INTRODUCTION
The definition of Geothermal energy is 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. Geothermal brine flows artesian and/or they can be getting to the surface by means deep wells.

Pumping is often necessary in order to get geothermal fluid to surface. Pumping is some times required to increase pressure or move the fluids from place to place once they are on the surface.

In certain geothermal fluids such as those with high carbon dioxide content, maintaining the water under pressure can reduce corrosion and scaling. Because production well pumps are usually of greatest concern and on the surface, pumping is not recurrently a problem well pumps will be considered first.

Deep well pumps are used to pump geothermal fluids to the surface and onward to user. As most low temperature geothermal reservoirs are non-artesian, the wells will not produce without pumping.

In artesian flow reservoirs, pumps may be installed to increase the flow rate and in case where the temperature is above boiling point or in wells with a high gas concentration, the pumps may be used to pressurize the water so that it will not boil nor, release the gas.

The benefits of the deep well pumps;

• Greater generating capacity and no reduction in output due to the well scaling.
• Increased production from each well, by lowering of water level.
• Higher wellhead temperature.
• No loss steam to the atmosphere, better energy recovery
• Scaling of calcium carbonate will be reduced, but the introduction of scale into the well below the pump to protect the pump; its assembly, transportation line etc. will have to be investigated.

1. SPECIFICATION OF DEEP WELL PUMPS FOR GEOTHERMAL WELLS
Basically there are two types of production deep well pumps for geothermal well, the difference being location of driver (motor) (1):

• LSP, Line Shaft Pump
• ESP, Electrical Submersible Pump

1.1 Comparison of Line shaft And Submersible Pumps
1.1.1 Line shaft
• Pump stage efficiencies about the same 68 to 78 % generally lower head/stage and less flow/unit diameter.
• Higher motor efficiency because it operates in air. Little loss in power cable
• Motor thrust bearing and seal accessible at surface.
• Usually lower speed (1750 rpm or less) although may be equal. Usually lower wear rate.
• Higher temperature capability, up to 250 C, although not used up to temperature limit in direct heat and some binary applications
• Shallower setting, 2000 ft. maximum.
• Longer installation and pump pull time.
• Well must be relatively straight or oversized to accommodate stiff pump and column.
• Impeller position must be adjusted at initial start up.
• Generally lower purchase price at direct use temperatures and depths.

1.1.2. Submersible
• Pump stage efficiencies about the same, 68/78 & generally, higher flow/unit diameter.
• Lower motor efficiency- operates in oil at elevated temperature. Higher loses in power cable. Cable at least partially submerged and attached to hot tubing.
• Motor, thrust bearings, seal and power cable in well - less accessible.
• Usually higher speeds (3600 rpm) although may be equal. Usually higher wear rate
• Lower temperature capability but sufficient for most direct heat and some binary power applications
• Deeper settings. Up to 12.000 ft in oil wells.
• Less installation and pump pull time.
• Can be installed in crooked wells up to 4 degrees deviation per 100 ft. up to 75 degrees off vertical. If it can be cased, it can be pumped.
• Impeller position set.
• Generally higher purchase price at direct use temperatures and depths.

2. CRITERIA FOR SELECTION, INSTALLATION AND OPERATION

There are four main steps to design excellent deep well pump for one LSP geothermal pump

- Collection correct basic data required
- Selection of correct deep well pump
- Correct installation of line shaft pump
- Correct main operation parameters

These points should be taken into the consideration in order to maximize its MTBF (mean time between the failure)

2.1 Collection Basic Data Required

- Size and depth of production casing
- Water level in reservoir, L
- Draw down coefficient \( c_1 \) of the well draw down \( = c_1 \times m^2 \) [m]
- Water temperature
- Discharge head pressure, \( P_s \)
- Gas in the water
- Sand- carry over in the well water
- Corrosive action of water & Chemical analysis of the water
- Straightness of well (crooked?)
- Electrical network data

2.2 Selection of Deep Well Pump

- Type
- Size
- Length

2.3 Installation of Line Shaft Pump - Maximize Its MTBF

2.3.1 Straightness of Line Shafts:

We should check shaft for straightness, shaft must be straight with 0.005” (0.127mm) total indicator reading. If the shaft is not straight, it must be straightened or replaced (if the shaft has sharp crook (dog-leg). If the deflection is gradual over the considerable length, the shaft can usually be straightened by supporting the crooked section on two blocks straddling and applying pressure to the high side to deflect the shaft to the opposite direction (3) (5),(6).

Figure 3: Total indicator reading set
2.3.2 Cleanliness and Lubrication: All machined mating surface must be clean and free of burrs and nicks removed with fine file or wire brush. All screwed connections with the threat must be lubricated, graphite etc.

2.3.3 Correct Initial Adjustment Of Impellers: There is an impeller adjusting nut at the top of the hollow shaft motor assembly, or three or four pieces coupling with adjusting nut for solid shaft driver arrangements.

2.3.4 Thermal Equilibrium: All pump assembly should be heated before starting operation to supply thermal equilibrium in sufficient time (5), (6).

2.4. Main Operation Parameters - Efficient Filtration of Lubricating Water:

- The installation of units using the water injection lubrication system in geothermal wells use filtered fresh hot water for injection tube at 0.2-0.3 l/s at 2.5-3.5 bar for lubricating the line shaft bearings (1).
- Maintain Thermal Equilibrium; we must keep the thermal equilibrium during the starting and stopping the pump.
- Output capacity of the pump: We should know what we are producing.
- Vibration Level; we should check the vibration level and compare the before vibration levels.
- Casing size of the well is the most important point for designing of LSP and chemical injection system.

Table 1: Recommended Flow Ranges for LSPC

<table>
<thead>
<tr>
<th>Pump Size</th>
<th>Column Size</th>
<th>Flow Ranges Recommended</th>
<th>Well Casing (min.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6&quot; and 8&quot;</td>
<td>6&quot; Column Pipe 2&quot; Enclosing Tube 1 3/16&quot; Line shaft</td>
<td>14-45 l/s</td>
<td>85/8&quot; and 103/8&quot;</td>
</tr>
<tr>
<td>10&quot;</td>
<td>8&quot; Column Pipe 2 1/2&quot; Enclosing Tube 1 11/16&quot; Line shaft</td>
<td>50-75 l/s</td>
<td>12&quot;</td>
</tr>
<tr>
<td>12&quot;</td>
<td>10&quot; Column Pipe 2 ½&quot; Enclosing Tube 1 11/16&quot; Line shaft</td>
<td>85-110 l/s</td>
<td>14&quot;</td>
</tr>
</tbody>
</table>

- Minimum Submersion Depth:
In order to prevent the cavitation, the minimum submergence must be taken in to the consideration. Because most pump curves are based on test at 20 oC. The engineer should calculate the NPSH (Net positive suction head) available under operating conditions... Or:

\[
(Pa - Pu) \times 10^5 \quad \text{NPSHR} \\
\ h_{\text{min}} = \frac{\rho t g}{\rho t / \rho_{20}} 
\]

Pa: vapor pressure (bar)  
Pu: atmospheric pressure (bar)  
r t: Density of fluid temperature T oC( kg/m3)  
r 20: Density of fluid temperature at 20°C (kg/m3)  
NPSHR: Net positive suction head required (m)  
g: acceleration of gravity (m/s²)

Example:
Flow Rate : 40 l/s  
Temperature : 130 oC  
Altitude : 26 m  
Pa: 2.7 bar  
Pu: 0.96 bar  
r t: 935 kg/m3  
lmin= 27.5 meter  
r 20: 998 kg/m3  
NPSHR: 8 m

- Maximum Recommended Pump Speed:
Pump curves are generally based on standard motor speeds. For performance of pumps at speeds other than those published, it is necessary to calculate:

Q: Quantity (l/s)  
BHP: Break Horsepower  
H: Head (m)  
N: Speed (rpm)

Formula for changing pumps speed chance in performance.
The following Affinity Laws are used in speed variation calculations:

1. The capacity of a turbine pump varies in direct proportion to the speed.
Ex: N1: 900 rpm  Q1: 10 l/s  Q2=Q1(N2/N1)  
N2: 1800 rpm  Q2: 20 l/s

2. The head of a turbine pump varies in proportion to the square of the speed.
Ex: N1: 900 rpm  H1: 100 m  H2=H1(N2/N1)²
Kaya, Mertoglu

N2: 1800 rpm  H2: 400 m

3. The horsepower varies in proportion to the cube of the speed.

Ex:
N1: 900 rpm  BHP1: 50 HP
N2: 1800 rpm  BHP2: 400 HP

\[
\text{BHP2} = \text{BHP1} \left( \frac{\text{N2}}{\text{N1}} \right)^3
\]

In general, it is good engineering practice that:

The speed of a turbine pump designed for 1700 RPM, not to be increased more than 2200 RPM.

At higher RPM, harmonic or shaft vibration may occur causing excessive wear in the pump.

2.5 The Cost Of Operating A Vertical Turbine Pump May Be Determined By Several Different Methods. 1. If the cost of operation per hour is desired, the power consumption as determined by use of the methods previously described may be used (4):

\[
\text{Cost / hour operation} = \text{kW's consumed} \times \text{cost per kWh}
\]

2. The cost of operation may be estimated by determining the input horsepower and converting it to kilowatts:

\[
\text{Cost / hour operation} = 1 \text{ HP} \times 0.746 \times \text{cost per kWh}
\]

3. A somewhat less accurate estimate may be made by using the following formula

\[
\text{cost / hour} = \text{GPM} \times \text{total head} \times 0.746 \times \text{cost/kWh of operation} \times 3960 \times \text{pump eff.} \times \text{Motor Eff.}
\]

2.6 Importance of Deep Well Line Shaft Pump For High Temperature Geothermal Well in Balçova

The first LSP for deep well and high temperature was installed in November 1997 in Balçova, Turkey. It has 150 setting depth (with 200 m setting design) and operating temperature 133°C.

First LSP, which has been installed in Turkey for deep and high temperature (150/220 m and 140 °C) well is Icelandic design pump, which is installed, commissioned, operated firstly by Orme Geothermal Inc.

It was turnaround for development of geothermal district heating in Balçova. After successful installation and operation of LSP for deep well and high temperature Balçova Geothermal Wells, it was started to increase the capacity of the DHS in Balçova.

3. ENGINEERING DESIGN OF BD-4 GEOTHERMAL WELL

BD-4 Geothermal Production Well has been drilled between 20.08.1998 and 01.10.1998 in Balçova Geothermal field which is located 10 km west from Izmir.

The geothermal brine whose temperature is 139 °C has been producing to supply energy for Balçova Geothermal District Heating System by using Icelandic Special Design line shaft pump (LSP) since 17.01.1999. Because of the high capacity and low draw-down, the well is called “GOLD MINE”.

In BD-4 geothermal well, in order to prevent CaCO3 scaling problem, scale inhibitor, which is carboxylic acid derivatives in aqueous solution, is being injected to 90 meters below the suction of the LSP. Inhibitor concentrations, constant throughout, vary from 2 to 5 mg/l.

Special chemical injection tube and metering pumps has been used to inject the inhibitor. 240 m auxiliary injection tubing (AIT) which is of cylindrical shape and composite structure (combines steel and thermoplastic) has been installed in this well.

The operated AIT has standard single encapsulation, which is PTFE (temperature resistance is 204° and tensile strength is 22 Mpa, OD/ID: 6/4 mm) core injection tubing and four bumper wires (2mm and steel). Section of AIT is shown in Figure 4 below.

During the production to monitor draw-down in the well bore, 140 m nitrogen gas continuous injection line (SS 316, OD/ID: 8/4 mm) has been installed. By injecting the nitrogen gas dynamic level is measured each day and after increasing or decreasing of LSP motor speed.

In LSP system, filtered geothermal water has been used as a lubricant, which is supplied to the line shaft bearings through the enclosing tube. Water lubrication system has been selected instead of oil lubrication system, because of the fact that, 15% of the geothermal brine is being used for balneological purposes after heating the supply water by means of heat exchangers (40-50°C).

There were installation difficulties during the installation of LSP and AIT into BD-4, because of the small diameter of production casing. The high productive capacity of BD-4, max pump size is selected. The gap size between AIT, LSP and production casing is 8 mm. Figure 6 clearly shows the...
installed configuration of the AIT, LSP and Well Casing of BD-4. In spite of these difficulties, installation has been completed successfully.

Figure 6: Cross Section of Well, AIT, Nitrogen Line

While selecting the installed LSP system for BD-4 (also for all the other wells), chemical composition of the geothermal brine (scale depositing and corrosive properties), geothermal brine temperature, well condition and casing design of geothermal production well are taken into consideration cautiously. For that reason, “specific design for each well” is rule of thumb.

As it is conventional in all LSP system which are under our contract, frequency converter (variable speed driver) has been used for all LSP. According to geothermal brine demand, speed of LSP motor is increased or decreased.

4. PUMPING TEST

In order to get operation data which will show to us operation strategy like expected draw down and production data during the operation of the well, pumping test is necessary for each production well.

The pumping tests are normally carried out to access the hydraulic behavior of well and so determine its usefulness as a source of waters; predict its performance under different pumping regimes.

Also to determine the hydraulic properties of the aquifer or aquifers which yield water to the well. These properties include the transmissivity and related hydraulic conductivities, storage coefficient, pressure drop and distance of any hydraulic boundaries. Furthermore, pumping test data are too useful to design deep well pump for other neighboring production wells on the same geothermal area.

Analytical Model one production well- BD-4

Analytical model is used to see dynamic water level during the pumping in this study.

Well Data:

 Depth : 624 m

Casing : 0-77 m 13 3/8” - 0-316 m 9 5/8” (closed) - 307-624 m 7” (slotted)

<table>
<thead>
<tr>
<th>Pump speed (Hz)</th>
<th>Pump speed (rpm)</th>
<th>Ratio of total speed %</th>
<th>Flow rate (l/s)</th>
<th>Water level (m)</th>
<th>Drawdown (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0</td>
<td>0</td>
<td>0</td>
<td>7</td>
<td>0</td>
</tr>
<tr>
<td>18</td>
<td>1065</td>
<td>35.9</td>
<td>14</td>
<td>25</td>
<td>18</td>
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<tr>
<td>24</td>
<td>1420</td>
<td>4705</td>
<td>22</td>
<td>34</td>
<td>27</td>
</tr>
<tr>
<td>32</td>
<td>1894</td>
<td>63.9</td>
<td>28</td>
<td>42</td>
<td>35</td>
</tr>
</tbody>
</table>

Pump Data:

Setting Depth : 150 m (design 220 m)
Design Temperature : 180 °C
Wellhead Pressure : 10 bar
Lubrication : Water Lubrication. (special system included)
Flow Rate : 45 l/s
Motor : 150 HP x 1.15 s.f./2900 rpm

The water level in the pumping well has been described by the following equation:

\[ H = A + BQ + CQ^2 \ldots \ldots (1) \text{ where;} \]

\[ H \quad : \text{water level (m)} \]
\[ A \quad : \text{initial water level (m)} \]
\[ B \quad : \text{laminar draw-down coefficient (m/(l/s))} \]
\[ C \quad : \text{turbulent draw-down coefficient (m/(l/s))} \]
\[ Q \quad : \text{well discharge or flow rate (l/s)} \]
\[ \Delta H \quad : \text{well draw-down (diff. between initial and measured water level) (m)} \]

\[ \Delta H/Q = B + CQ \]

The ratio \( \Delta H/Q \) is plotted against to \( Q \) as a straight line, the coefficients \( B \) and \( C \) is determined. According to this step draw-down test, draw-down curve is obtained, well operation has been don After obtaining the laminar and turbulent draw-down coefficient, the equation becomes:

\[ \Delta H = 0.352174*Q + 0.0423913*Q^2 \]

Table 2: Measured Water Level Data During the Pumping for BD-4
BD-4 Geothermal Production Well Step-Drawdown Test
(Ocak 1999)

Figure 7: Step Draw-Down Test, DH/Q (m/(l/s)) versus Q (l/s)

Table 3: Calculated Water Level Data during the Pumping for BD-4

<table>
<thead>
<tr>
<th>Flow Rate (l/s)</th>
<th>Drawdown (m)</th>
<th>Flow Rate (l/s)</th>
<th>Drawdown (m)</th>
<th>Flow Rate (l/s)</th>
<th>Drawdown (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2</td>
<td>0.87</td>
<td>18</td>
<td>20.07</td>
<td>34</td>
<td>60.98</td>
</tr>
<tr>
<td>4</td>
<td>2.09</td>
<td>20</td>
<td>24.00</td>
<td>36</td>
<td>67.62</td>
</tr>
<tr>
<td>6</td>
<td>3.64</td>
<td>22</td>
<td>28.27</td>
<td>38</td>
<td>74.60</td>
</tr>
<tr>
<td>8</td>
<td>5.53</td>
<td>24</td>
<td>32.87</td>
<td>40</td>
<td>81.91</td>
</tr>
<tr>
<td>10</td>
<td>7.76</td>
<td>26</td>
<td>37.81</td>
<td>42</td>
<td>89.57</td>
</tr>
<tr>
<td>12</td>
<td>10.33</td>
<td>28</td>
<td>43.10</td>
<td>44</td>
<td>97.57</td>
</tr>
<tr>
<td>14</td>
<td>13.24</td>
<td>30</td>
<td>48.72</td>
<td>46</td>
<td>105.9</td>
</tr>
<tr>
<td>16</td>
<td>16.49</td>
<td>32</td>
<td>54.68</td>
<td>48</td>
<td>114.57</td>
</tr>
</tbody>
</table>
5. ECONOMICAL ASPECT OF A GEOTHERMAL PRODUCTION WELL, BD4;

Is 40°C there is no doubt that BD-4 geothermal well is a “Gold Mine”. It is very easy to realize that it is a very profitable well both in engineering and economical aspects. The total cost for BD-4 drilling operation, line shaft pump system, auxiliary chemical injection tubing, frequency converter is approximately 420,000 USD.

Total investment for BD-4 : $420,000 USD

Operation + maintenance cost

(electricity + inhibitor included): $55,000 USD/year

Production temperature : 139°C

Flow rate : 45 kg/s

Geothermal brine has been used to heat the residences and tap water by heat exchanger in heat center. The temperature of the geothermal brine after heat exchanger, outlet temperature. We assume that BD-4 is used under 100% capacity all year.

Capacity (MWt) = Max flow rate (kg/s) x (inlet temperature (°C) – outlet temperature (°C)) x 0.004184 = 45 kg/s x (139°C-40°C) x 0.004184 X 0.95

BD-4 Capacity = 17.7

MWt conversion efficiency: %95 so

Energy use (TJ/yr) = Flow rate (kg/s) x (inlet temperature (°C) – outlet temperature (°C)) x 0.1319 = 45 kg/s x (139°C-40°C) x 0.1319 x 0.95

BD-4 Energy = 558.2 TJ/yr = 133,550,000,000 kcal/yr

If we use fuel-oil instead of geothermal brine to supply energy:

Lower heating value of fuel-oil : 9.700 kcal/kg

Efficiency : 0.8

Specific gravity of fuel-oil : 0.85

The price of fuel-oil : 36.70 cent/litre

(Turkey, March 2004)

Total fuel-oil saving : 21,312,757 l/yr

Total money is saving in one year : 7,821,782 USD.

When we compare an oil production well in Turkey with BD-4, it is very easy to understand how geothermal well income.

Economical Aspect of one Oil Production Well, KAW-X;

KAW-X oil production well is in Diyarbakır Oil Field, in Turkey. The total cost for KAW-X drilling operation, ESP (Electrical Submersible Pump) system, frequency converter, etc. is approximately 1,700,000 USD.

Total investment for KAW-X : $1,700,000 USD
Operation + maintenance cost
(Electricity + inhibitor included) : 394,000 USD/year
Flow rate : 5,500 bbl/d
Water cut : 85%
Net oil flow rate : 825 bbl/day

We assume that KAW-X runs with 100% capacity all year.
Total flow rate : 300,000 bbl/year
Price of oil : 40 USD/bbl (May 6, 2004)
Total income : 12,000,000 USD
Net income : 10,300,000 USD/year

6. CONCLUSION
Pumping is often necessary in order to get geothermal fluid
to surface. Pumping is some times required to increase
pressure or move the fluids from place to place once they
are on the surface.

There are two types of production deep well pumps for
geothermal well, the difference being location of driver
motor LSP, ESP.

There are four main step to design excellent deep well
pump for one LSP geothermal pump. These point should be
taken into the consideration in order to maximize its MTBF
(mean time between the failures)

Vertical line shaft turbine pumps (LSP) in deep well
settings have two definite limitations. They must be
installed in relatively straight wells and economical setting
limit 250 meters.

This study describes how a geothermal production well is
designed including chemical injection tubes; dynamic water
measurement tube and geothermal deep well line shaft
pumps.

During production of the geothermal brine from the well,
water level should be measured systematically. By means
of systematic measuring of the dynamic level, it will be
easier to get information on the hydrological condition of
the well and reservoir system.

In order to prevent the CaCO3 scaling in geothermal well, a
suitable scale inhibitor is to be used. Having too much kind
of scale inhibitors in the market, it is necessary to be
careful. It should be not only more efficient to prevent the
scale in the well, but also should not threat human health.

Because of the high vibration of the pump and/or motor in
artificial lift geothermal wells (with LSP or ESP) and well
condition, selection of the chemical injection tubes (AIT)
for artificial lift (with LSP or ESP) geothermal production
wells is more important than self flowing well systems.

While selecting AIT for well, operating temperature, tensile
strength, elongation, flexes modulus, hardness and water
absorption should be taken into the consideration.

It was turnaround for development of geothermal district
heating in Balçova. After successful installation and
operation of LSP by deep well and high temperature
Balçova Geothermal Wells, It was started to increase the
capacity of the DHS in Balçova

While selecting LSP system for a geothermal production
well, chemical composition of the geothermal brine (scaling
and corrosion problems), geothermal brine temperature,
well condition and casing design are taken into
consideration fastidiously. For that reason, “specific design
for each well” is rule of thumb.

In order to get operation data which will show to us
operation strategy like expected draw down and production
data during the operation of the well, pumping test is
necessary for each production well.

When we compare an oil production well and geothermal
production well as economical aspect in Turkey, in spite of
the total investment cost of geothermal well is less than oil
well, income of the geothermal well is as much as oil well.

Monitoring is gold key of the project progressing for
geothermal project. Pwh, Twh, Dynamic Level, Flow Rate
has been collected since first day of GDHS 2nd November
1996. All data has been used for the reservoir modeling of
Balçova.

Production casing size of geothermal well should be
designed as minimum 9 5/8” in proven geothermal field.
Because of easy and large size of LSP/ESP pump
installation and chemical/monitoring injection line.

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