Energy output of Geopressed Geothermal Reservoir for Electricity Generation

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Abstract

An investigation of electricity generation from geopressed geothermal reservoir in Croatia as example, involves calculation of hydraulic power, net power of binary cycle, Hydraulic and binary power ratio for different temperature of geothermal fluid at the entrance and exit wells. the increase in power ratio occur at temperature range of (393 to 413 K°), while the power ratio was decreased at temperature range of (413 to 453 K°), then it increased at temperature range of (433 to 453 K°), that in the range $T_{gf,in}(393$ to $413$ K°) there is a decrease in net power of binary cycle, then the net power will increasing in the range of (413 to 453 K°), then it decreased in the range between (453 to 433 K°), the increase in power ratio occur at temperature range of (393 to 413 K°), while the power ratio was decreased at temperature range of (413 to 453 K°), then it increased at temperature range of (433 to 453 K°) and the power ratio was increased with decreased the net power of binary cycle, then decreased with increased the net power of binary cycle, and then increased with decreased the net power of binary cycle.

Keywords: geothermal energy, hydraulic and electrical power, cycle and utilization efficiency, binary power plant, Rankine cycle.

Introduction

Geopressed resources are deep reservoirs of high-pressured hot water that contain dissolved natural gas. A geopressed reservoir is formed in sedimentary formations when water percolates into the pores of a layer of sand. When non-porous shale settles on top, it traps the fluid into the sand layer at very high pressures. Over millions of years, this pressure increases even more as additional sedimentary layers build on top of the reservoir. If the sand body in which the water is trapped is large enough, the reservoir can economically produce energy for quite a long time. An important characteristic of geopressed reservoirs, at least from an energy perspective, is that they contain dissolved methane, or natural gas. This, therefore, yields three sources of energy that can be utilized from the reservoir [Geo Energy, 2000]:

1. Hydraulic energy from extreme pressure.
2. Heat energy from the fluid.
3. Dissolved natural gas.

Comparing to other natural gas reservoirs, the amount of dissolved methane in these types of reservoirs is very small. For the natural gas alone, the reservoir would be uneconomical. However, with two more sources of energy, their utilization becomes worthwhile.
Development activities are currently in progress to utilize the thermal and hydraulic energy available in geopressed-geothermal (geopressed) resources for a variety of direct uses. The higher pressure and temperature found in geopressed resources create the opportunity for many new applications.

Geothermal energy can be defined by splitting it into its components, geo meaning ‘Earth’ and thermal meaning ‘heat’, making geothermal the heat within the Earth. Geothermal energy represents the natural, internal heat of the Earth that is stored within the rock and fluid [Ben Lunis, 1990].

**Example for Electrical and Hydraulic Power at the reservoir VELIKA CIGLENA**

Geothermal reservoir Velika Ciglena shown in Figure (1). Optimal production of the geothermal energy can be obtained on the well VC-1A, because of its production equipment and the thermodynamic conditions of the reservoir. The production layer is at 2545 m, with the static pressure of 247.3bar and the static temperature of 175 °C. total energy production from the VC-1A can be obtained through two heat exchanger cycles.

![Fig. (1) Scheme of Geothermal Power Production](Olurvody, 1984)
Input Parameter for Velika Ciglena Geothermal Reservoir [Olvurdy, 1984]

\[ m = 84 \text{ kg/s} = 7200 \text{ m}^3/\text{d} \] (maximum flow rate at the wellhead conditions)

\[ \rho = 990 \text{ kg/m}^3 \] (at the wellhead conditions)

\[ P_{wh} = 20 \text{ bar} = 20 \times 10^5 \text{ pa} \]

\[ T_{gfin} = 433 \text{K} (160\degree\text{C}) \]

\[ T_{gfout} = 353 \text{K} (80\degree\text{C}) \]

\[ T_o = 284.6 \text{K} (11.6\degree\text{C}) \]

**Hydraulic Power**

\[ P_h = m \left[ \frac{P_{wh}}{\rho} + \frac{W^2}{2} + g.z \right] \]

If second and third terms are omitted:

\[ W^2/2 = \text{velocity at the wellhead is omitted because of small influence to the power output} \]

\[ g.z = \text{elevation at the wellhead is zero} \]

Finally equation for hydraulic power could be written:

\[ P_h = m \frac{P_{wh}}{\rho} \] [KWm]

Thus hydraulic power would be:

\[ P_h = 84 \times 2000000 \times 10^{-3} / 990 = 170 \text{ KWm} \]

If we suppose efficiency of hydraulic turbine approximately 90%, net hydraulic power would be:

\[ P_{hnet} = 170 \times 0.9 = 153 \text{ KWm} \]

If capacity factor is assumed \( \beta = 8000 \) hours annually total produced energy would be:

\[ E_{hnet} = P_{hnet} \times \beta = 1224 \text{ KWhm} = 1.2 \text{MWhm} \]

Available electrical power from Clausis-Rankine binary cycle according to new expression for maximum useful work:

\[ P_{bin} = m \cdot C_{pgf} \cdot (T_{gfin} - T_{gfout})^2 / 2 \cdot T_{gfout} \]

Where \( P_{bin} = \text{maximum useful theoretical work from binary cycle, KW} \)

\( T_{gfout} = \text{heat sink temperature from primary side of heat exchanger, K} \)

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\[ P_{\text{bin net}} = P_{\text{bin}} \cdot \eta_{\text{util}} = 3122 \times 0.312 = 974 \text{ KWe} \]

\[ E_{\text{bin net}} = P_{\text{bin net}} \cdot \beta = 974 \times 8000 = 780 \text{ MWh} \]

If we compare both hydraulic and binary cycle power, the ratio gives total power output for end use:

\[ E_{\text{tot}} = E_{\text{h net}} + E_{\text{bin net}} = 1.2 + 780 = 781.2 \text{ MWh} \]

**Hydraulic and binary power ratio**

\[ \frac{P_{\text{h net}}}{P_{\text{bin net}}} = \frac{153}{974.1} = 0.157 \]

Hydraulic power is the mechanical power could be used for injection of geothermal water back into the reservoir.

The above calculations are repeated for other temperatures of geothermal fluid at entrance and exit and listed in table (1).
Results and Discussions

Results were obtained for geopressed geothermal reservoir in Velika Ciglena station in Croatia as example, where the temperature at the production well was 160°C, pressure of 20 bars and 11.6°C at the reinjection well.

**Fig. (2)** represents the relationship between the temperature of geothermal fluid at the exit (T_{gf\text{out}}) with the temperature of geothermal fluid at the entrance (T_{gf\text{in}}). The increase in T_{gf\text{in}} will increase T_{gf\text{out}}.

**Fig. (3)** represent the relationship between net power of binary cycle with temperature of geothermal fluid at the entrance (T_{gf\text{in}}), at which we observe that in the range T_{gf\text{in}}(393 to 413 K°) there is a decrease in net power of binary cycle, then the net power will increasing in the range of (413 to 453 K°), then it decreased in the range between (453 to 433 K°).

**Fig. (4)** represent the relationship between hydraulic/binary power ratio with (T_{gf\text{in}}), the increase in power ratio occur at temperature range of (393 to 413 K°), while the power ratio was decreased at temperature range of (413 to 453 K°), then it increased at temperature range of (433 to 453 K°).

**Fig. (5)** represent the relationship between power ratio with net power of binary cycle, in which one can observe that the power ratio was increased with decreased the net power of binary cycle, then decreased with increased the net power of binary cycle, and then increased with decreased the net power of binary cycle.

Conclusions

We can write the following conclusions:

1. Maximum temperature of the geothermal fluid at the exit occurs at 453 K of entrance temperature of geothermal fluid.

2. Maximum net power of binary cycle at temperature of geothermal fluid at the entrance of 433 K°.

3. Maximum value of hydraulic/binary power ratio can be obtained at temperature of geothermal fluid at the entrance of 413 K°, and minimum value at 433 K°.
References


Table (1) Net Power, Produced Energy, and Hydraulic/Binary Power Ratio for Different Resource Temperature in Croatia

<table>
<thead>
<tr>
<th>$T_{gf\text{ in}}(\text{K}^\circ)$</th>
<th>$T_{gf\text{ out}}(\text{K}^\circ)$</th>
<th>$\Delta T(\text{K}^\circ)$</th>
<th>$P_{\text{bin net}}$(Kwe)</th>
<th>$E_{\text{bin net}}$(MWe)</th>
<th>Hydraulic/Binary Power Ratio (%)</th>
</tr>
</thead>
<tbody>
<tr>
<td>393</td>
<td>333</td>
<td>60</td>
<td>601</td>
<td>4.8</td>
<td>25</td>
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<tr>
<td>403</td>
<td>343</td>
<td>60</td>
<td>480</td>
<td>3.8</td>
<td>31</td>
</tr>
<tr>
<td>413</td>
<td>353</td>
<td>60</td>
<td>398</td>
<td>3.1</td>
<td>38</td>
</tr>
<tr>
<td>433</td>
<td>353</td>
<td>80</td>
<td>974</td>
<td>7.8</td>
<td>16</td>
</tr>
<tr>
<td>443</td>
<td>363</td>
<td>80</td>
<td>822</td>
<td>6.5</td>
<td>18</td>
</tr>
<tr>
<td>453</td>
<td>373</td>
<td>80</td>
<td>703</td>
<td>5.6</td>
<td>21</td>
</tr>
</tbody>
</table>
Fig.(2) Variation of Temperature of Geothermal Fluid at the Entrance($T_{gfin}$) with Temperature of Geothermal Fluid at Exit($T_{gfout}$).
Fig.(3) Variation of Temperature of Geothermal Fluid at the Entrance with Net Power of Binary Cycle.
Fig.(4) Variation of Hydraulic/Binary Power Ratio with Temperature of Geothermal Fluid at the Entrance.
Fig. (5) Variation of Hydraulic/Binary Power Ratio with Net Power of Binary Cycle.