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Technical and Economic Possibilities of Using Low Temperature Geothermal Sources in Croatia

D.Rajkovic, M.Golub & S.Koscak-Kolin

Department of Petroleum Engineering, University of Zagreb, Croatia

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 are mostly so-called low-temperature geothermal sources with water temperatures lower than 100°C. 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. This paper examines the technical and economical possibilities of using low-temperature sources for conversion of thermal energy into mechanical work and electrical energy.

I INTRODUCTION

Geothermal sources in Croatia do not contain steam of relatively high temperature like in Italy, although both countries are in almost the same position with respect to geothermal belt. Nevertheless, the low-temperature difference Stirling engine can be successfully applied even when hot water is of a moderate temperature. Calculations based on the recently confirmed geothermal wells indicate there is a potential for generation of about 46 MW of electrical power. The feasibility of the low-temperature difference Stirling engine for exploitation of the existing geothermal potential in Croatia is analyzed on the ground of energy and economic advantages.

A binary process is used for geothermal reservoirs at relatively low temperature. In this process, the geothermal fluid in the heat exchanger only transmits heat to the secondary highly volatile fluid used to drive the turbine, to be reinjected into the reservoir through the injection well.

The Stirling cycle seems to be a better and more practical solution resulting in considerably higher efficiency because it is thermodynamically equivalent to optimum Carnot's cycle, while Clausius-Rankine follows this cycle only partially. The development of Stirling's engine with flat plate heat exchangers has shown that low-temperature geothermal reservoirs may also be successfully used for conversion of heat into mechanical work or electrical energy. The temperature difference of not more than several degrees Celsius which enables the process makes the flat plate low AT Stirling engine particularly attractive for exploitation of this kind of geothermal source. Hot water from the well circulates through a number of Oat boxes connected with a crankshaft driven by a generator. After transferring its heat to the plant, the cooled water is returned to the reservoir by means of the injecting pump. In addition, a geothermal plant using the Stirling cycle has considerable technical and economic advantages over the classic Clausius-Rankine process because there is no evaporator, condenser, FW pump or numerous other mechanical elements. This makes the Stirling cycle technically simpler and less investment- and cost-intensive.

For this reason, this paper gives a comparison of technical and economic efficiency for binary and Stirling facilities using a geothermal reservoir *with* known reserves, constructed wells and geothermal water quantities.

Figure 1. Locations of the geothennal fields in Croatia.

2 GEOTHERMAL ENERGY POTENTIAL IN REPUBLIC OF CROATIA

All the geothermal reservoirs in the Republic of Croatia can be classified in two groups:

A) reservoirs with temperature of geothermal water below 100°C (1 to 23 in Figurel);

B) reservoirs with temperature of geothermal water above 100°C (24 to 28 in Figurel).

The geothennal reservoirs are situated in the central and Panonian regions of Croatia, as shown in the geographical map. The central region comprises the areas from Kordun and Banovina to Medimurje. The Panonian region extends through the Panonian basin and Medimurje to the eastern border of Croatia.

In Croatia, there are 14 locations where geothermal energy is used mostly for balneology, recreation and space heating. Still, this is only a half of the total of 28 geothennal reservoirs situated in the northern part of Croatia. Therefore, techno-economical analysis of direct geothennal energy use is provided for all fields. The main parameters in the technical part of the analysis are the number of geothennal wells and related flows and temperatures as the basis for installed thermal power calculation.

3 TECHNICAL AND ECONOMIC POSSIBILITIES OF USING GEOTHERMAL ENERGY

3.1 *Direct geothermal energy usage*

Existing capacities are presented in Table 1, where the flow (q) and temperature (t) of geothermal water at production wells are actually utilized.

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The temperature difference (At) is the average value of the differences between geothermal water temperatures (t) and the outlet temperature at relevant heat exchanger, given by user. These data are the basis for thermal power (Q) calculation, which is the sum of power at each well at one location. The total geothermal capacity used at the 14 locations in Republic of Croatia is only 42 MW thermal.

A possible increase in geothermal energy use can be realized in three ways. The first is use of the maximum peak flow at existing wells. The next step is utilization of the maximum temperature difference, with an outlet temperature from the heat exchanger of 20°C. The third power increase can be realized by involving more wells in heat generation. When all these conditions are put together, the maximum geothermal potential could reach 740 MW,.

The unit costs (cGE) of direct geothermal energy use are calculated by adding the unit capital cost, unit maintenance and unit electrical cost for pumping energy at every reservoir, as presented in the diagram below.

Unit costs (cGE) are different for the various geothermal locations. The lowest energy cost is at Velika Ciglena, while the highest is at Krizevci, as shown in Diagram 1. However, the reference value of importance for future geothermal development is an average price of 0.0166 USD/kWh,, which should be taken as the same for all the geothermal fields in distribution.

In Diagram 1 it can be seen that exploitation of most reservoirs is below the average line, and is profitable. The other 10 reservoirs with unit costs higher than the average price are not competitive economically.

The most valuable are higher temperature resources. They can produce the largest capacities with increased capital cost and the lowest energy price.

Table 1. Installed capacities for direct geothermal energy use.

No.	Name of reservoir	Geothermal well	Flow q (m^3/h)	Temp. t (°C)	Delta T Δt (°C)	Power Q (kW_t)
1	Bizovac	Biz-4	14	98	42	1560
		Slavon-1	18	86		
2	Daruvar	Antunov ı.	34	47	27	2000
		Ivanov iz.	30			
3	Ivanic Grad	Iva-Tl	10	60	26	300
4	Jastrebarsko	izvor	190	26	6	1320
S	Krapina	KRT-1	145	42	13	2200
6	Lipik	B4a	30	61	26	900
7	Pofcga	izvor-1	10	27,5	5	740
		izvor-2	MO	25		
		trofi-1	7	24,5		
8	Samobor	STB-I	108	28	8	1000
9	Stubica	izvor	35	48	20	3720
		B-l	126	57		
10	Topusko	TEB-1	45	63	26	9200
		TEB-2	35	63		
		TEB-3	225	63		
II	Tuhelj	izvor 1	145	32	12	3760
		izvor 2	125			
12	Varazdui	BI	72	58	23	2600
		B2	7			
		B3	18			
13	Zagreb-Ml.	MIadost-1	11	70	50	3420
		MIadost-3	50	80		
14	Zlatar	Sutinka-1	210	26	10	9420
		Sutinka-2	30	26		
		Sutinka-3	570	39		

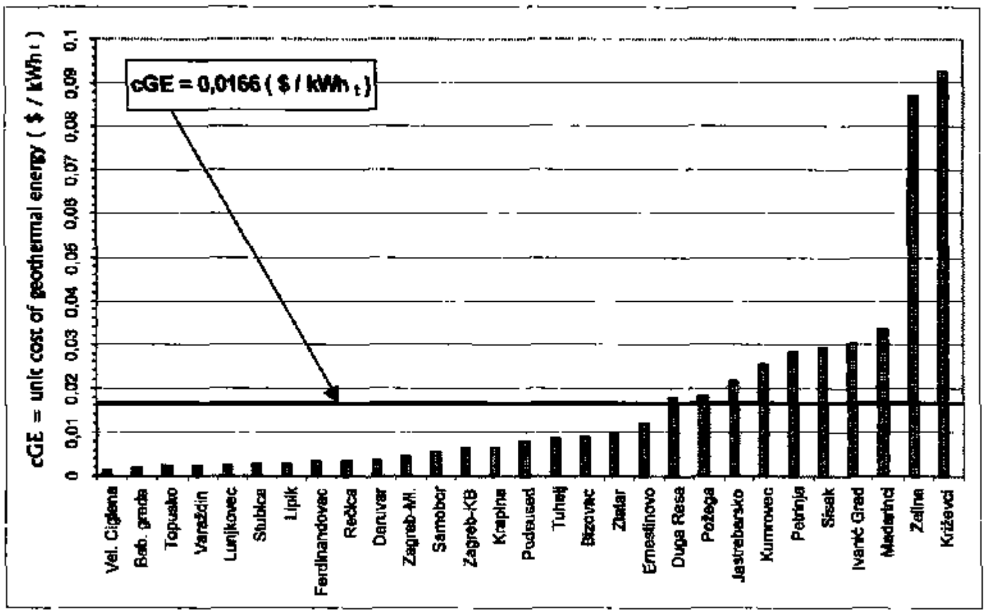

Diagram 1. Geothermal reservoirs sorted according to unit energy cost.

3.2 *Binary process*

By conversion of thermal into electrical energy (Table 2) in a binary cycle, it is possible, with the existing water yield and temperature, to ensure gross power of Nb=3.8 MW_e. The power necessary for station service consumption is 0.5 MW_e, so the net power (delivered to the power grid) is N_n=3.3 MW_e. For the economic analysis, die selling price of electricity is p=72.2 USD/MWh. Assuming the facility would be in operation for 8,000 hours a year, the annual electricity output would be:

E= N„*8,000 = 3.3*8,000 = 26,400 MWh/year.

The total revenue from electricity sales would be:

UPe= E*p_e = 26,400*72.2 = 1,906,880 USD/year

With regard to downstream heat exchangers, the water temperature is 70°C, and its thermal energy could be used by numerous consumers (greenhouses, fish ponds, dryers, *the* tourist industry, and die like). The available temperature difference being At=30°C, it is possible to ensure maximum heat generation of Q=22.6 GJ/h. Assuming the heat delivery is planned for 2,000 hours, and a with selling price of PQ= 2.76 USD/GJ, die total revenue of thermal energy sales would be:

UPo=Q*2,000*po=22.6*2,000*2.76=124,807USD/year

The total annual revenue from selling thermal and electrical energy from the binary cycle would be:

SUP = UPe +UPQ = 2,030,887 USD/year

and it would remain constant for me calculation period of 20 years.

3.3. *Stirling process*

In all thermodynamic processes in which heat is converted into mechanical work or electrical energy, and particularly when low-temperature sources are involved, ambient temperature plays an important role. Therefore, use of the Stirling process in a hypometical geodiermal reservoir would change energy potential throughout the year relative to changes in average ambient temperature.

Calculation of the possible power generation from geothermal reservoir "X" - cascade process.

Well yield: D= 146 l/s = 525,600 kg/h
Outlet temperature: T_i= 136°C = 408°K
Ambient temperature: T_0= 20°C = 293°K
Mean temperature: T_s= $(T_i+T_0)/2$ = (136+20)/2 =78°C = 351°K
Temp, difference: ΔT= T_s-T_0 =408-293 = 58°K

Camot's efficiency: $\eta c = \Delta T/Ts = 58/351 = 16.5\%$
Thermal power: $Q = D * cp * \Delta T =$
$= 525{,}600 * 1/860 * 58 =$
$= 35{,}447$ kWt ~ 35.5 MWt
Electrical output: $N = Q * \eta c = 35.5 * 0.165 = 5.9$ MWe
Power generation: $E = N * z = 6 * 8{,}760 * 0.8$
$= 42{,}048$ MWh

The values calculated could be achieved in a cascade process and by use of a flat plate Stirling engine, with a yield of 146 1/s, geothermal water outlet temperature of 135°C and assumed constant ambient temperature of 20°C.

The calculation basis was a gross plant power of Nb = 5.9 MW_e. As for the binary process, the station service consumption is assumed to be 0.5 MW, and the net power (to be delivered to the grid) is N_n=5.4 MW_e. Assuming 8,000 operating hours a year, the power generation would be:

$E = N_n * 8{,}000 = 5.4 * 8{,}000 = 43{,}200$ MWh/year

The total income from power sold would be:

$UPe = E * p_e = 43{,}200 * 72.2 = 3{,}119{,}040$ USD/year

The calculations presented above show that by use of the Stirling process, under thermodynamic conditions in a hypothetical geothermal reservoir, it would be possible to achieve a total output which is 50% higher man that achieved in a binary process. This results in equal increases in generated power and total revenues.

4 CONCLUSIONS

Economic evaluation of the geothermal reservoir "X" pilot project includes comparison of the binary and Stirling process. The basic input evaluation data are given in Table 2.

Table 2. Basic input data for geothermal reservoir :X pilot proiecL

Input data		Binary process	Stirling process
Construction duration	year	1	1
Project lifetime	year	20	20
Plant capacity	MWe	3.8	5.9
Specific investment	USD/kW	2,926	1,319
Internal rate of return (TRR)- predetermined	%	10.00	10.00
Operation duration	h/year	8,000	8,000
Power generation	MWh	26,400	43,200
Heat generation	GJ	45,200	#
Employees	personnel	13	8
Generation costs			
Depreciation			
Depreciation rate for civil works	%	5.00	5.00
Depreciation rate for equipment	%	6.67	6.67
Depreciation rate for intangibles	%	20.00	20.00
Other material expenses (% of total revenue)	%	4.50	4.50
Other non-material expenses (% of salaries)	%	11.60	11.60
(% of total revenue)	%	2.00	2.00
Maintenance costs (% of investment)	%	3.00	3.00
Insurance costs (% of investment)	%	0.58	0.58
Gross salaries	USD/employee	7,680	7,680
Royalties (% of total revenue)	%	2.50	2.50

All expenses include investment, operational and maintenance costs, and any other expenses related to power generation which reduce the final financial outcome (taxes, royalties, contributions, membership fees, etc.). Total investment includes all the resources necessary for preparation for geothermal energy exploitation. For the binary process, this is assumed to be 12,120,000 USD, and for the Stirling process, 8,484,000 USD. The technical simplicity and smaller number of parts (no boiler, condenser, FW pumps or other related mechanical parts) make the Stirling process considerably cheaper than the classic binary process. For this caLulation, it is assumed that the total investment in the Stirling process is 30% lower than that in the binary process. The cost estimate is important for capital investment efficiency evaluation. Individual input standards were taken into account, along with the total quantity of each particular input, input unit prices, purchase value of equipment, number of employees and gross salaries.

The lifetime planned for both processes is 20 years. Dynamic methods were used in economic evaluation:

payback period,
net present value (NPV) method,
internal rate of return (IRR).

The economic evaluation results are much better for the Stirling process than for the binary process. With considerably higher power, annual output and total revenue, the Stirling process results in twice as short a payback period. With a predetermined discount rate of 10%, the net present value for the binary process is negative, and according to the economic evaluation criteria, the project is not feasible.

For the Stirling process, the net present value is positive and therefore the process is feasible. The internal rate of return is therefore a relative criterion of project efficiency which offers information on the average annual rate of return. For the binary process project, this is only 9%, which is below a feasible rate. The internal rate of return for the Stirling process would be 29%, and this makes it feasible.

REFERENCES

Cubric, S. & Jetic, K.1993. Geothermal Resource Potential of the Republic of Croatia, *Proc of the World Geothermal Congress,* Volume 1, 87-91.

Cubric, S. 1995. Power and Energy of Geothermal Reservoirs In the Republic of Croatia, *Nafta* 44 (9) 459-470.

Golub, M. et al. 1998 GEOEN - program of geothermal energy usage in Croatia, Energy Institute "Hrvoje Poiar", Zagreb, 124 p.

Jelté, K., Pavicié, H. et al 2000 Geothermal Energy Potential and Utilization in the Republic of Croatia, *Proc. of the World Geothermal Congress,* 3051-3059

Kolin, I. 1987 Geothermal Energy Exploitation by Stirling Cycle, Proc. *of Alternative Energy* Sources, Dubrovnik

Kolin, 1.1983. Isothermal Stirling Cycle Engine, 187 p

Koäcak-Kolin, S., Golub, M. & Rajkovic, D. 2000. New Aspects of Direct Geothermal Use in Croatia, *Proc. of International Congress Energy and Environment,* 43-51

Rajkovic, D. 1999. Economic Aspect of Using Stirling Engine for Moderate Geothermal Sources in Croatia, *Proc of* 9* *International Stirling Engine Conference,* 245-253

TrojanoviC, F. 1988 Cascade Exploitation of Geothermal Sources, *Proc. of Alternative Energy Sources Today and in 21st Century,* Brioni.