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Industrial Experiences with Downhole Geothermal Line-Shaft Production Pumps in Hostile Environment in the Upper Rhine Valley

Thomas Hettkamp*, Jörg Baumgärtner*, Ricardo Paredes**, Guillaume Ravier+, Olivier Seibel+

* Bestec GmbH, Bismarckstr. 19, 76870 Kandel, Germany

**Frost Consulting Group, 12263 Blackstone Drive, Rancho Cucamonga, CA

+ES-Geothermie, 5 Rue de Lisbonne, 67300 Schiltigheim, France

hettkamp@bestec-for-nature.com

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ABSTRACT

The Upper Rhine Valley is a Graben structure in Central Europe, which extends north-south over 300 km from Mainz to Basel. The Graben is approximately 50 km wide and is shared by Germany, France and Switzerland.

Five geothermal power & heat plants are presently operating within the Upper Rhine Valley, Bruchsal, Soultz, Landau, Insheim and Rittershoffen. Two new projects in Illkirchen and Vendenheim, both close to Strasbourg, are presently drilling demonstrating that there is an economical potential for geothermal in this Graben structure.

All projects but Bruchsal produce at temperatures above 135°C, even approaching 170°C. All of these latter four projects are equipped with an oil lubricated Downhole Geothermal Line-Shaft Pump (LSP) to exploit the geothermal resource. The first oil lubricated Downhole Geothermal LSP in Europe was put in operation in 2007 in Landau, followed in 2012 by Insheim and in 2016 by Soultz and Rittershoffen. In these pumps a lineshaft travels from surface down to the pump stages. It is enclosed in tubing with bearings every 1.524 m. This tubing, the lubestring, is flooded with oil, which once it is used up, is dispersed into the cased wellbore, floats on top of the water level and can be recovered at regular intervals if the annulus of the hot well can be activated to flow artesian. Alternatively, a closed loop lubrication system with an oil return to surface is available, too.

The brine produced in all these geothermal plants in the Upper Rhine Valley is quite similar. It is an Na(Ca, K)Cl rich brine with a fairly high content of dissolved gases, mainly CO_2. The CO_2 content of the produced brines varies between 0.12 to 0.13 in mass percent, therefore the produced brines have to be kept at pressures above the gas break out pressure (GBO) to minimize CO_2 corrosion, which is well-known from the Oil and Gas Industry since a long time. Although the oil lubricated Downhole Geothermal LSPs have to survive in such a harsh and corrosive environment, life cycles of more than 4 years for such downhole pumps are not rare.

The design of the Downhole Geothermal LSPs has evolved over the years, with greater resistance to wear, deeper settings, higher temperatures, greater pump speed variations and longer pump life. In Europe some important lessons have been learnt since this pump technology was introduced into the geothermal market and the pumps have been (and still continue to be) adapted to the local reservoir conditions. Efforts have been undertaken to tailor the oil lubrication, the quality of the used materials as well as the handling of the long pump bodies. For sensitive environments such as the Molasse reservoir in South Germany, a fully closed loop oil lubrication system has been developed. This oil recovery system has been presented to the Bavarian authorities and is ready for approval.

Today these robust Downhole Geothermal LSPs have been installed at depths up to 730 m. A very good overall system efficiency and their high temperature resistance characterize these pumps. Production temperatures exceeding 200 °C are acceptable. Flow rates greater than 180 l/s have been achieved. However, the main advantage of this pump type is, that all sensitive elements such as seals, electrical connections and the motor are on surface, where they can easily be accessed and serviced.

1. INTRODUCTION

The concept and application of a turbine type centrifugal pump in a vertical configuration dates to at least the 1870s. The great shortcoming of these pumps was adequate depth for reaching the water table and the need for such was great in the Western United States which was mostly arid, dry and uninhabitable. Oil lubrication, developed early in the 20th century, allowed these pumps to reach depths of 100-200 meters. By the 1950s, oil-lubricated lineshaft pumps were extremely common, reliable and the preferred method of water well pumping (setting depths to 240-300 m) throughout the Western Hemisphere, the Middle East and elsewhere around the world. With and without oil lubrication, these pumps became common in many industrial applications. The hydrodynamic and thermodynamic considerations to develop a commercially viable geothermal pump have required a number of design changes with actual field experience playing a critical part in the evolution of the Donwnhole Geothermal LSPs. There are currently more than 150+ Downhole Geothermal LSPs in operation throughout California, Nevada, Utah, New Mexico, Oregon and Idaho. The success of the geothermal industry in the United States is directly proportional to the success of these pumps (Frost 2013).

The Downhole Geothermal LSP operates the same as the water well lineshaft pumps developed during the 1st part of the 20th century: the impellers are submerged providing the necessary NSPH. An electrical motor on surface turns an oil-lubricated lineshaft connected to the impellers within the pump's bowls. The number of pump stages determines the amount of head produced. The rotating impellers are sucking the fluid out of the reservoir, the static fluid level drawing down to the dynamic water level. The line

shaft is enclosed in a 3 ½" oil tube with bearings every 1,524 m. The pumped fluid moves in the annular space of the 10 ¾" production casing and the 3 ½" oil tube (see fig. 1).

As a result of reducing head, all vertical pumps will generate at a given speed and flow rate an unbalanced pressure above and below each impeller. This results in a down thrust load which is carried by the motor thrust bearing, but yields a dynamic net elongation of the shafting. Assuming proper tensioning of the lube string, tensioning and down thrust work together to minimize wear. The net elongation of the line shaft (typically referred to RSS or relative shaft stretch) becomes largely a function of setting depth and the head produced by the pump and can be readily calculated, but only at thermal equilibrium. Although all three strings, line shaft, lube string and production casing have similar temperature elongation coefficients, the three components expand at different rates owing to different geometries and boundary conditions. The adjustment (setting) of the impellers must account for this. The adjustment of the impellers is made on the top of the electric motor (see fig. 2). Pre heating the pump, before it is started the first time will help to minimize the effect of different elongations of the three strings. Starting a pump the first time in a well, the impeller setting should be repeated with increasing production temperatures at least two to three times. After a full day of production at nominal speed a last hot spacing is recommended, before the pump will continuously will produce the fluid.

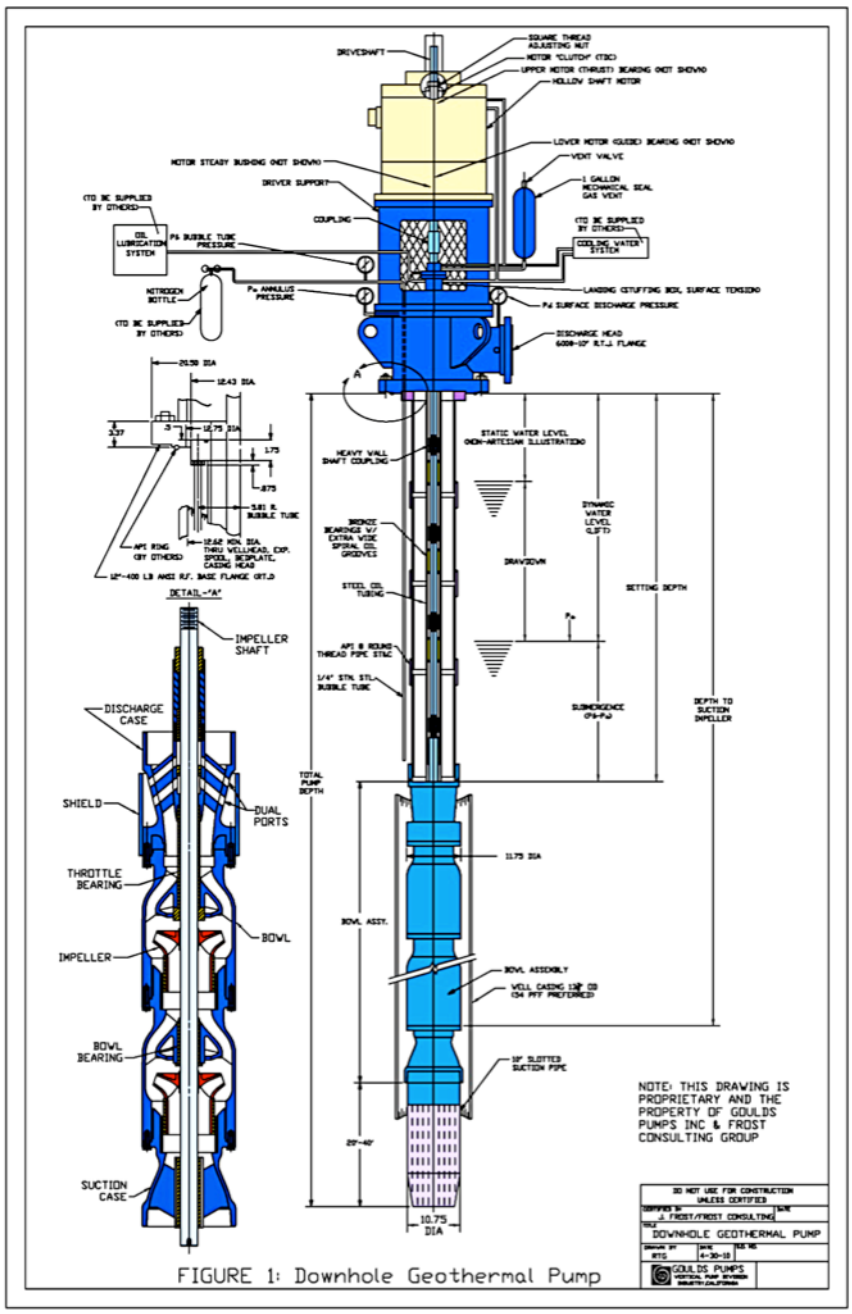


FIGURE 1: Downhole Geothermal Pump

Figure 1: Principal of a line shaft pump



Figure 2: The Adjustment (setting of the) impellers by the motor nut

2. OPERATING GEOTHERMAL POWER PLANTS IN THE UPPER RHINE VALLEY

In Germany three areas are known as possible geothermal resource areas, the Northern German Basin, the Upper Rhine Valley and the Molasse Basin around Munich in South of Germany.

In Germany in 2005 a new renewable Energy law has been implemented, which guaranteed a feed in tariff for geothermal electricity production. Because of this state driven incentive many geothermal projects have been started in Germany, mainly in the Upper Rhine Valley and the Molasse Basin.

2.1 Bruchsal

The first 1930 m deep well has been drilled in 1985 in Bruchsal, the second app. 2540 m deep well has been drilled in 1987 at a distance of 1,5 km on surface. The Bruchsal project has been initiated by the city and the city utilities of Bruchsal. Since the EnBW AG took over the project in 2006, it is mainly used for geothermal research in all aspects, scaling, deposits, corrosion, seismic activity etc.

Since 2009 a 550 kW Kalina Power plant has been installed in Bruchsal. At the moment the power plant is operating at app. 23 - 29 l/s and 123 °C production flow and temperature. Because of the good permeability of the production well the installed capacity might be extended in the future. At the moment the production well is equipped with an Electrical Submersible Pump to produce the brine from the Sandstones reservoir, in case the plant capacity will be extended in the near future the pump market will be evaluated.



Figure 3: Bruchsal geothermal site

2.2 Soultz

The Soultz-sous-Forêts geothermal project started in 1987, and is the cradle of the geothermal energy European research in granitic and fractured systems. After almost 30 years of research, the geothermal site is exploiting the fractured basement at 5 km depth, under commercial conditions, for the EEIG Heat Mining (see figure 2.2). The installed gross capacity of the plant is 1.7 MWe.

The actual geothermal system is made of three wells: one production well named GPK-2 and two injection wells named GPK-3 and GPK-4. The geothermal brine is produced at a temperature of 150°C, reaching the wellhead with a nominal flow rate of about 30 kg/s provided by a Downhole production Line Shaft Pump (Baujard et al., 2018).

The geothermal brine is then flowing through a system of three consecutive double-pass tubular heat exchangers supplying heat to an Organic Rankine Cycle (ORC), in order to produce electricity. The geothermal brine is then fully reinjected at around 70°C, and the volume of reinjected brine is shared between the two injection wells, one third in GPK-4 and two thirds in GPK-3 without using

reinjection pumps. The reinjection temperature varies depending on the outside temperature through the conversion process. The geothermal plant has been successfully producing electricity since September 2016 under commercial conditions (Genter et al., 2018).



Figure 4: Soultz-sous-Forets geothermal site

In Soultz both kind of down hole pumps have been tested ESP and LSP. The first installed line shaft pump has been a water lubricated one (Ravier et al., 2015). In 2016 a small prototype oil lubricated Line shaft pump was installed to fit in the 9 5/8" production casing of the GPK-2 well. The pump is since this date in continuous operation

2.3 Landau

The first app. 3 km deep production well was drilled in Landau in 2005, the second reinjection well was drilled in 2006. Officially on 21st of November 2007 the electrical power production in Landau has been started. The Landau power plant is equipped with an Organic Rankine Cycle from Ormat Systems LTD, the net average electrical production is app. 2,9 MW (Baumgärtner et al., 2013). After the extension of the power plant in 2010 in Landau an additional thermal power within the MW range has been supplied for heating devices, too.

After nearly two years of operation in August and September 2009 two local seismic events with magnitude of 2,4 and 2,7 occurred in the vicinity of the wells. After several months without operating, the plant could be started again on reduced power in 2010. Together with the mining authorities operational rules have been developed to allow an operation of the Landau power plant in a safe manner. The plant availability in 2012 reached 92% (Baumgärtner et al., 2013).

In March 2014 ground movements around the Landau power plant have been realized (Heimlich et al. 2015) and the power plant has been stopped as a precaution. Several months after the geothermal power plant was stopped no earth movements were observed. The reason of the observed earth movements is still being investigated. In August 2017 the geothermal Landau power plant got the permission from the mining authorities to start operation again. Since then the power plant has been in operation.

The operating company in Landau is the geox GmbH. The ownership has changed several times in the past years. The main shareholder of the geox GmbH today is the Gysir Europe GmbH.

In Landau in 2007 the very first line shaft pump in central Europe has been installed to produce hot brines (Frost, 2013). The pump installed in Landau in December 2012 is still operating today.



Figure 5: Landau geothermal site

2.4 Insheim

In 2008 and 2009 two app. 3,8 km deep wells were drilled in Insheim, app. 4km South East from Landau. After a long and extensive testing period an additional successful side track was drilled in the reinjection well in Insheim in 2010. The ORC power plant was ordered in spring 2011 from Ormat Systems LTD, the name plate capcity is 4,8 MWe, the erection started in November 2011 and the operation of the power plant started in October/November 2012 (Baumgärtner et al., 2013).

The owner company of the geothermal power plant in Insheim is Pfalzwerke Geofuture GmbH, which is owned 100 % by the Pfalzwerke AG. BESTEC GmbH has been the general contractor for the down hole and surface construction of the power plant. From November 2012 to April 2019 the BESTEC Services GmbH has operated and maintained the power plant in Insheim.

Based on the good experience in Landau with the line shaft pump, the second line shaft in central Europe has been installed in Insheim in 2012.

In February 2013, after a sudden hard stop of the power plant caused by a power failure, the production well's surface casing collapsed clamping the production string of the LSP pump, app. 15 m below ground. In a several weeks long complicated operation the well could be repaired and the pump retrieved. In May 2013 the LSP pump was rerun into the repaired production well.



Figure 6: Insheim geothermal site

2.5 Rittershoffen

The heat plant of Rittershoffen has been developed in order to supply Roquette Frères Company, a bio-refinery, with geothermal heat for their industrial processes. This industrial user, located in Beinheim, France, totals 100 MWth of thermal needs. The geothermal heat plant, with an installed capacity of 27 MWth, is then providing the entire heat production to this company via an isolated heating transport loop with a length of 15 km (Ravier et al., 2017). The geothermal brine is produced at a temperature of 170°C from a production well, GRT-2 at a depth of 2700 m, penetrating into Triassic sedimentary layers and the top crystalline fractured basement interface (Baujard et al., 2015, Baujard et al., 2017). The geothermal brine is flowing through a system of twelve consecutive tubular heat exchangers, (Ravier et al., 2016), and is fully reinjected without additional pumps at in average 80°C into one injection well, GRT-1, having a depth of 2500 m (see fig. 7). This reinjection temperature varies in function of the return temperature of the transport loop. The flow rate of the brine is regulated at 75-80 kg/s using a downhole production Line Shaft Pump. The geothermal plant has been successfully producing heat under commercial conditions since June 2016.



Figure 7: Rittershoffen geothermal site

In Rittershoffen exactly the same kind of line shaft pump model as in Insheim has been installed to have the possibility to exchange spare parts within these two projects. The pump in Rittershoffen has been installed in December 2015 and since the start of the power plant in June 2016 the pump is in operation until today.

2.6 Upcoming Projects

Around Strasbourg there are two further Projects for electrical production planned, in Vendenheim and Illkirchen. The Vendenheim Project is still drilling the second well and in the Illkirchen Project the first well is nearly finished. The start up of the power plant in Vendenheim is planned for the beginning of 2020 and the installation of a line shaft in the production well is planned in the second half of 2019.

2.7 Discussion of the pump technology used in the Upper Rhine Graben

The produced fluids in the Upper Rhine Valley are Na (Ca, K)Cl rich brines with Total Dissolved Solids (TDS) of up to 200 g/l (Sanjuan et al., 2016) and a very high content of dissolved gases, with gas to liquid ratios of up to 2:1 (Seibt and Thorwart, 2011). In Soultz and Rittershoffen a TDS around 100 g/l was observed, while in Landau and Insheim the TDS appears to be a little less than 110 g/l. In Bruchsal the highest TDS of 125 g/l were recorded (see table 2.1). The brines with the higher TDS show the higher gas to liquid ratio, too (see table 2.1) In Bruchsal a gas to liquid ratio of 1.5:1 is observed, while in Soultz a Gas to liquid ratio of 0.8:1 is observed. The gas content in all five projects is mainly carbon dioxide CO_2, with more than 90 %, additionally nitrogen N_2 and methane CH_4 are measured. In Bruchsal the gas content is 94.9 % CO_2, 3,1 % nitrogen N_2 and 1.7 % methane CH_4 (Seibt and Thorwart, 2011) while in Soultz a gas content of 95.5 % CO_2, 4.1 % nitrogen N_2 and 0.4 % methane CH_4 (Scheiber et al., 2015) is recorded.

The observed high chloride and carbon dioxide contents have a great corrosion potential within the casings and the brine pipes of the power plant. In case the pressure drops anywhere in the flow system below the Gas Break Out (GBO) pressure the Carbon dioxide CO_2 is degassing and carbonate scales will be produced. Therefore the pumps need to be operated at pressures above the GBO to avoid any degassing, whereby of course friction losses in the surface pipes have to be taken into account, too. Additionally the setting depth of the pump has to be chosen correctly to avoid any degassing of the brine column above or at the intake of the pump. Because of the high GBO in the produced fluids in the Rhine Valley, the submergence i.e. the minimum allowed fluid level above the intake of the pump needs to be more than 200 or better 250 m. The minimum allowed fluid level above the intake of the pump varies at different locations within the Upper Rhine Valley, because the GBO increases with the production temperature and the gas content (see table 2.1).

Beside Bruchsal, in all geothermal plants the brine cycles are operated at pressures above the GBO to avoid degassing. The Bruchsal power plant is operating below GBO pressure, therefore gases are released. As gases inside the heat exchanger would impair the heat transfer, a gas bridge was installed to separate the released gases before the heat exchangers of the plant. These gases are bypassing the power plant via the gas bridge and are remixed again into the cooled and reinjected fluid.

Each installed pump is an individual story, the lessons learnt from each pump are summarized in the next chapter and will show the adaptation of this pump technology in such a hostile environment. Nevertheless, the already realized operating periods and the realized overall efficiencies (see table 2.1) are demonstrating the potential of the Line-Shaft Pump Technology in the hostile environment of the Upper Rhine Valley.

Table 2.1: The produced brines and the used pump technology in the upper Rhine Valley Geothermal Projects

	Project				
	Bruchsal	Soultz	Landau	Insheim	Rittershoffen
Reservoir	Triassic and Permian	Fractured Granite	Triassic sandstones and	Triassic sandstones	Triassic sandstones and
Salinity [g/l]	121 -125	96 -101	106	107	100
GBO [bar]	App. 28 bar	18,0–18,5	18,2	19,2	19
Gas water ratio	1.5:1	0.8:1	1.1:1	1.1:1	1:1
Gas content	Mainly CO2 (> 90 %) plus nitrogen and methane				
Production flow [l/s]	24 – 29	31	50-60	App. 70	87.5
Production temperature [°C]	123	150	159	163.8	168.5
Production pressure [bar]	22	22.5	19-21	21–22	25.3
Pumptype	ESP	LSP small	LSP	LSP	LSP
Pump bowl material	Stainless steel	Stainless steel	Cast Iron	Stainless	Stainless steel
Setting depth [m]	427	371,5	369	730	480,6
Power consumption [kW]	130	212	-	App. 560	541
Global pump efficiency	-	App. 42%	App. 70 %	App. 68 %	App. 70%
Runtime	Installed in 2014	1050 days still in operation	Pump was installed in December 2012	4 years	1100 days still in operation
Casing size [inch]	10 ¾	9 5/8	13 3/8	13 3/8	13 3/8

3. INVESTIGATIONS TO IMPROVE THE LINE SHAFT TECHNOLOGY

Before the first industrial geothermal power plant within the MW range in Landau has been put into operation only minor experience with smaller ESP pumps have been made in Soultz and Bruchsal in the upper Rhine valley. Because of the high salinity and the high gas content of the produced brine and the higher (compared to the Molasse basin) production temperature the line shaft technology was finally chosen to exploit the reservoir in Landau.

Ormat Systems LTD, suggested initially the the LSP technology for Landau, because of their good experience in their US geothermal power plants, where mineralized brines are produced at temperatures comparable to the Landau production temperature. The Icelandic water lubricated LSP was also tested during several years in Soultz, but with a very limited success (Ravier et al., 2015).

3.1 Oil investigations

The installation of the oil lubricated LSP in Landau was the first installation of this kind in Europe. In the preparation meetings with the authorities the fact, that lubrication oil is “lost” into the annulus caused some misunderstanding, because the technology was new for everybody. After the oil has travelled nearly two months through the lubrication string (2,2 l oil per m, oil pump rate app. 15 l/day, setting depth 369m), the oil is transported via ports with a little production brine flow into the annulus of the 10 ¾” production casing and the 13 5/8” well casing. In a well which becomes artesian at elevated temperatures this oil volume can be produced any time from the annulus, so all used oil can be recovered from the well, no oil is lost. All geothermal reservoir wells in the Rhine valley are artesian when hot or can be forced to become artesian by injecting water with a density of 1 g/ccm.

Nevertheless, initially, as the term lost lubrication had settled in many heads, an attempt was made to operate the line shaft pump by using biodegradable oil. A series of special laboratory tests was carried out to test the lubrication behavior of a high temperature biodegradable oil within the bronze bearings at operating temperatures and pressures. As the oil has performed very good in the laboratory tests, it was used for shaft lubrication of the first pump installation in the production well in Landau.

After only one year of operation of the first line shaft pump in Landau the shaft parted, because the biodegradable oil turned into a tar being in contact with the hot brine in the well (Frost, 2013). After pulling the pump it could be seen that the pump itself was still in a good shape, while the shaft appeared to have been widely not lubricated and the lube string had parted several times. Nevertheless as the cause of the damage was obvious, it was decided to switch back to a normal mineral oil for lubrication. Since than the used and produced oil volumes are recorded and documented. No oil losses have been observed so far in all projects with a LSP installation.

In case the production well is not artesian or can’t be pressurized to produce the oil from the annulus, the Line Shaft Pump can be installed with an oil recovery system.

3.2 Conbox

As the reservoirs within the Rhine valley get deeper, the productivity index might be only a little better than 2 l/s/bar, so the installed pumps are equipped with more and more stages. Every pump stage has a height of 55 cm, therefore pumps with 39 stages are longer than 20 m. Items of this length are difficult and costly to ship from US to Europe. Additionally the transport of the one long pump in one piece is costly. Therefore a connection box (Conbox, see fig. 8) has been developed to be able to deliver the pump in two or more pieces if necessary. This allows to avoid the difficulty of having to transport a pump of special size. Additionally, handling of the shorter pieces of the pump is easier on location while installing (see fig. 8).



Figure 8: Installation of Geothermal Downhole Line shaft pump and a detail of the Conbox

Nevertheless, the installation of the Conbox requires some time, too, which is widely regained by the time, which is saved, while handling the shorter pump sections. The first Conboxes developed were made out of standard cast iron steels. Meanwhile the Conboxes are available in stainless steel, too.

3.3 Material investigation

In a geothermal well the used casing materials are standard oil field API-5CT materials, like J55, K55, N80, L80 or P110. These casing materials are seamless hot rolled carbon steels. N80, L80 and less P110 are typically used in the production wells in the Rhine graben.

Knowing the quality of the casing materials used, the bowls of the first installed pump in Landau in 2007 were made out of carbon cast iron, only. This bowl material is still used in Landau and the LSP with cast iron in Landau is still operating successfully. All other

The thermal expansion factor of the installed lube string, the line shaft and the production casing need to be very similar, to avoid different elongations of these three strings at equilibrium temperature. Therefore in all three strings, the shaft, the lube string and the production are made from similar carbon steel alloys. The thermal expansion coefficient of the installed shaft is 1,12 mm/m/100 °C. The production casing, which is typically installed with the LSP inside a 13 3/8 casing, is usually a J55 10 3/4" 40,5 lbs/ft casing.

Like for any other downhole pump, it is not possible to install a redundant pump. Normally geothermal plant operators acquire a spare pump, which is stored on surface nearby, to be able to exchange the pump if required. The operating pump and the spare pump are usually the same model and size.

Although the mineral and gas content of the produced brines in Insheim and Landau are very similar, the resource in Insheim is deeper and the production temperature is slightly higher. The productivity index of the production well in Insheim requires the pump to be installed deep with an increased number of stages. If the pump in Insheim is operating at nominal speed the submergence is just 1-2 bars above the GBO pressure, if the pump in Landau is operating at nominal speed the submergence is still more than 5 bar above the GBO.

The first two pumps with Iron cast bowls installed in Insheim suffered from erosion /corrosion holes in the cast iron bowls. The exact cause of these holes is still not fully understood. It is assumed, that the safety margin to avoid degassing in the fluid needs to be higher, more like 5 bars above the GBO pressure rather than 1-2 bars at which the pumps were operated. The observed holes appear to have started from the outside of the pump to the inside. During pump operation there is always some fluid flow around the pump bowls, because some additional production flow of 1-2 l/s is leaving the pump at the top at the pump assembly through the throttle bearing below the oil ports (see fig. 9). This 1-2 l/s are cycling permanently around the pump bowls. It is assumed, that here some kind of degassing is occurring which might have caused the observed holes.

After the first holes were observed, the pump bowls were replaced with stainless steel bowls. Again more stages have been installed and the pump has been set deeper. Knowing the difficulties to transport the pump in one long piece, these pumps have been equipped with Conboxes. The stainless steel pump operated for more than 4 years. After 4 Years no more holes were observed in the bowls, however some eerosion/corrosion damage occurred in the Conbox, which still had been made out of carbon steel.

After the holes in the cast iron bowls in Insheim were observed all later installed line shaft pumps are manufactured with stainless steel bowls. In all spare pumps the Conboxes will also be upgraded to stainless steel.

3.4 Slim Line Shaft Pump

Soultz has been started already in the end of 80ties as a research project for HDR or HFR. During the project duration the target depth was shifted from 2 through 3.6 to 5 km. The well GPK-2 was originally drilled to app. 3800 m in 1995 and in the year 2000 deepened to 5000m. The pump chamber installed in GPK-2 was unfortunately only a 9 5/8" casing. So the normal 11 3/4" line shaft pumps would not fit into the 9 5/8". Therefore a 7" slim prototype Geo 8JHC-46 SS was developed for Soultz. This slim LSP with 46 stages is operating at faster speeds of app. 2200 RPM. A 7" 26 lbs/ft J55 production casing is attached to the pump, while a 1 15/16" diameter shaft is turning inside a 3" lube string.

The smaller diameters have been installed only below ground. Just before the the combined strings come to surface, special connections have been prepared, to switch from the small 7" casing to the 10 ¾" casing to switch from 3" lube string to the 3 ½" lube string and to switch from 1 15/16" to the 2 3/16" shaft. Consequently, on surface the same discharge head, the same motor stand, the same mechanical seal, the same motor shafts can be used like for the normal size LSP. This gives the prototype pump quite some spare part interchangeability with the other LSP's installed nearby.

3.5 Oil return

In the Bavarian Molasse the static water levels of the production wells are quite deep. Here a closed oil loop needs to be installed to be able to permanently recover the oil while pumping. Additionally in the Bavarian Molasse the fluid reservoir produced for geothermal usage is the drinkable water reserve for the Year 3000. In 2015 the newly designed closed oil loop system has been introduced to the Bavarian Environmental Authorities. The authorities made two restrictions to the proposed oil return system, the oil used must be free of aromatics and the oil flow in and out needs to be continuously recorded. In case a difference in the flow in and out is observed the operation should be stopped.

An aromatic free oil has been located, so the Bavarian Environmental Authority was willing to give their approval to an installation of a Downhole Line Shaft Pump within the Molasse. Unfortunately, the envisaged project was stopped, before the pump could be installed.

The fully closed loop oil lubrication system is recovering the oil via two additional 1/2" lines beside the 10 ¾" casing. The lube oil return system relies on simple pressure balancing. During pump operation the brine pressure at the secondary throttle bearing is higher than the oil pressure, so the oil is returned via the return lines during pump operation (see fig. 9).

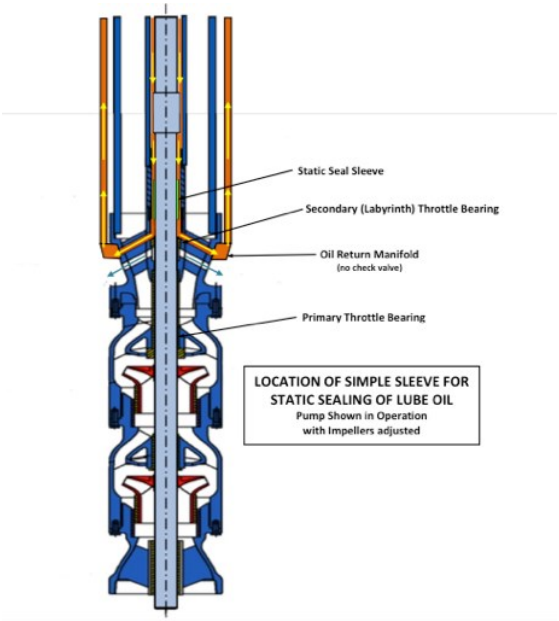


Figure 9: The pump is operating, the oil return line is shown beside the 10 3/4" production casing. While producing the static sleeve is above the secondary throttle bearing, the produced bypass brine flow is sealing the oil at the secondary throttle bearing.

A static sleeve needs to be installed, which is above the secondary throttle bearing, while the pump is producing. If the pump is stopped, the impellers are set to bottom, now the sleeve seals against the secondary throttle bearing (see fig. 10). In case the pump needs to be pulled, Nitrogen will be purged via the return lines to evacuate the oil (see fig. 10).

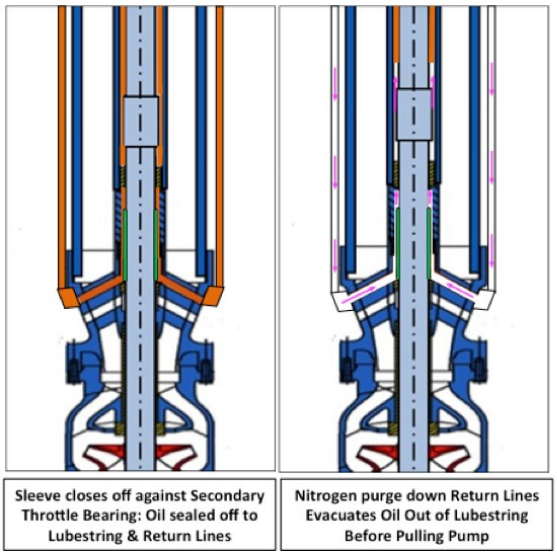


Figure 10: The pump is not operating the impellers are set to the bottom, now the sleeve is sealing the oil to the brine outlet. Before the pump is pulled, Nitrogen will be purged down the return lines to evacuate the oil out.

4. COMPARISON OF LINE SHAFT PUMPS AND ELECTRICAL SUBMERSIBLE PUMPS

These two different pump systems have evolved separately from each other in response to different historical demands. Whereas the LSP had its roots in the response to the water well demands in the early 1900s, the ESP had its roots in the demand for the oil fields of the 1930s. As these two seemingly similar pumps evolved, they did so quite independently. This resulted in pumps that are different in terms of their impeller design, bowls and bearings, and shafting. Lineshaft pumps evolved for pumping large volumes often sandy water from relatively large diameter wells of relatively shallow depths. Conversely, the ESP evolved for pumping relatively small volumes of oil from very deep small diameter wells.

4.1 Operating Limits

Temperature has no correlation to the operating life of an LSP. The Downhole Geothermal LSP has a theoretical temperature limit of 260 °C (500 °F) and has field experience in the 194-216°C (380-420°F) operating range. As the LSP's motor is located at surface it avoids the challenges of sealing and thermal management presented by placing the motor in the well. In extreme cases the temperature limit of the LSP can be dictated by the dynamic water level and the minimum necessary sufficient submergence to prevent flashing, which for high temperatures combined with high gas content may exceed the setting depth limitation of the LSP.

4.2 Setting Depth & Well Requirements

Owing to relative shaft stretch and the combined shear stress placed on lineshaft couplings, the maximum practical setting depth of LSP's has been approximately 750m. LSP's need only to transmit the motor's torque through the bowl assembly and thus can be set at deeper depths. LSP's are manufactured in a variety of diameters, but the majority of LSP's is 12" diameter and requires a minimum of 13 3/8" casing between surface and the pump's setting depth.

4.3 Efficiency

Both LSP and ESP's have bowl assembly efficiencies that approach or exceed 80% with the LSP showing a slightly better efficiency. However, when evaluating the overall system efficiency the LSP will be significantly more efficient for most applications. Both pumps have pumping losses associated with moving water from the bowl assembly's depth to surface. While the LSP has a reduced cross sectional area owing to the space occupied by the oil tube, the impact of pumping losses on the overall system efficiency is minimal for flow rates below 125 l/s (2000 GPM) if column pipes of 273 mm (10 ¾") diameter are installed. The LSP motor is very efficient (93-95%) and the majority of the LSP's parasitic losses occur in the lineshaft as a result of friction between the rotating shaft and stationary bearings. These frictional losses increase linearly with setting depth and rotating speed and are independent of brine temperature or pump power consumption.

Submersible pumps have parasitic losses associated with transmitting current from surface to the motor through an insulated cable. In addition to the transmission losses, larger capacity submersible pumps may require that the downhole motors be installed in series which results in lower overall efficiency for higher capacity and higher temperature submersible pump installations.

4.4 Operation and Durability

As of August 2018, the mean runtime of all the LSP's supplied by ITT and installed by Frost Consulting is 5.1 years, with several pumps exceeding 8 years of continuous operation. The LSP benefits from having several key components at surface where they can be easily serviced or replaced. The electric motor is in design a relatively common motor in the United States. The motor has an oil bath-water cooled spherical roller thrust bearing riding on a bored-out drive shaft; hence, the name "Vertical Hollow Shaft" (or VHS). The motor benefits from both a cooler ambient operating environment and cooling of the lubricating oil which prolongs bearing and winding life. Should the motor need service, a spare motor can be swapped into place without removing the pump from the well (minimal downtime). Motor oil can be sampled at regular intervals to determine oil quality. Beside annual oil changes the motor maintenance is minimal.

Table 4.1: Comparison line shaft pump with electrical submersible pump

	LSP	ESP
Motor	Hollow shaft motor at surface Efficiency 93-95%	Small down hole motor cooled with the produced brine Efficiency 85% - 90 %
Maximum Power	Up to 1,6 MW	>2MW
Speed	2200 RPM	Up to 3600 RPM
Power cable	At surface	Down hole
Head losses within the pipe	Negligibly higher	Lower for same size pipe
Power Losses	Oil lubricated lineshaft	Power cable
Thrust bearing	At surface spherical roller oil bath	Down hole plate type oil bath
Seal	At surface water cooled, dual cartridge lube oil against air	Down hole cooled by produced brine
Pump diameter	11 ¾" and 8 ½"	8,63 – 11 ¼"
Well casing	13 3/8" or 9 5/8"	13 3/8" or 9 5/8"
Impeller Type	Enclosed Long Lateral type Francis Vane Francis Vane	Enclosed Minimal lateral – Radial to low Francis Vane
Impeller Adjustment	At top of motor, adjusted during start up until thermal equilibrium is reached	Fixed, set at factory or during installation
Maximum stages	42	Over 100
Shaft Diameter	2 3/16" or 1 15/16"	1 – 1 ½"
Maximum setting Depth	750 m	> 1000 m
Pump efficiency	76-82%	76-80%
Overall Efficiency	>70%	50-60%
Installation	More connections, longer	A little simpler
Start up	At the first cold start impeller adjustment has to be repeated	A lot of starts and stops shorten the life duration
Initial Investment	Needs to be checked at each project.	
Life duration	4 -7 Years	Over 140 °C less than one year

The mechanical seal about the shaft seals against the lube oil and not brine. Since the thrust bearing in the motor requires water cooling to dissipate the heat generated by the thrust load, cooling water is also plumbed into a cooling jackets surrounding the

stuffing box and through the mechanical seal. Therefore, the stuffing box and mechanical seal run at much lower temperatures than the discharge brine temperature.

Submersible pump motors are sealed prior to installation and the failure of either the electrical cable insulation, the motor seal, or the motor itself requires the removal of the submersible pump. The submersible motor and cable are submerged in brine and must operate in a high temperature and sometimes acidic brine environment.

5. CONCLUSIONS

The design of the Downhole Geothermal LSPs has strongly evolved over the past 10 years, with greater resistance to wear, noble materials, deeper setting depth, higher temperatures, greater pump speed variations and longer pump life. The pumps have proven their reliability in Central Europe in a very difficult and chemically challenging environment. Setting depths of up to 750 m can meanwhile be handled and lifespans of 4 Years and much more are achieved under these conditions. In Europe some important lessons handling aggressive and gas rich fluids have been learnt since this pump technology was introduced into the geothermal market and the pumps have been (and still continue to be) adapted to the local reservoir conditions. Efforts have been undertaken to tailor the oil lubrication, the quality of the used materials as well as the handling of the long pump bodies. For sensitive environments such as the Molasse reservoir in South Germany, a fully closed loop oil lubrication system has been developed and is ready for installation.

Temperature has little effect on the performance and the life of an LSP. As long as the pump depth is adequate for the drawdown required at very high temperatures, users only need to be more diligent during start up procedures. Quite generally, it can be stated with greater pump speed, the sooner any rotating machinery will wear. Slower speeds are favored. It is the combination of pump modeling values, which may limit pump operation. For example one should not expect a 200 l/s rated pump operating at this flow rate with a setting depth of 750 m. The combination of motor horsepower, thrust loads, shear stresses and/or shaft stretch, as well the production well's hydraulic behavior will determine the physical limits.

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J.A. Frost, the man behind the Downhole Geothermal Line Shaft Pump technology passed in December 2017. For all of us, it has been a great pleasure to work with Jack and to learn from Jack. We miss Jack as a great engineer, but even more as a strong character. We are very grateful for sharing parts of our professional live with Jack.

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