up to 150 deg C and the highest available power is 1500 HP at 60 Hz. In this family, the maximum external diameter of the motors is 7.38 inches. In order to control the installation risk, in standard applications Schlumberger has developed the *maximus* technology with plug and play capabilities and already pre-filled from factory. This family of motors can handle bottomhole temperatures up to 177 deg C, however it is limited to 900 HP at 60 Hz because, in this case, the maximum external diameter of the motors is 5.62 inches. In higher temperature applications the *hotline 550* family is available. This family can provide a maximum of 320 HP at 60 Hz and can handle bottomhole temperatures below 218 deg C. In this family the maximum external diameter for the motors is also 5.62 inches. The reason for the lower power availability in the *hotline 550* family is because, in the both *maximus* and *dominator* families, two or three motor sections can be attached in tandem configuration increasing the total power. However, it is not possible in the *hotline 550* family.

	Standard System	HOTLINE System	HOTLINE 550 System
Maximum Bottomhole Temperature	300 degF (150 degC)	350 degF (177 degC)	425 degF (218 degC)
Maximum Motor Winding Temperature	400 degF (204 degC)	550 degF (288 degC)	550 degF (288 degC)
Motor Insulation	KAPTON™/PEEK	proprietary insulation	proprietary insulation
Motor Bearing	SLK	SLK	SLK
Motor Elastomer Material	HSN/AFLAS™	Chemraz™	Chemraz
Protector	modular protector	modular protector	advanced protector
Protector Positive Seal Chamber Design	HSN/AFLAS bag	AFLAS bag	metal bellow
Protector Radial Bearing	bronze	bronze	ceramic
MLE Configuration	KELB/KEOTB/ELB	KELB/ELB	KKPLB
Power Cable	various	ELB/ELBE	ELB/KKPLB
Motor Pothead	standard	special design (HOTLINE design)	special design (HOTLINE 550 design)
Pump	standard	special design	special design
Motor Oil	Reda No. 5	Reda No. 7	Reda No. 7

Table 1 –ESP summary by family

## Monitoring equipment

A downhole sensor provides the engineers with powerful information to perform analysis, diagnosis and optimization of the electrical submersible pump system and inflow conditions.

For high temperatures there are available two types of downhole sensors.

The first and preferable option is a standard sensor which is coupled below the electrical submersible pump and is able to measure the following parameters: temperature, pressure and three-axis vibration at the different points (annulus, intake, discharge head and sandface), motor winding temperature, motor three-axis vibration, motor y-point voltage and current leakage. This sensor gives the capability to perform nodal analysis to provide a better monitoring and or surveillance for the performance of the electrical submersible pump. The data transmission to the surface is performed by superimposing the electrical signal on the electrical submersible pump power cable therefore no additional cable is necessary. This kind of sensor can withstand temperatures up to 150 deg C and the transmission rate varies from 6 s to 31 s according to the parameter.

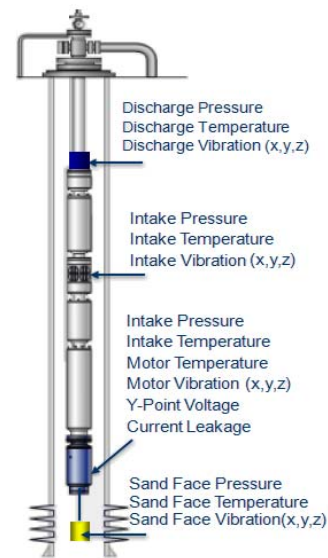


Fig. 6 –ESP Downhole Sensor

Alternatively, for higher temperature rates there is the possibility to run a fiber optic inside a control line along the tubings and the electrical submersible pump string. In this case, the parameters to be measured are pressure, acoustic and temperature, this last parameter is measured every meter along all the wellbore. The system is rated to 300 deg C.

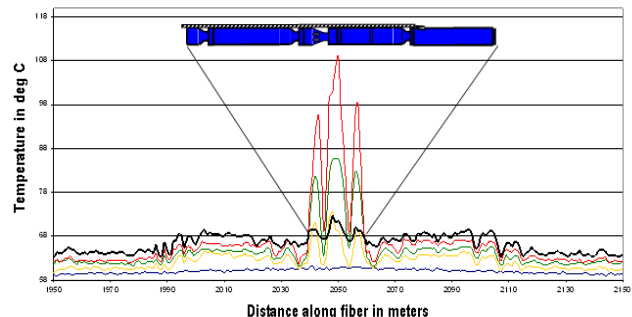


Fig. 7 – Schlumberger Sensa fiber optic sensor output



## Cable

There are innumerable factors that must be taken in consideration while selecting a cable for electrical submersible pump applications:

- Motor voltage and current;
- Well temperature;
- Downhole pressure;
- Gas migration;
- Corrosion resistance;
- Damage resistance;
- Cost.

In addition to that, there is a wide range of materials with different properties for the various components of a cable. This fact leads innumerable possibilities of cable profiles.

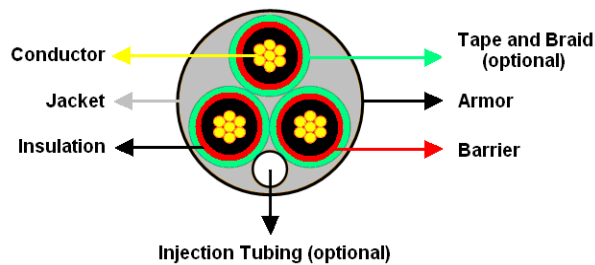


Fig. 8 –Cable components

The armor is the most external component. It provides mechanical protection and it protects the cable against swelling. The standard materials for the armor are: monel, stainless steel (316) and galvanized steel. Monel has the best corrosion resistance followed by stainless steel.

Schlumberger has designed two families of cable for high temperature environments: the *redamax* and the *redalead* families, which can be built in round or flat configuration.

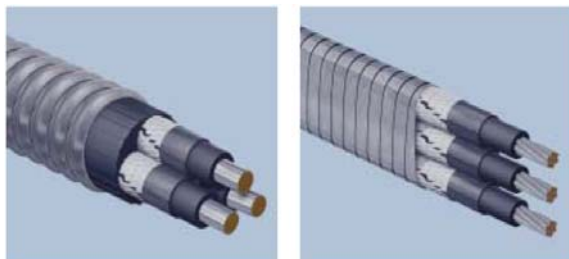


Fig. 9 – Example of *redalead* round and flat cables

The first family can use two different materials for the insulation: high temperature nitrile or EPDM (Ethylene Propylene Diene Methylene), a rubber compounding with excellent high temperature properties. The option to have tape and braid barrier provides some degree of protection against gas decompression effect. The *redamax* temperature limit varies from 121 deg C up to 177 deg C.

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The *redalead* family has a higher temperature rating that varies from 202 deg C up to 220 deg C. It also utilizes EPDM insulation and it has an impervious lead barrier that prevents failure from chemical attack and gas decompression, ensuring superior performance in high-temperature wells with hostile environments.

A Motor Lead Extension (MLE) is a special flat cable that is spliced to the main cable some meters before it reaches the beginning of the electrical submersible pump string. This short section requires a premium cable because it is submitted to casing friction during the run in hole process, it is submitted to a higher wear and corrosion in the intake region and it is subjected to higher temperatures.

CONDUCTOR	SOLID	COMPACTED STRAND	STRANDED		
INSULATION	POLYPROPYLENE COPOLYMER	EPDM RUBBER			
BARRIER	TEDLAR TAPE	SOLEF EXTRUSION	FEP EXTRUSION	PROPRIETARY TAPE	LEAD
JACKET	LOW TEMPERATURE NITRILE	NITRILE	HIGH TEMPERATURE NITRILE	EPDM	
ARMOR	.025" GSA	DOUBLE ARMOR	.034" GSA	STAINLESS STEEL	MONEL

Table 2–Cable options

## Surface Equipment

Typical surface equipment are: step-down transformer, variable speed drive with motor controller, step-up transformer and downhole sensor acquisition unit.

The variable speed drive is a frequency converter. The input is typically any voltage up to 480 V and the output is a sinusoidal wave at the desired frequency and voltage (always below the input voltage). By using a variable speed drive the electrical submersible pump is able to operate across a wider range because the characteristics of the pump vary according to the running frequency. Therefore, it is possible to change the electrical submersible pump characteristics to match changes in the reservoir parameters or production targets, putting electrical submersible pump always operating near the best efficiency point.

A step-down transformer is necessary if the input voltage is higher than the variable speed drive voltage rating and a step-up transformer is needed if the electrical submersible pump surface voltage is higher than the variable speed drive output voltage.

Variable Speed Drives are typically available in different models up to about 1500 KVA. For system requirements above 500 KVA it is also possible to use a Medium Voltage Drive (MVD). Medium voltage drives have the same function as a variable speed drive, however they operate in the medium voltage region (above 600V) and because of that they can

decrease internal losses improving the system efficiency. Medium voltage drives have a built in step-down transformer and do not require step-up transformer. The normal output voltage value is adjustable at any value between 0 V and 4160 V while the input value is fixed according to the available power voltage at any value between 480 V and 18.8 kV.

For both variable speed drives and medium voltage drives there are different options of input and output filters and devices available in order to decrease the total harmonic distortion and comply with international standards for instance the IEEE-519 or IEC-1000.

A surface acquisition unit is necessary to filter the signal generated by the downhole sensor and to register the measured values in a memory device.

Modern site controllers integrate the function of a motor controller, variable speed drive controller and surface acquisition unit in a single device. They have standard analogical and digital inputs to communicate with other devices, for example digital well head pressure and temperature sensors. It is also possible to set alarms and trip points for any measured parameter and to connect the site controller to a supervisory system (SCADA) by using a network interface.

### Geothermal Installations in Europe

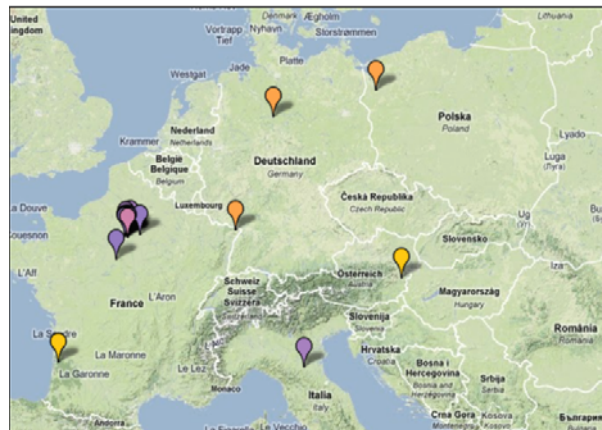


Fig. 10 –Schlumberger ESP installations for geothermal wells in Europe. (note: some sites have more than one ESP)

In Europe Schlumberger performed more than 20 electrical submersible pump installations for geothermal wells in Austria, France, Germany, Italy and Poland. One of the installations was for power generation while all the other involved direct use application for heating purposes whose bottom hole temperature vary from 85 deg C to 141 deg C and the flowrate vary from 400 m<sup>3</sup>/day to 6720 m<sup>3</sup>/day.

### The Soultz Project

The European EGS (Enhanced Geothermal Systems) Project, located in Soultz-sous-Forêts, France, near the French-German border, is a research project

sponsored by European funds. The objective of this project is to produce electricity, by using a 1.5 MWe ORC (Organic Rankine Cycle) conversion module, from the heat contained in a granite reservoir, that was hydraulically and chemically stimulated to improve the initial low permeability. The multi-well geothermal system consists of two lateral production wells, from where the geothermal fluid is produced and a central well for reinjection of the cooled fluid closing the loop. The bottom hole distance from each production well to the injection well is around 700 m and the depth is about 4000 m. Because the artesian pressure was not enough to provide the desired flowrate, it was necessary to install an artificial lift method.

Two pumping technologies were selected: a line shaft pump and an electrical submersible pump.

The line shaft pump was installed in the well GPK2 at a depth of 350 m and it was expected a maximum flowrate of 35 l/s. At the same time a Schlumberger electrical submersible pump was installed in the well GPK4. The electrical submersible pump was expected to operate at a downhole temperature of 185 deg C and the maximum expected flowrate for this well was 25 l/s, however the electrical submersible pump was designed to handle up to 40 l/s. The initial plan was to leave the system running for a test period of 6 months. The brine was very salty and therefore corrosive. Schlumberger provided an electrical submersible string solution with the following characteristics:

- Hotline 550 family equipment;
- 9Cr 1Mb housing material coated with Inconel 625;
- Head and bases made of 25 Cr Duplex Stainless Steel;
- Pump stages material is 5530;
- Advanced protector (labyrinth chambers only);
- Chemraz O-rings;
- Inconel 625 shaft material for the pump and protectors;
- 4130 steel material for the motor shaft;
- Redalead cable, monel, with peek and kapton insulation;
- Fiber optic sensor for temperature;

The electrical submersible pump started successfully within the expected flow rate of 25 l/s. However, after few days the inflow was reduced by half to 12.5 l/s. The electrical submersible pump run for a little more than one year before failing. It is not clear the root cause of failure because the string was not pulled from the well and a dismantle and failure analysis has not yet been performed. One hypothesis is that the low flowrate impacted the motor cooling. As a consequence the motor overheated above its limit potentially melting the internal insulation and causing a short-cut.

For comparison purposes, during the first years the line shaft pump failed three times.

### Hotline 550 Family Record Worldwide

The *hotline 550* family was launched by Schlumberger in 2003 and up to date there were more than hundred installations of electrical submersible pumps from this family, most of them in Canada and Oman. During this

period, there was a huge improvement in run life from an average of 330 days in 2003 to 851 days in 2009.

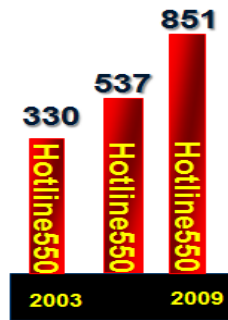


Fig. 11 – Hotline 550 run life (days) improvement since 2003.

### Future Perspectives

The limitation of the motor families that are currently in the market is basically the ability to provide high horse power in a high temperature environment. Schlumberger has performed many researches and it is developing a new hotline family with improved characteristics:

- 7.38 inches motor diameter;
- 250 deg C of bottomhole temperature;
- 1000 HP available power;
- 7kV motor voltage;
- 8kV rated power cable and sensor.

New materials and components were already developed, however they are still under field trial and should be commercialized soon.

### Conclusions

This paper demonstrates that it is viable to use electrical submersible pumps as an artificial lift technology for geothermal applications.

The electrical submersible pump technology was introduced here and its advantages and limitations were presented.

Currently, the ability to provide high horse power in high temperature environments (above 177 deg C) is limited by the maximum motor horse power available in the market (320 HP). However, new materials and technologies are currently under development and field trials. A new family of motors is expected to be launched commercially in the near future increasing not only the motor horse power availability but also extending the its temperature limits.

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