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THERMODYNAMIC CYCLE OPTIMIZATION IN THE GEOTHERMAL ENERGY PRODUCTION

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Abstract

Optimization of geothermal energy production process means the minimization of all energy losses from the reservoir conditions to the user. As the available energy is being utilized mostly in the wellbore and in the surface equipment, process optimization requires scientific access including the extraction technology parameters.Specific energy on the geothermal wellhead is calculated for two possible cases. The first embraces only geothermal water production, while the other takes into account the saturated steam production as well. Each of these working conditions defines unambiguously designed pressure on the wellhead.The steam and water energy ratio, in function of predicted sink temperature for reinjection of geothermal water, points out the possibilities for commercialization of reservoir Velika Ciglena.

Ključne riječi: geotermalna energija, optimizacija termodinamičkog ciklusa

Sažetak

Optimizacija procesa proizvodnje geotermalne energije obuhvaća smanjenje svih energetskih gubitaka od ležišnih uvjeta do potrošača. Raspoloživa energija uglavnom se troši u kanalu bušotine i površinskoj opremi, pa optimiziranje cjelokupnog procesa zahtjeva znanstveno-istraživački pristup zasnovan na tehnologiji pridobivanja geotermalnih fluida. Jedinična energija na ušću geotermalne bušotine može se izračunati za dva moguća slučaja. Prvi, uzima u obzir proizvodnju geotermalne vode, dok je u drugom prisutna i zasićena para. Odabran način proizvodnje jednoznačno određuje projektirani tlak na ušću bušotine. Omjer jediničnih energija pare i kapljevine u funkciji pretpostavljenih utisnih temperatura geotermalnog fluida može ukazati na komercijalizaciju ležišta Velika Ciglena.

INTRODUCTION

Geothermal reservoir Velika Ciglena is placed 11 km southeast from the city Bjelovar. According to the physical characteristics of rocks, it is the high-temperature reservoir. Optimal production of the geothermal energy can be obtained on the well VC-1A, because of its production equipment and thermodynamic conditions of the reservoir. The production layer is at 2 545 m, with the static pressure of 247,3 bar and the static temperature of 175°C. The geothermal water production should flow through the annular space between the tubing and the casing, which are designed for the wellhead pressure of 20 bars.

According to the temperature of the geothermal fluid and wellhead pressure, two possible cases of production optimization can be considered. The first one is production of liquid and the second is saturated geothermal steam, entering the primary heat exchanger of the binary power plant. In the case of the maximum liquid flow, the wellhead pressure should be kept above

20 bars, because of the scaling. When saturated steam is produced, the wellhead pressure must be below 8 bars along with the inhibitor usage.On the reservoir Velika Ciglena both working conditions are possible, but specific energy in each case is different. These approach leads to the steam-liquid energy ratio being important in determining whether it is more economic to produce steam rather then liquid phase (5), (6).

GEOTHERMAL POWER PLANT INSTALLATION

Simplified diagram on the picture 1 shows the power production from geothermal well VC-1A, using binary cycle based on the thermodynamic Clausius-Rankine process (7). Selection of a working fluid, in a function of the geothermal fluid temperature, is of the major significance for optimized electricity production (4). The best choice of working fluid for the Velika Ciglena reservoir conditions seems to be ethane, because of its physics and chemical characteristics. Total energy production from the VC-1A can be obtained through three heat exchange cycles. After the primary heat exchanger, remaining heat of geothermal fluid can be still utilized for direct applications, such as the greenhouses, balneology or space heating. At primary heat exchanger outlet temperatures can be 70, 80 or 90°C respectively due to binary cycle efficiency needed.

In accordance to the primary heat exchanger, the outlet temperature of the second heat exchanger can be used to 35°C arbitrary (8), (3). Energy usage of the second temperature drop can be considered as probable heat utilization. Possible heat utilization to 11,6°C, according to the average year temperature in Panon, canbe realized at the tertiary heat exchanger for the direct application as well (9).

Significance of the geothermal plants is their ecological advantages. One of the most important is reinjection of geothermal fluid, as in case of reservoir Velika Ciglena, where VC-1 is injection well.

Two following diagrams are calculated for further thermodynamic optimization of Croatian reservoirs which are liquid dominated with temperatures below 200°C.

SPECIFIC ENERGIES OF GEOTHERMAL LIQUID AND STEAM

Comparison of a specific steam and liquid energy gives a new approach for the thermodynamic cycle optimization in the geothermal energy production (2). Specific energy (je) for steam and liquid, calculated upon equations 1 and 2, is given in a function of wellhead temperature (t_{gf}) for different sink temperatures.

For example, if the wellhead temperature is 150°C and sink at 90°C, it can be seen that one kilogram of steam, has specific energy of nearly 400 kJ. If sink temperature is decreased to 70°C for the same wellhead temperature, specific energy arises for almost 50% being about 600 kJ. When liquid phase is produce, it is obvious not only that sink temperature doesn't influence the specific energy, but that its value is much lower than in the case of steam, for the same wellhead temperature. Theoretical maximum work at diagram 1 gives quantitative limits for the energy production, in two different ways:

a) LIQUID

When liquid production is defined with the wellhead temperature and pressure, specific energy follows from next expression:

$$je = \frac{c_{pgf} \cdot \Delta T^2}{2 \cdot T_o} \quad \left[\frac{kJ}{kg}\right] \qquad (1)$$

Equation 1 represents geothermal water production between the temperature of geothermal fluid at wellhead, until its temperature is reduced and rejected to the sink as waste heat.

b) SATURATED STEAM

If steam is produced, defined also with the wellhead temperature and pressure, specific energy is determined from:

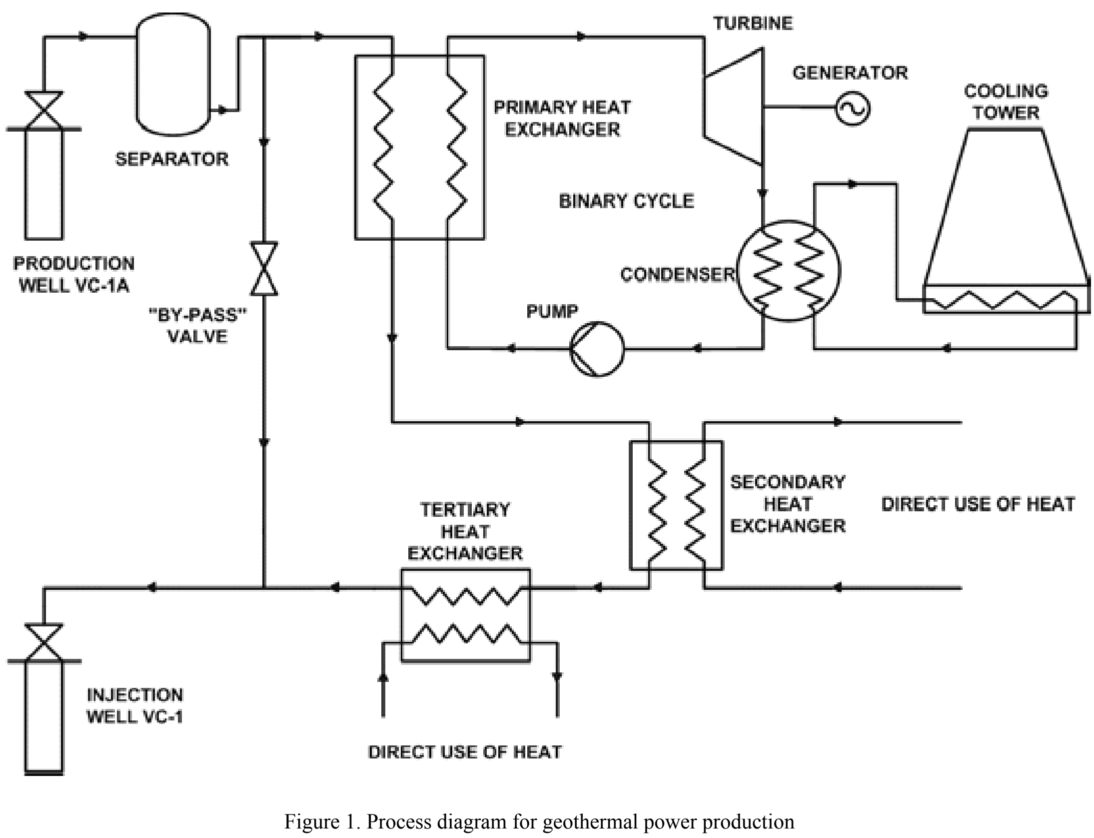

Figure 1. Process diagram for geothermal power production

Slika 1. Procesni dijagram geotermalnog postrojenja

$$je = i''_{gf} \cdot (1 - \frac{T_o}{T_{gf}}) + \frac{c_{pgf} \cdot \Delta T^2}{2 \cdot T_o} \quad \left[\frac{kJ}{kg}\right] \quad (2)$$

Equation 2 shows two consecutive reversible processes; the first part of expression includes the heat from the condensing vapour and the second part of equation extracts the reminder of the heat from the liquid condensate.

Symbols given in formulae are:

je - specific energy, kJ/kg

c_{pgf} - specific heat of geothermal fluid, kJ/kg K

ΔT - temperature difference between inlet and outlet temperature of geothermal fluid at the power plant's heat exchanger, K

T_o - sink temperature at the injection well, K

T_{gf} - temperature of geothermal fluid, K

i''_{gf} - enthalpy at the steam saturation line, kJ/kg

The worth of expressions in equations 1 and 2 is that specific energy (je) strongly depends on the square temperature difference increase (ΔT). Mathematically speaking, second power of temperature difference in both equations points out that heat exchanger is the most important part in thermodynamic cycle optimization (1).

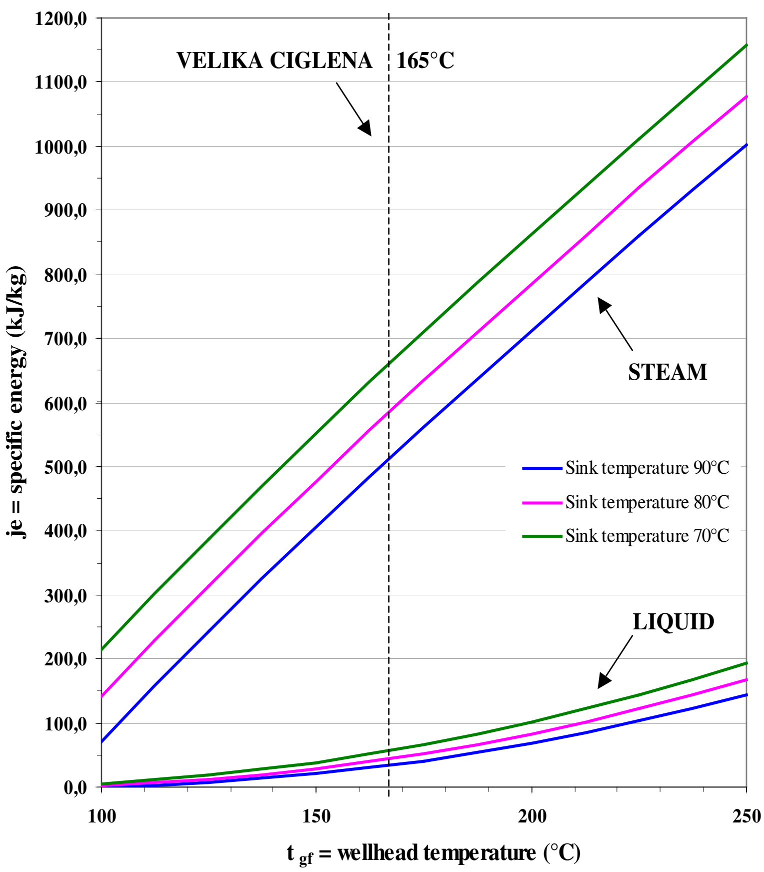

Diagram 1. Specific energy related to the wellhead temperature

Dijagram 1. Odnos specifične energije i temperature ušća

SPECIFIC ENERGY RATIO ON VELIKA CIGLENA

Specific energy ratio (r) from equation 3, in function of the wellhead temperature (T_{gf}), for different sink temperatures (T_o), is shown on diagram 2.

$$r = \frac{je(steam)}{je(liquid)} \quad (3)$$

The steam-liquid ratio for geothermal wells with the temperature above 180°C is of minor significance, as it convergates to same value for each sink temperature (1).

But, it has major significance for wellhead temperature range from 100°C to approximately 180°C. This new approach can be particularly analyzed for Velika Ciglena conditions, having 165°C on the wellhead and 80°C at outlet of heat exchanger. Working point on diagram 2 shows that steam energy is14 times higher than energy from liquid, for the same wellhead and sink temperature. The curves for sink temperatures on diagram 2 are given for whole range of the wellhead temperatures only due to entire mathematical presentation, but the real working condition of heat exchanger should be balanced to the conditions of the whole geothermal system.

CONCLUSION

Reservoir Velika Ciglena is taken as an example for thermodynamic cycle optimization in geothermal power production, although the proposed approach can be applied to all high temperature reservoirs. The whole idea is based upon the specific energy, analyzed for both possible production fluids. In each case, the wellhead temperature is related to the geothermal energy as the temperature difference at the primary heat exchanger mostly influences total amount of produced energy. Moreover, it is proved that energy of the geothermal fluid arises with second power of temperature difference.

Thermodynamic cycle in power production can be further optimized from the view of the energy ratio, impacting the efficiency of heat transfer from geothermal fluid to the working media. Although it is known that the saturated steam gives more energy per unit than liquid, a quantitative value of the steam-liquid ratio is mathematically demonstrated for Velika

Ciglena. If the value of sink temperature is constant, steam-liquid ratio strongly decreases with the geothermal fluid temperature growth. In the case of sink temperature of 80°C, this ratio can be changed for as much as 60 to 10, if the wellhead temperature would be alternated from 100 to 200°C. This kind of investigation can be useful in the determination of working point in whatever geothermal installation.

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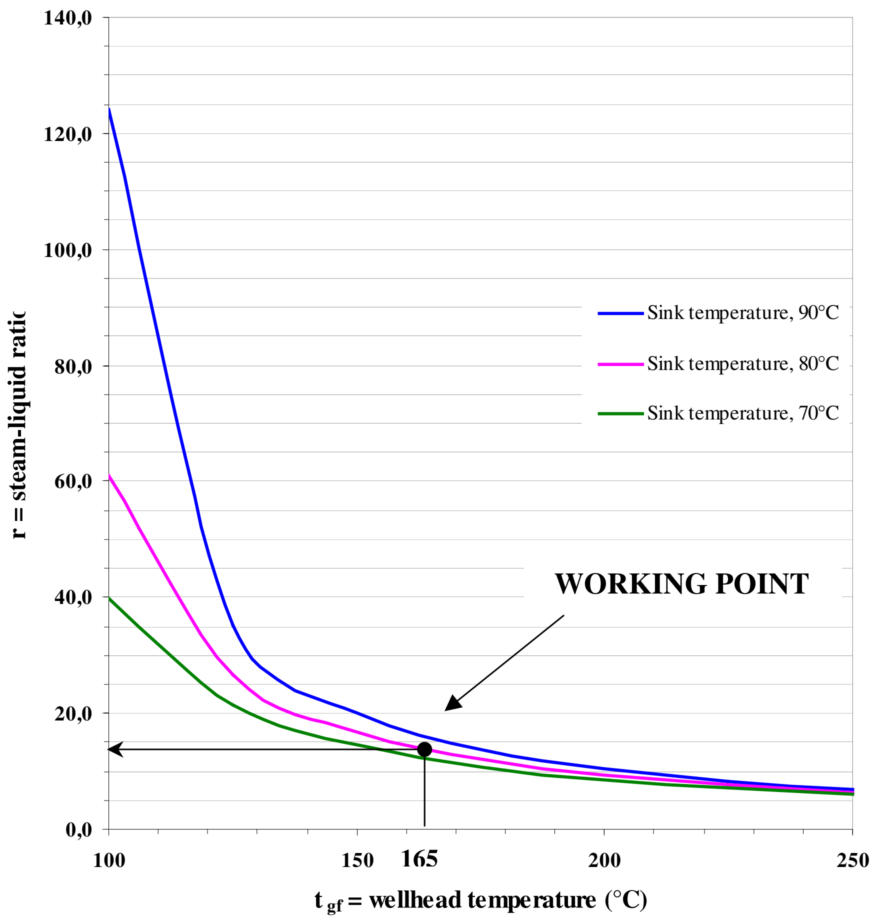

Diagram 2. Steam-liquid ratio related to the wellhead temperature

Dijagram 2. Omjer energije pare i kapljevine prema temperaturi ušća