Powerful Production Pumps to lift the Economy of Deep Geothermal Projects

Reliable and highly available production of hot thermal water from deep wells is an essential requirement for running geothermal projects economically. The characteristics of reservoir and wells as well as the availability of a technology to produce necessary amounts of water determine the performance of the power plant and the financial revenues that can be obtained. This is especially true in Germany, where the reservoirs for electricity power generation are deep located with temperatures rarely above 140 °C. The production rate decides the economic feasibility of the projects.

Change of the ESPs at the geothermal power plant in Unterhaching. Due to separate pump garage with a new pump the delay time of the pump exchange was reduced significantly. (Source: Geothermie Unterhaching)■

Pump manufacturers offer various technologies to produce different liquids out of deep wells. These applications are typically used for fresh water wells, the soil watering in agriculture and particularly for the hydrocarbon industry.

Operating conditions within the hydrocarbon industry can be rather complicated and have stringent requirements on materials and techniques. However this means there is a pump manufacturing industry with decades of experiences and know-how to operate pumps at great depths and at high temperatures as well as under harsh well conditions. This industry seems to have solutions for any application or demand, regardless whether it is pumping fluids with high gas content, or containing corrosive substances like hydrogen sulfur or abrasive materials.

The pump industry also has decades of experience worldwide in the production of hot thermal water. There are now hundreds of production pumps operating in geothermal wells producing hot water for district heating and power generation. ■

Technical Principles

There are several techniques for pumping liquids to the surface. The technology used in the geothermal energy sector differs for each manufacturer and application depending on the motor concept. It could use submersible pumps driven by a downhole motor or a surface motor with a long shaft that connects the motor to the pump.

This distinguishes Electrical Submersible Pumps (ESP) from Line Shaft Pumps (LSP). In ESP, a subsurface motor running a submersible pump needs an elaborate sealing system to ensure no water enters the motor.

The motor obtains electricity from a power cable and frequency converter installed above ground. In LSP, the motor is located on top of the wellhead and drives the pump stages with a continuous shaft. Again, a frequency converter is usually used to power the pump. There are different limitations for applications in deep geothermal energy production depending on the motor concept.

Pump speed

In ESP, the downhole motor is cooled by the pumped medium. This means a minimum pump speed is required to adequately cool the pump motor. Under LSP, the speed can be driven continuously and be started with a low speed over ramps. There is no minimum pump speed.

Installation Location and Depth

Depending on the effectiveness of the motor seals, an ESP system can be operated in nearly any installation position or depth. Pumps can also be installed in strongly deviated wells and apart from cost, the size of the pump is the only limitation.

LSP motors can only work in the upper undeviated part of the well. Its limitations are the long shaft, the shaft bearing and its lubrication. Dependent on the transferred input rating, there are also limitations on the installation depth of LSP pumps. Besides the increasing length of the shaft, there is also the hydraulic head and the power increase required, along with a varying water level in the well. The stability of the shaft has to be taken into account. To date, the deepest installation handled by an LSP pump (in a U.S. plant) is 760 meters.

Well Temperature

ESP motors are limited by the operating temperature of their deep location which can be considerably higher than surface temperatures. LSP motors on the other hand only have to cope with surface temperatures, even if downhole temperatures exceed 200 °C. ■

History of ESP and LSP Systems

Armail Arutunoff developed ESP techniques in the 1920s, taking advantage of the early 20th century boom in hydrocarbon production. Since then, the technology of the ESPs has been continuously improved.

LSP is much older and first introduced in the 1870s. However the development of oil lubrication at the turn of the 20th century helped LSPs to gain much wider acceptance. For example, LSPs were much used by farmers in dry regions to pump deep water for irrigation.

Today in the U.S., about 95 % of geothermal plants produce deep thermal water using LSPs. Their reliability in high water temperatures is an important advantage in this market. ■

Requirements

Following an international workshop with geothermal experts and representatives of the pump industry, Molloy et al. (2009) published a pump specification defining boundary conditions for future petrothermal projects. The requirements were very ambitious, especially with respect to production temperatures and pump efficiency and availability.

Nonetheless, the Molloy specification only partially met the general framework for geothermal utilization in the Bavarian Molasse Basin. A pump completely suitable for the high production rates and installation depth of geothermal wells in the Malm reservoir has yet to be developed. The fundamental problem is that EGS reservoirs need pumps capable of handling water at high temperatures, whereas water temperatures in the Bavarian Molasse Basin are relatively low. The Molloy specification requires pumps to be able to handle fluid temperatures of up to 230 °C. In other regions with similar or higher capacity geothermal power plants – e.g. the Binary ORC and Kalina plants – several wells have been drilled. But these wells are relatively shallow – none exceed 5,000 meters – providing a reasonable and economic approach to achieve high availability.

To extract water with temperatures higher than 120 °C in the Bavarian Molasse Basin, much greater well depths are required. However this only produces a production rate of 70 liters per second, which is not economic given the high costs of deep drilling. Moreover, the hydraulic conditions of the wells demand a high subsidence of the dynamic water table. The conclusion is that pumps with a performance of more than 1 MW hydraulic power are required.

These economic and technical requirements bring ESP- and LSP-pump technologies to their performance limits and demand new innovations from the pump industry. LSPs which are not yet installed in the Bavarian Molasse Basin can meet requirements if well conditions and installation depths are right. Up to now primarily production depth was the limitation. However there is an LSP installed in the geothermal project in Insheim, Rhineland-Pfalz pumping to a depth of more than 600 meters. In the U.S., there are LSPs with installation depths of up to 760 meters achieving production rates of over 100 liters per second.

Thomas (2013) published in the journal of the “Association of German Engineers“ VDI Nachrichten the article “Deep Geothermal Energy bring Pumps to its Performance Limits“. This article described experiences of various projects operating in Germany which concluded that pump technology has not yet achieved the required maturity. Herein Thomas (2013) refers to discussions with manufacturers and operators of units installed in wells with

Table 1: *Pump specification matrix with an overview about the most powerful submersible pumps for deep geothermal wells of different manufacturers. This matrix was compiled for a Workshop on pumps within the frame of the Praxisforum Geothermie.Bayern in Munich in October 2013. The matrix was updated for this publication and is based on manufacturer data.*

	Manufacturer	ITT / Goulds	Baker Hughes		Canadian Advanced ESP	Flowserve
	System	Line Shaft Pump	Electrical Submersible Pump			
In General	Type of pump: T>150 °C / Q>150 L/s / head>600 m	**12E or 12 GHH (LSP)**	**WM2800**	**WNE2100**	**CAI 9CSL78000@1800HP TuT**	**QT 14**
	$T_{max (Fluid)}$ [°C]	> 205	175	170	150	160
	Q_{max} [L/s] at a head of 600 m	186	200/160	160	175	160
	installation depth$_{max}$ [m]	760	1,000	900	~[1]	1,000
	Pump Diameter [Zoll/mm]	11 3/4 / 298[2]	10 3/8 / 264	9 / 229	12 / 305	10.63 / 270
	inlet pressure [m_{WS}]	dependent on gas content	30-40 failure criteria, 6-10 bar is necessary	30-40	min. 50 / dependent on Bubble point	50 / dependent on location
	number of stages - head 600 m	36-42	15	20	9	5
Motors	regulating range regulable (via VFD) [Hz]	0-60 (max. 67)	30-60	30-60	45-60[3]	35 - 60 - 40 % / + 20 % BEP
	Motor concept	hollow shaft motor(at surface)	single system	single system	Tandem upper Tandem (TuT)	modular
	Number of Motor segements	1	2	2	2 Tandems parallel (4 Motor segments)	8
	Max operating temperatur [°C]	-	225	225	205	230
	length [m]	2 (above surface)	20	20	about 11 / motor	22
	power name plate [KW]	up to 1,190	1,672	1,672	1,340	1,200
Protector	Type	*not needed as installed above surface*	675/ 875 series	675/875 series	CAESP Piston type[4]	protector integrated in motor
	Bearing Type		enhanced high load	enhanced high load	ceramic lager	separted axial bearings; motor and pump separately
	Filling		mineral-oil	mineral-oil	blocking fluid[5]	special motor oil[6]
	Sealing		Aflas balge+Labyrinth	Aflas balge+Labyrinth	heavy oil and piston sealing	double mechanical seal
Resistance	H_2S content	dependent on gas content	medium	medium	if known at the rigt time: change in the materials	ok
	Low mineralised water < 1 g/L	ok	high	high	ok	ok
	High saline water < 150 g/L	ok	medium	Medium	ok	ok
	High saline water >150 g/L	ok	high	high	-	ok
	Contruction year of the firts pump 'ready for series'	1980	2013	2009	2011[7]	2010
	Delivery time of spare parts	2 - 4 weeks	2 - 3 weeks	2 - 3 weeks	matter of negotiation	--
	Delievery time for a new pump	up to 24 weeks	20 weeks	20 weeks	20 weeks	after consultung
	Operating hours per installed system so far (under full load) [h]	4-5 years		8,500	5,000 [8]	--
	Locations/References	Landau, Insheim, USA[9]	Grünwald	Unterhaching	Kirchstockach, Dürrnhaar	--
	Max.setting depth so far	760	750	900	1,050	--

[1] no limitation, but as deep as possible to minimise thermocycling
[2] with 13 3/8" Casing
[3] frequency controlled, dependent from the whole system. For big pumps about 60-100 % of the production rate
[4] new development in 2014
[5] specification will not be published
[6] with corresponding dielektrical and tribological characteristics
[7] since then continuous developement
[8] up to now maximum lifetime
[9] over 250 (95 % of the geothermal wells) in the US (California, Nevada, Oregon, Idaho, Utah)

groundwater temperatures over 120 °C and production rates exceeding 100 liters per second.
However smaller pumps are running successfully at temperatures up to 100 °C in geothermal projects in Germany. LSP pumps have operated geothermal projects in Insheim and Landau for many years very successfully. But their production rates are below 100 liters per second. ■

The Manufacturers

In October 2013 the manufacturers of pumps for deep geothermal applications were invited to present their most powerful systems within a given specification matrix at a workshop at the Praxisforums Geothermie in Bavaria. The aim was to get an overview about the applied technology and the performance.

The boundary conditions for the specification matrix *(Table 1)* were:

- Production rate more than 150 liters per second
- Temperature of the produced medium above 150 °C
- Installation depth of 600 meters

The manufacturers showed three ESPs and one LSP system. These represented developments of technologies already used in geothermal energy production. The various systems showed clear technical differences. In the case of the LSP system, the performance has to be transferred by increasing shaft length. For ESP systems, motors have to be developed that can cope with high liquid temperatures, and improved seals to prevent water entering the motor and to provide volume for the expanding oil.
The LSP system seems to have the advantage if installation depth is not an issue. In fact, the experiences with installation depth over 700 meters and production rates above 100 liters per second are limited to certain projects in the U.S. For ESPs in geothermal applications, there is experience with installation depths of up to 1,000 meters and production rates of over 100 liters per second. Indeed, the biggest pumps using this technology are installed in Bavaria. However, the lifetime for these installations remains too short and much longer lifetimes are required. The manufacturers said they were already working on improved lifetimes. ■

LSP at the geothermal power plant in Insheim with the motor on top of the well. (Source: enerchange) ■

Outlook

The challenge to design a pump fulfilling the requirements of the Bavarian power plant projects is not yet solved completely. The pump specification matrix shown here shows the status of the technology that can be provided by the pump industry today. However continuous and long term performance of the technology has still to be proven.
LSPs with installation depth up to 760 meters are an option for some Bavarian projects. But to use ESP, further improvements are needed. While the manufacturers are solving some problems, pump lifetime remains a big limiting factor. However it is likely that ESP technology will develop under demand from other industries such as hydrocarbons, and the geothermal industry should benefit from this.
In conclusion, for the economic development of new geothermal projects, the base case requires a pump with references and a proven operational experience of more than one year. The operator needs to be able to run the plant and generate electricity with a standard pump economically. This means the base case has to fit to standard pump technology and not to a prototype. ■

Literature

Molloy, L., Lindsay, M. und Maloney, M. (2009): The Lemelson Meeting: Scoping the Design Criteria for the Global Geothermal Challenge. GRC Transactions, 33.
Thomas, T. (2013): Tiefe Geothermie bringt Pumpen an ihre Leistungsgrenzen. VDI NACHRICHTEN, 46. ■

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