Evaluation of the Low Temperature Geothermal Sources in Croatia

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1.1.1 Abstract

Geothermal sources are exploited in two basic forms, i.e., the primary form of thermal energy and that converted into electrical energy by using an adequate thermodynamic cycle. There is a possibility of applying several processes for the conversion of thermal into mechanical or electrical energy which depend on the thermodynamic characteristics of the geothermal water. Geothermal sources in Croatia do not contain steam of relatively high temperature, like in Italy, although both countries are nearly in the same position with respect to geothermal belt.

Geothermal sources in Croatia are mostly so-called low-temperature geothermal sources with water temperatures lower than 100°C. A few of them have been exploited, although the percentage of utilization of their available power is still very small. The low-temperature potential is a major disadvantage when it comes to power generation, since state-of-the-art geothermal power plants require reheated steam or hot water to operate. There is a common belief that the optimum way of exploiting low-temperature geothermal sources is heat generation.

Therfore, this analysis is especially aimed at potential users and showing the technical and economical possibilities of using low-temperature sources for conversion of thermal energy into mechanical work and electrical energy.

2 INTRODUCTION

The Croatian underground contains geothermal potentialities mainly as low grade energy. The maps of heat flow density (Jelić) and temperature distribution are drawn, and area of geothermal resources is defined by the estimation of the heat in place according to geothermal gradient. First effort is made by Croatian government and authorities to develop allover geothermal investigation. Under the scientific research of the University of Zagreb and Faculty of Mining, Geology and Petroleum Engineering first reliable assessment are done, and geothermal potential covered the whole country. The results are obtained and published (Golub et al., 1998) on the base of subsurface temperatures determinations, hydrogeological characteristics of aquifers and geothermal fluid flow in drilled boreholes (approximate 80 wells made by INA Oil Industry).

3 GEOTHERMAL ENERGY UTILIZATION

Geothermal water utilization from natural springs in Croatia has a very long tradition primary for medical and balneological purposes. Along with research for oil and gas, geothermal activities are being observed mainly in the last two decades of twentieth century. The geothermal reservoirs are placed in the northernwest and eastern parts of Croatia. Some of them, exactly three only, could be converted into electricity because of their relatively high temperature between 150-200°C with saturated water under the high pressure exceeding 250 bar. None of them has been successfully used until today, nor is production of electricity established.

Some pre-feasibility studies on combined electricity and heat production at Velika Ciglena geothermal reservoir showed acceptable economic production in the future. According to Petroleum Engineering Department anticipated development with pilot project and two scenarios should bring Croatia closer to the countries in our neighborhood. Ministry of Science and Technology financed these investigations (Competitiveness of energy price of geothermal pilot project in Croatian economy, Project No. TP-01/0195-01, www.mzt.hr) (Golub, 2000) and Faculty of Mining, Geology and Petroleum Engineering finished this study two years ago, but pilot project has not yet been established because of lack in financial support.

4 VELIKA CIGLENA RESERVOIR (MODES OF PRODUCTION)

This geothermal field consists of four drilled boreholes of which are two production wells and two injection wells. High flow rate of 10000 m^3/day has to be achieved in order to keep the wellhead temperature of 170°C and pressure of 20 bar. Used geothermal water needs to be re-injected to meet environmental regulations. Design of proper re-injection procedure has not been established because of the limited knowledge about reservoir conditions and lack of the interference test. In spite of these limitations global power formula could be applied according to two possible production procedures: steam or saturated water named cases (A) and (B).

5 POWER CYCLE THERMODYNAMICS

Theoretically available mechanical energy (exergy) under own investigation could be as follows (Golub, 2002):

A) Liquid dominated geopressurized geothermal well (saturated liquid)

$$P_{ex} = \frac{D \cdot c_p \cdot \left(T_{gf} - T_{cs}\right)^2}{2 \cdot T_{cs}} \cdot \eta_u$$

where D is the mass (delivery) of geothermal fluid in kg/s, c_p the heat capacity of the fluid in kJ/kg°K, T_{gf} the temperature of geothermal fluid at the wellhead in °K, T_{cs} the temperature of the cold sink in °K, η_u the utilization efficiency (Milora and Tester, 1976), P_{ex} the exergy of the geothermal fluid in MW_e (1)

B) Steam dominated geothermal well (saturated steam)

$$P_{ex} = \left[h_{gs}'' \cdot \left(1 - \frac{T_{cs}}{T_{gf}} \right) + \frac{c_{pw} \cdot \left(T_{gw} - T_{cs} \right)^2}{2 \cdot T_{cs}} \right] \cdot \eta_u \qquad (2)$$

where h_{gs}'' is the enthalpy of geothermal steam at the saturated line (enthalpy of vaporization) in kJ/kg

These two formulas now could be applied for Velika Ciglena reservoir (Figure 1)

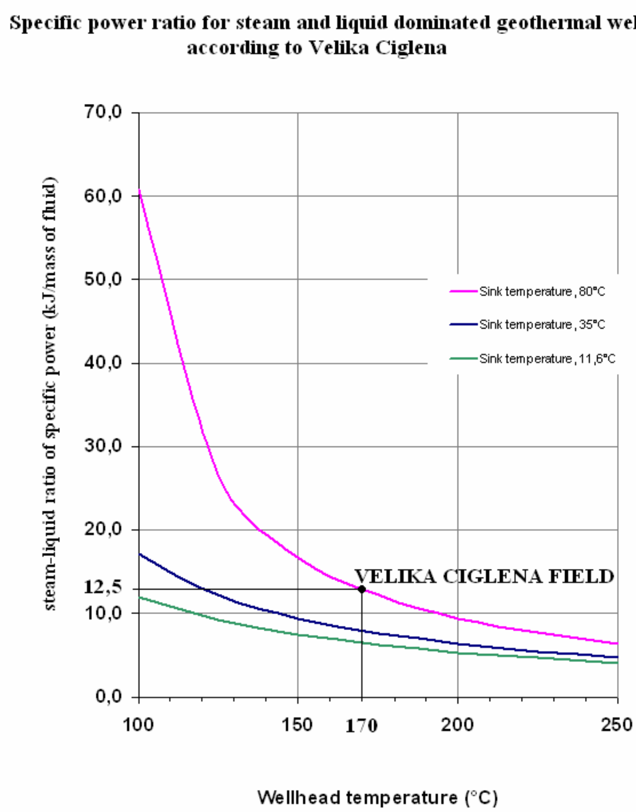

Figure 1. : Specific power ratio for steam and dominated geothermal wells according to Velika Ciglena reservoir

6 EXAMPLE FOR VELIKA CIGLENA RESERVOIR

Conversion of energy (Lamb et al., 1980) depends on the temperature of the geothermal fluid (T_{gf}),as well as on heat rejection conditions (T_{cs}). If we assume temperature at the wellhead (T_{gf}) of 170°C with the heat capacity for saturated water, at the constant pressure, of c_p=4,109 KJ/kg°C, and with sink temperature (T_{cs}) of 80°C, specific power according to case (A) would be approximately 47 kW·s/kg of geothermal fluid production. For the same (T_{gf}) and (T_{cs}), specific power derived from geothermal flashing plant would be 12,5 times greater (Figure 1.) than the thermodynamic process with saturated water. Below 200°C the superiority of steam is evident which leads to power plant capital cost, and it is reasonable to assume that costs are close related on the delivery of geothermal fluid. Steam liquid ratio is given by dividing specific power of flashing cycle on the saturated vapor line with denominator of liquid dominated geopressurized geothermal thermodynamic cycle. In these calculations (Figure 1.) utilization efficiency is not included because the real thermodynamic cycle for the Velika Ciglena reservoir has to be designed according to re-injection of fluid. Utilization efficiency (Milora and Tester, 1976) describes the fraction of the theoretically available mechanical energy which can be transformed into electrical energy by real Clausius – Rankine or Brayton thermodynamic cycles. Generalized cost model for Velika Ciglena pilot project with arbitrary chosen saturate liquid production (case A) is enclosed here.

The maximum reversible work-availability or exergy could be produced by single fluid cycle optimization (Optimization of thermodynamical process in geothermal energy utilization, project No. 0195045, www.mzt.hr) (Golub, 2002) for supercritical and subcritical binary cycle plants with temperature differences between (T_{gf}) and (T_{cs}) for negligible levels of potential and kinetic energy.

Power cycle economics is the most influenced by the direct and indirect cost for wells and economic factors for subsurface and surface equipment (pumps, heat exchangers, condensers and etc.) In economics which will be introduced, two different calculations are made as follows.

7 ECONOMICAL ANALYSIS

7.1. Market analysis

Utilizing geothermal reservoirs as an energy resource it is possible to assure production of:

- electrical energy
- heat energy
- combined heat and electrical energy

Characteristics of most Croatian geothermal reservoirs are low temperatures of geothermal water (around 100°C, or slightly higher), allowing only production of heat energy. From economic aspect this is the most cost effectiveness way to utilize geothermal energy, but only if a nearby consumers are present with potential of maximum exploitation of geothermal capacity.

Geothermal reservoir Velika Ciglena is one of the few with temperatures of geothermal water around 170°C (without throttling effect named Joule-Thompson coefficient), enabling production of both electrical and heat energy.

Theoretically available mechanical and heat energy of the Velika Ciglena reservoir is calculated according to case (A) for two production wells (fluid flow of 10000 m^3/day) as follows:

- 11 MW_e of electric energy (from wellhead temperature of 170°C to sink temperature of 80°C)
- 34 MW_t of heat energy (from 80°C to 35°C)
- 18 MW_t of heat energy (potential resources, from 35°C to dead state heat rejection temperature of 11,6°C)

Assuming rate of exploration of:

- 8000 h/y for production of electric energy and
- 2500 h/y for production of heat energy,

it is possible to assure following amount of energy production:

electric energy:

- $11 MW_e \times 8000$ h/y = 88000 MWh/y

heat energy:

- $34 MW_t \times 2500$ h/y = 85000 MWh/y
- $18 MW_t \times 2500$ h/y = 45000 MWh/y

Advantage of overall system is in its cascade utilization of heat energy. After primary electrical production cycle of 11 MW_e, remaining heat energy could provide 34MW_t of power (secondary cycle) with sink temperature of 35°C. With further utilization in tertiary cycle (balneology) up to mean annual ground temperature (for Croatia this value is 11,6°C regarding to condition of dead state heat rejection temperature) additional 18 MW_t could be used. Heat energy is planned to be used for only 3,5 months annually which is only 30% of disposed capacity. Every further increment of heat energy annual load factor contributes to greater cost effectiveness of project investment. Moreover, tertiary cycle of geothermal heat energy utilization is classified as potential energy resource of geothermal energy (after criteria of consumer's admissibility) and it is not taken in consideration of cost effectiveness of Velika Ciglena geothermal reservoir.

7.2. Potential energy consumers for geothermal reservoir

Electric energy practically doesn't have limitations in today's common energy consumption. Also, it can be used as a source of energy for internal consumption of major energy users.

To such energy user it would be reasonable to invest in own energy resource, like geothermal reservoir, because of its reliability in power supply and independence towards centralized energetic systems. Electric energy could be also distributed in central energetic network of Croatia, through National Energetic Company HEP. Terms of distributing electric energy from renewable resources are still undefined through law regulative, but selling price should be about 10% lower than ordinary tariff of 1 kWh of electric energy which HEP distributes.

When heat energy is utilized there are constraints in distributing energy only to near facilities and consumers. Justifiability of using heat energy requires concrete users with heat energy demand and their location nearby geothermal well. Potential users could be:

- greenhouses for growing vegetable or flowers,
- driers of agricultural products,
- economical and health facilities,
- smaller settlements (or part of the settlement),
- recreational, health and sports centers (for the purposes of heating and balneology) etc.

If nearby there are none of this kind of consumers, the existence of geothermal reservoir can stimulate some of the above economic activities thanks to disposition of available energy at the site.

Heat and electrical energy can be used even for cooling purposes which enable possibility of solving all energy needs (heating, cooling and electric power) for possible users, simultaneously making greater load factor of geothermal reservoir utilization.

8 MARKET COMPETITION AND COMPETITIVENESS OF PRODUCT

Energetic resources and some forms of energy in general do not tend to be a subject of market competition. Their strategically importance for every country assume that their price is only partially been determined under market influence and mainly by political and economy relations. It's the fact that renewable energy resources for now cannot substitute energy produced from conventional resources. Nevertheless, they can contribute to partial decentralization of energetic sector and reduction of dependence upon imported energy.

Renewable energy market practically does not exist in Croatia nor the organized production. Despite of significant potentials in producing renewable energy, it is still only part of the declarations, strategies and commitments. (Rajkovic et al., 1999) In "Croatian Strategy of Energetic Development", which was brought by Croatian Ministry of economic as late as 1998, and it is divided into three alternatives, amount of energy from renewable resources in total energy consumption predicts to be 6% in unfavorably alternative and 11,6% in favorably alternative.

Reason for lack of market is in whole series of obstacles which would otherwise stimulate production and consumption. Some of them are:

-legislature regulations
-economical, financial and fiscal measures
-tariff policy
-system of technical and organizations measures

However, most of all, complete lack of marketing advertisement is responsible that potential contractors didn't invest in energy production from renewable resources nor the consumers were interested in their usage. In this way this is somewhat closed circle, without any public demand there is absence of production, and inversely.

Therefore, today most favorable possibility of using renewable energy is for internal consumption. (Rajkovic et al., 2001) Certain economic activities (such are tourism, production and manufacturing of vegetables, production of structural materials and glass etc.) which are large consumers of energy would benefit from investment in their own renewable resource of energy for internal consumption.

Geothermal energy is one of the most perspective renewable resources in Croatia. There are many defined geothermal wells with complete or partially made infrastructure. This imply to numerous already made geothermal wells, which is most expensive part of investment in geothermal energy. There are result of exploration for gas and oil by INA-Naftaplin Company. Therefore, if these existing wells will not be included in totally needed investment, major factor for competitiveness of geothermal energy utilization would be assured. For an example, utilization from Velika Ciglena field does not require drilling of new wells whose price is around 2 350 000$ for depth of 2900m.

In case of non-utilization from four wells of Velika Ciglena, wells would have to be closed, according to Mining law (NN 35/95 paragraph 51). Average price of closed-in time well is around 350000$, which means that in case of starting production, recovery cost for each well would be included in investment.

9 EVALUATION OF INVESTMENT

Necessary investments are estimated for assumed power of geothermal reservoir Velika Ciglena and for following variants:

-production of electrical energy only

-production of electrical and heat energy, respectively

For each of two variants two possibilities are assumed:

-value of existing wells is included in total investment with amount of 2 350 000$ per well,

-in total investment value is include only reconstruction and preparing of existing wells for geothermal energy production with amount of 350 000$ per well.

9.1. Necessary investments

Table 1.: Necessary investments in electric and heat energy production on Velika Ciglena reservoir (USD)

Description	With total wells cost	Only reconstruction of wells
PRODUCTION OF ELECTRICAL ENERGY		
1. Technical documentation	50 000	50 000
2. Production of geothermal water	5 214 000	1 214 000
-production wells (2)	4 700 000	700 000
-other (collective system, pumps, facilities)	514 000	514 000
3. Power production plant (2 binary units, electric equipment, diesel aggregate etc.)	10 077 000	10 077 000
4. Re-injection system	5 090 000	1 090 000
-injection wells (2)	4 700 000	700 000
-pumps, pipelines, facilities	390 000	390 000
5. Unexpected (cca 20%)	2 112 800	2 112 800
ELECTRIC ENERGY - TOTAL	22 543 800	14 543 800
PRODUCTION OF ELECTRICAL AND HEAT ENERGY		
6. Facility for production of heat energy (primary cycle)	3 205 000	3 205 000
7. Facility for production of heat energy (secondary cycle)	838 000	838 000
ELECTRIC AND HEAT ENERGY - TOTAL	26 586 800	18 586 800

Amount of working capital for each variant is estimated to be 150 000$.

9.2. Mean Investments

Table 2.: Mean investments for electricity and heat energy production (USD/MW)

	With total wells cost	Only reconstruction of wells
ELECTRICAL ENERGY		
For 11 MW_e	2 049 436	1 322 163
Ratio	1	0,65
For 33 MW_t	683 145	440 721
ELECTRICAL AND HEAT ENERGY		
For 64 MW_t	415 419	290 419

For purposes of mean investments comparison, total power of heat and electrical energy production is displayed in heat units. Without inclusion of total wells cost investments could be lower for as much as 35% for electric production only. With production of electric and heat energy, and without total wells cost, investments deflate additional 35% regarding production of electricity only. This considerably encourages cost effectiveness of the pilot project.

9.3. Financial analysis

One of the factors of competitiveness is selling price of electrical and heat energy. Selling net price for electric energy is derived on the basis of lower and higher tariff according to which HEP company delivers electricity to users and additionally reduced for 10% (term of HEP company for electricity takeover from other producers, still legislative undefined). Therefore, resulting selling price would be 6,46 UScent/kWh (0,4842 HRK/kWh). In first variant profit would be 1,33 UScent/kWh or 20% of selling price, and for second variant profit would be 2,64 UScent/kWh or 41% of selling price. Time factor was not taking into consideration, but with discount rate of 8% annually cost effectiveness would be assured for each of two variants.

Basis for calculation of heat energy selling price is cost of 1m^3 of natural gas, in distribution for wide consumption, with amount of 26,68 UScent/m^3.This selling price is reduced for 30% which gives 18,68 UScent/m^3, making basis for calculating geothermal heat energy selling price.

(Rajkovic et al., 2003) Reason for this method is determination of competitiveness for geothermal energy over natural gas. Therefore, gained selling price would be 4,85 US$/GJ.

9.4. Main financial index

Table 3.: Main financial index for Velika Ciglena geothermal reservoir project

	With total wells cost	Only reconstruction of wells
Investments (US$/$MW_e$)	2 116 690	1 389 418
Ratio	1,00	0,65
Cost price (UScent/kWh)	5,13	3,81
Cost price (HRK/kWh)	0,3846	0,2859
Selling price (UScent/kWh)	6,46	6,46
Selling price (HRK/kWh)	0,4842	0,4842
Gross profit (UScent/kWh)	1,33	2,64
Gross profit (%)	20	41
Heat energy selling price (US$/GJ)	4,85	4,85
Heat energy selling price (HRK/GJ)	0,3669	0,3669

10 IMPACT ON EMPLOYMENT

Project Velika Ciglena would ensure employment of 13 workers which doesn't represent greater impact of overall employment. However, with utilization of greater number of geothermal reservoirs, as well as employment in economic sector which would be initiated by available energy from geothermal reservoirs, degree of employment would be indirectly enhanced.

11 CONCLUSION

Amount of geothermal energy from Velika Ciglena reservoir was calculated according to production case A (section 4), which refers to liquid dominated geothermal source. Theoretical power from two production wells was analyzed through economic study in two possible ways. First method does not take into account total well price, but only reconstruction of wells. Second method takes full price of wells and financial comparison between two cases was made, taking into account price of heat and electric energy on Croatian market. The cost of power derived from geothermal flashing plant at Velika Ciglena (case (B)) in section (4) has to be made in the future.

REFERENCES

[1] Golub et. all: *GEOEN, Geothermal energy utilization; Previous results and future activities*, Energy institute Hrvoje Požar, Zagreb, Croatia, 1998

[2] Golub, M.: *Competitiveness of energy price of geothermal pilot project in Croatian economy*, Project No. TP-01/0195-01, www.mzt.hr

[3] Golub, M.: Optimization *of thermodynamically process in geothermal energy utilization*, Project No. 0195045, www.mzt.hr

[4] Lamb, J.P.; Polansky, G.F.; Bradley, S.P.: *Generalized performance predictions for energy conversion plants using geopressured geothermal fluids*, Proceedings Fifteenth Intersociety energy Conversion engineering conference, Vol.1. pp 804-809, USA, 1980

[5] Milora, S. L.; Tester, J. W.: *Geothermal energy as a source of electric power*, The MIT Press, New York, 1976.

[6] Rajković, D.; Golub, M.; Košćak, S.: *"Energetic and economic justification of using low temperature geothermal fields in Croatia"*, 24th International Petroleum Conference and Exhibition, Ferekes H., Tihany, Montan Press, Hungary, 18-20 October 1999, pp.6

[7] Rajković, D.; Golub, M.; Košćak-Kolin, S.: *"Technical and economical possibilities of using low temperature geothermal sources in Croatia"*, 17th International Mining Congress and exhibition, Ankara, Turkey, 3-7 June 2001, pp.6

[8] Rajković, D.; Golub, M.; Košćak-Kolin, S.: *"Profitability of investment in the low temperature geothermal sources in Croatia"*, Book of proceedings, International Conference on Sustainable Development Indicators in the Mineral Industries, Milos Island, Greece, 21-23 May 2003, p. 217-222