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EXERGY POWER OF THE BINARY RANKINE CYCLE AT THE GEOTHERMAL RESERVOIR KUTNJAK-LUNJKOVEC

Abstract

With comprehensive exploration activities and production field testing of the geothermal reservoir, that were conducted by INA d.d. Zagreb, as well as with engagement of Legrad municipality and Koprivničko-Križevačka County, necessary conditions for construction start-up of the Kutnjak-Lunjkovec geothermal power plant have been realized. Furthermore, Government of the Republic of Croatia, during year 2006, has adopted project support mechanism. Due to fact that in the "Concept Study of Commercial Utilization of the Geothermal Energy at the Kutnjak-Lunjkovec locality", done by Faculty of Economics in Zagreb, there is no exact thermodynamic analysis of the installed power values, nor the internal losses of energy in the power plant were taken into consideration, value of presented 2 MWe installed net power becomes quite doubtful. Taking into account that entire economical analysis of the project relies on this particular value, in this article actual energy potential of the Kutnjak-Lunjkovec reservoir will be determined, in view of production and injection capabilities of two wells and exergy principle of reservoir valorisation, as well as in the light of the first and second law of thermodynamics.

1. INTRODUCTION

Pursuant to Article 30, paragraph 3, of the *Law on Government of the Republic of Croatia* (NN 101/98, 15/2000, 117/2001, 199/2003 i 30/2004), Government has adopted support mechanism programme for *Project of Geothermal Energy Commercial Utilization at the Lunjkovec-Kutnjak Locality*, which is demonstrational project of geothermal energy power production since renewable energy utilization is of particular interest in the Republic of Croatia. Ministry of Economy, Labour and Entrepreneurship was obligated to inform Governemnt about activities and advances of the Project once a year, and with Croatian Privatization Fund and Environmental Protection and Energy Efficiency Fund also to co-finance, within their framework and possibility, further development studies and research activities within the Project. In the support mechanism programme it is also stated that INA d.d. Zagreb and HEP should entirely finance exploitation of the geothermal energy. Obligation of INA would be investment in the wells (I phase-70 l/s of geothermal water from existing production and injection well; II phase-300 l/s of geothermal water from three new production wells and three new utilization wells) with obligation of HEP to finance power plant and heat distribution system (I phase-2 MW_e; II phase-4+4 MW_e) [3].

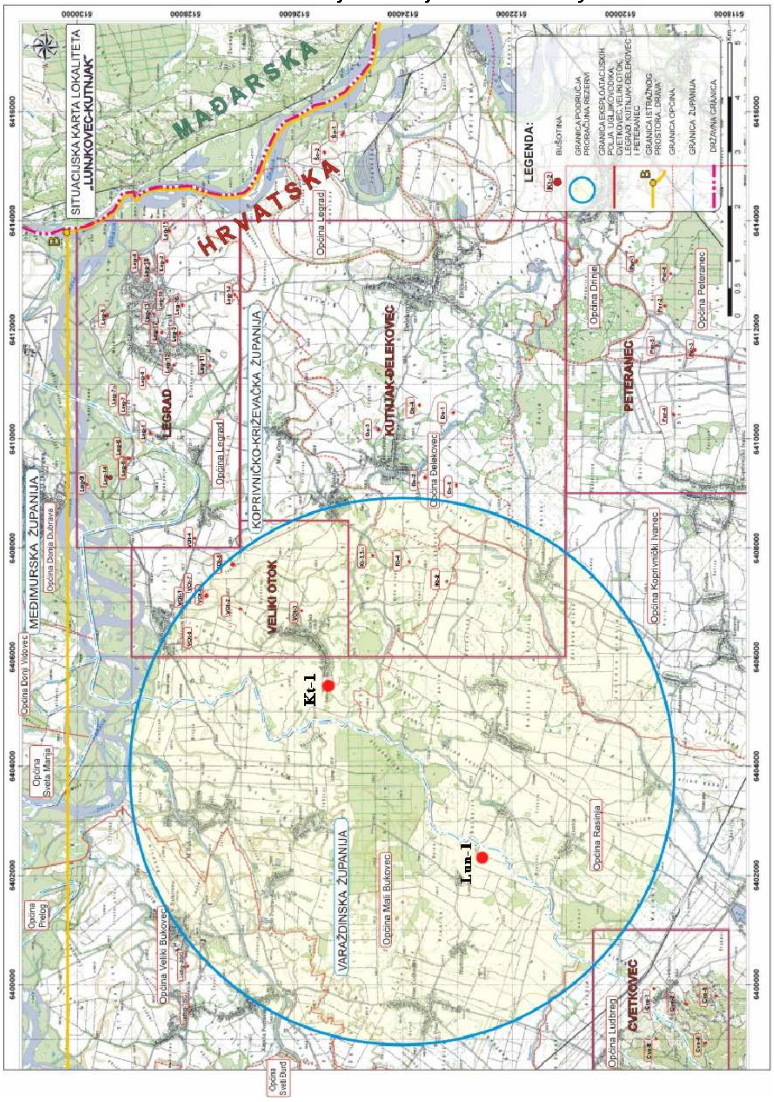
Faculty of Economics in the Zagreb has finished study during 2006 called *Concept and Capability Programme of Geothermal Energy Economic Utilization at the Lunjkovec-Kutnjak Locality*, which represented comprehensive analysis of geothermal energy utilization. During calculation and analysis of the given data in the Study, authors have found oversights regarding gross and net electrical energy which could be delivered to electrical grid. Therefore, in the following chapters authors will be presenting integral thermodynamic analysis of the power plant, which takes into account internal losses of the plant and energy necessary to inject geothermal water back into the reservoir, and in that way determine real value of power plant's delivered electrical energy.

2. GEOGRAPHICAL LOCATION OF THE RESERVOIR AND EXPLORATION ACTIVITIES

Geothermal locality Kutnjak-Lunjkovec has been discovered during oil&gas exploration processes in the northwest part of the exploration region "Drava" with following wells drilled at the site; Lunjkovec -1 (Lun-1), Kutnjak-1 (Kt-1), Kt-2, Veliki Otok-1 (VOt-1), VOt-2 and VOt-4. All wells drilled carbonate rock formations which are the main collector of geothermal water. Reservoir engineering analysis proved that exploitation potential exists with cascade principle of utilization, from power generation via Rankine binary cycle to the direct heat energy utilization in the industry applications, as well as in the greenhouses and heating purposes. Locality is 100km away from Zagreb, and only 10 km from town of Koprivnica. Production well Kt-1 is located within Koprivnica-Križevci County while utilization well Lun-1 is situated in the Varaždin County (Figure 2-1). The climate is continental with mean minimum air temperature of -1,6 ℃ measured in January, mean maximum air temperature of 21,7 ℃ in July and mean annual air temperature of 10,3 ℃.

First oil&gas exploration activities began during nineteen forties with first exploration deep well Kt-1 drilled in 1968, which didn't discover any hydrocarbons. With a view to determine stratigraphic range of Koprivnica sands and collectors and fluid characteristics, during nineteen seventies remaining wells have been drilled. In the 2004 well servicing and testing procedures in the well Kt-1 have been completed, whereby maximum eruption flow of 55 l/s with temperature of 140℃ was achieved. For further geothermal reservoir engineering two wells have been completed, production well Kt-1, and injection Lun-1.

Figure 2-1: Geothermal reservoir Kutnjak-Lunjkovec locality



3. ENERGY AVAILABILITY AND EXERGY POWER OF THE GEOTHERMAL RESERVOIR

Availability is defined as the maximum amount of reversible energy that can be extracted from the geothermal source. According to Bošnjaković [1] exergy is defined as technical work ability which can be obtained when state of the working medium is reversibly brought to mechanical and heat equilibrium with surrounding, respectively exergy is maximum useful power from medium stream. Concept of work ability is useful for evaluation of continuous processes relating to energy transformation. When processes flow entirely reversible, preserved exergy of output matter, which includes obtained mechanical work, must be equal to the exergy sum of input matter, whereby it must not be neglected exergies of the conducted power and heat transfer, as well as other forms of energy. With effect of irreversibility, total exergy of entire process will decrease and therefore, this decrease is direct measure of losses, which for given conditions, can not under any means and methods be subsequently retrieved. The potential maximum useful work is equivalent to the change in availability of the geothermal fluid between condition at the wellhead, and the dead state at ambient or sink condition. [4]

$$P_{ex} = q_g \cdot \left(\Delta i - T_o \cdot \Delta s\right) \Big|_{To\, po}^{Tg,\, pg}$$

Change in enthalpy:

$$i - i_o = c_{pg} \cdot (T - T_o)$$

Change in entropy:

$$s - s_o = c_{pg} \cdot \ln(T / T_o)$$

For *p* = const:

$$s = \int_{T_0}^{T} \frac{c_{pg}}{T} dT - R \ln \frac{p}{p_o} + s_o$$

$$P_{ex} = q_g \cdot \left[c_{pg} (T - T_o) - T_o \cdot c_{pg} \ln \frac{T}{T_o} \right] = q_g \cdot c_{pg} \left(T - T_o - T_o \ln \frac{T}{T_o} \right)$$

$$P_{ex} = q_g \cdot c_{pg} \left[\Delta T - T_o \ln \left(1 + \frac{\Delta T}{T_o} \right) \right]$$

From mathematics:

$$\ln(1 + x) = x - \frac{x^2}{2} = \frac{\Delta T}{T_o} - \frac{1}{2} \left(\frac{\Delta T}{T_o} \right)^2$$

$$P_{ex} = q_g \cdot c_{pg} \left[\Delta T - T_o \left(\frac{\Delta T}{T_o} - \frac{1}{2} \frac{\Delta T^2}{T_o^{\ 2}} \right) \right]$$

Final expression for exergy power can be obtained:

$$P_{ex} = q_g \cdot c_{pg} \cdot \frac{\Delta T^2}{2T_o}$$

This expression (P_{ex}) presents the maximum theoretical power for binary Rankine cycle according to above assumptions. For the site conditions T_o corresponds to outlet temperature from power plant heat exchanger ($T_{g\,out}$). Therefore, the final equation for the total power output is:

$$P_{ex} = q_g \cdot c_{pg} \cdot \frac{\Delta T^2}{2T_{g\,out}}$$

Equivalent to above deduced equation, the same relation could be written through the first and second law of thermodynamics [7]:

$$P_{ex} = q_g \cdot c_{pg} \cdot (T_{g\ in} - T_{g\ out} - T_o \cdot \ln\left(\frac{T_{g\ in}}{T_{g\ out}}\right) \cdot \eta_{util}$$

The utilization efficiency describes the fraction of theoretically available mechanical power from geothermal fluid which can be used for electricity generation by the major plant components including heat exchangers, condensers, turbines and feed pumps. Economic optimum performance of binary plant occurs when η_{util} assumes some intermediate value. Second law efficiency η_{util}, for binary Rankine cycle, is the ratio between net power and specific thermally transferable exergy multiplied by the total flux of geothermal fluid. In other words, second law efficiency for a process is a ratio between the actual work and reversible work for the fictional reversible process. Economic optimum performance of binary plant occurs when η_{util} assumes some intermediate value. Utilization efficiency as second law efficiency (for Rankine organic cycle) and thermodynamic cycle efficiency (η_{cycle}), at the primary side of heat exchanger, as first law efficiency, now can be expressed solely in terms of the cycle operating conditions and temperatures of geothermal fluid and sink temp. [7][4]:

$$\eta_{util} = \frac{\Delta T \cdot \eta_{cycle}}{\Delta T - T_o \cdot \ln\frac{T_{g\,in}}{T_o}}$$

First law efficiency η_{cycle} is the ratio between net power developed by the cycle and total available heat energy from the geothermal source at the surface. It means that for the chosen temperature difference at the heat exchanger, which is related to predicted values of resource temperatures for optimum performance (secondary working fluid choice for binary power plant), first law efficiency is [7][4]:

$$\eta_{cycle} = \frac{P_{ex}}{Q_{tot}}$$

First law efficiency could be also written as:

$$\eta_{cycle} = \frac{P_{ex}}{Q_{tot}} = \frac{q_w \cdot \frac{c_{pg} \cdot \Delta T^2}{2 \cdot T_{g\ out}}}{q_w \cdot c_{pg} \cdot \Delta T} = \frac{\Delta T}{2 \cdot T_{g\ out}} < \eta_{carnot} = \frac{\Delta T}{T_{\max}} < 1$$

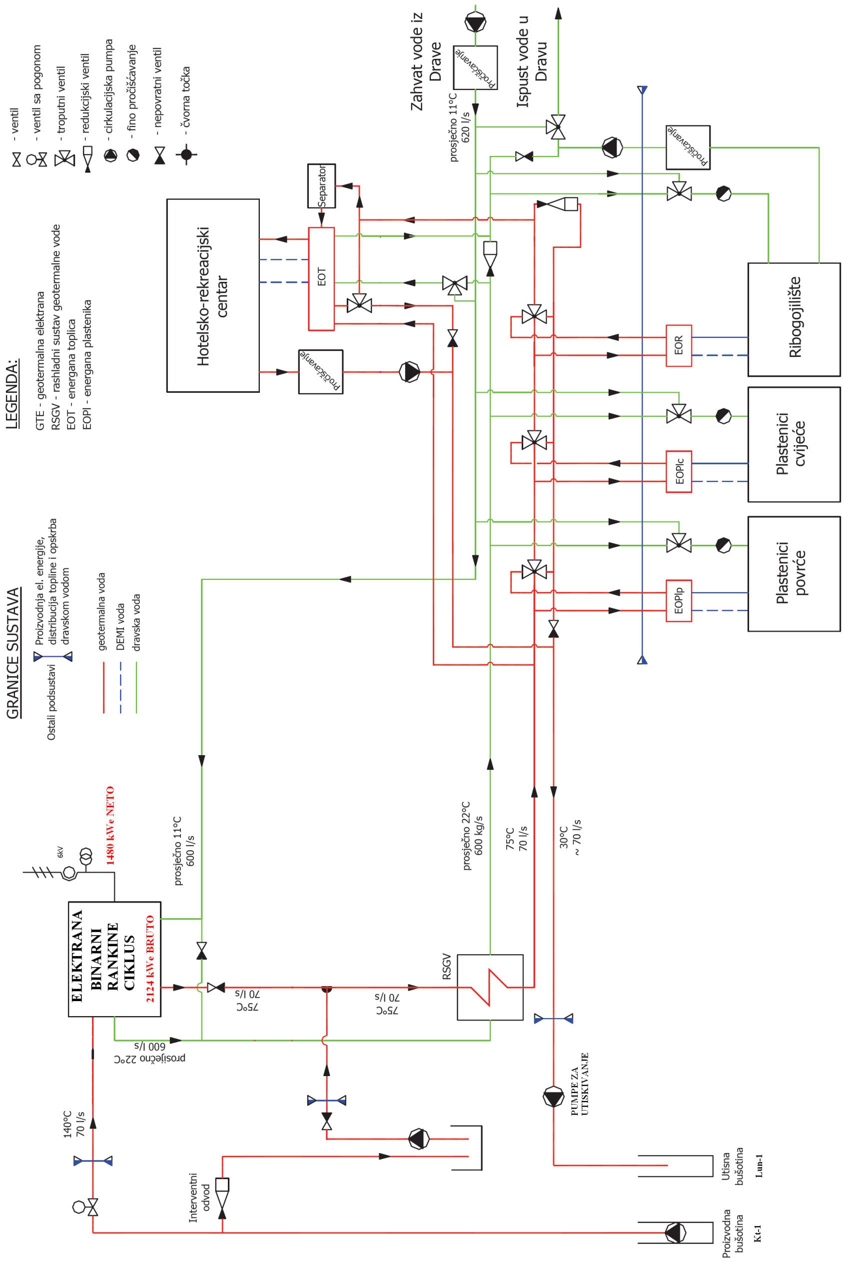
Thermodynamic cycle efficiency (first law efficiency) is the measure of how efficiently the transferred geothermal heat is converted into work. In other words, first law efficiency is defined to be the ratio of the net power produced to the thermal energy input. Since Carnot cycle possess the maximum possible efficiency, the efficiency of irreversible cycle must be less than Carnot cycle, for the same temperature difference. This first cycle efficiency is lower in comparison with the limes of Carnot's reversible thermodynamic efficiency $\eta_{carnot} = \frac{\Delta T}{T_{\max}}$, where ΔT is temperature difference at the primary side of heat exchanger.

4. ANALYSIS OF THE EXERGY POWER AND PRODUCED ENERGY AT THE KUTNJAK-LUNJKOVEC LOCALITY

According to the physical properties of rock formation and measured data, Kutnjak-Lunjkovec reservoir classified as medium temperature reservoirs. Production interval is at 2167 m of depth with static pressure of 225,6 bar and static temperature of 145℃. Production of geothermal water is planned th rough annular space, between tubing and casing, with the pressure at wellhead of 6 bar. Total energy production from the proven reserves of the geothermal water could be obtained through two heat transfer cycles as shown on figure 6-1.

Geothermal water, with temperature of 140℃ and flo w of 70 l/s (6050 m^3/day), enters in the power plant heat exchanger with temperature drop till 70℃. Cooled geothermal water then enters in the secondary heat exchanger with temperature drop till 30℃. In this secondary cycle geothermal water is directly used for heating purposes in the recreational-hotel complex and in the greenhouses. According to determined quantity of water production (70 l/s) and temperature drops for both heat exchanger cycles, following chapters will present analysis of the installed power in the power plant and produced energy for production well Kt-1.

Figure 4-1: Technological scheme of the cascade heat energy utilization principle at the Kutnjak-Lunjkovec locality



4.1. First Circulation Cycle – Production of the Electrical Energy via Rankine Binary Cycle

Theoretical exergy power of the Rankine binary cycle, according to expression for maximum useful work [4] is:

$$P_{ex} = \frac{q_w \cdot c_{pg} \cdot \Delta T^2}{2 \cdot T_{g\ out}} = \frac{q_w \cdot c_{pg} \cdot \left(T_{g\ in} - T_{g\ out}\right)^2}{2 \cdot T_{g\ out}}$$

$$P_{ex} = \frac{70 \cdot 4{,}25 \cdot (413{,}15 - 343{,}15)^2}{2 \cdot 343{,}15} = 2\ 124\ \ kW_e$$

Thermodynamic cycle efficiency of the binary power plant (share of available heat energy convert into electrical energy according to the first law of thermodynamics:

$$\eta_{cycle} = \frac{T_{g\ in} - T_{g\ out}}{2 \cdot T_{g\ out}} = \frac{P_{ex}}{Q_{total}}$$

$$\eta_{cycle} = \frac{413{,}15 - 343{,}15}{2 \cdot 343{,}15} = \frac{2124}{70 \cdot 4{,}25 \cdot 70} = 0{,}102 = 10{,}2\,\%$$

Utilization efficiency of the binary power plant according to the second law of thermodynamics:

$$\eta_{util} = \frac{\Delta T \cdot \eta_{cycle}}{\Delta T - T_o \cdot \ln \frac{T_{g\ in}}{T_o}}$$

$$\eta_{util} = \frac{(413{,}15 - 343{,}15) \cdot 0{,}102}{(413{,}15 - 343{,}15) - 283{,}45 \cdot \ln\left(\frac{413{,}15}{283{,}45}\right)} = 0{,}418 = 41{,}8\%$$

Consequently, value of installed gross power could be also written as [7]:

$$P_{ex} = q_g \cdot c_{pg} \cdot (T_{g\,in} - T_{g\,out} - T_o \cdot \ln\left(\frac{T_{g\,in}}{T_{g\,out}}\right) \cdot \eta_{util}$$

$$P_{ex} = 70 \cdot 4{,}25 \cdot (413{,}15 - 343{,}15 - 283{,}45 \cdot \ln\left(\frac{413{,}15}{343{,}15}\right) \cdot 0{,}418 = 2\ 124\ kW_e$$

Due to fact that every power plant has own internal consumption of electrical energy, and geothermal plant also has supplementary energy consumption for injection of water into the reservoir, it is necessary to decrease gross power with this amount of power plant internal losses. In the study *Pre-feasibility Report on Geothermal Development for combined Electricity and Heat Production in the Republic of Croatia*, done in the1996 by Virkir Orkint Consulting Group Ltd. from Reykjavik, Island, for the client INA d.d. Zagreb, share of internal consumption for future power plants at the Kutnjak-Lunjkovec and Velika Ciglena geothermal reservoirs were estimated. Assessment was carried out in correlation with reservoir and power plant characteristics, location specification and available field test data, with conclusion presented in the table 4-1.

Table 4-1: Internal consumption of the geothermal power plant

	% of gross power installed	**kW_e**
Binary ancillaries	13,16	279,5
Re-injection pumps	12,11	257,2
Production well pumps	2,76	58,6
Hot water circulation pumps	0,79	16,8
Miscellaneous	1,58	33,6
Total	**30,40**	**645,7**

Almost one third of installed gross power needs to be used for re-injection of geothermal water back into the reservoir and operation of power plant (available net power for grid distribution will be ~1480 kW_e). If annual capacity factor for the power plant is assumed to be 95%, respectively 8 320 hours, then total annual energy delivered to the electricity grid will be:

$$E_{net1} = P_{ex\ net} \cdot \beta = 2124 \cdot (1 - 0{,}304) \cdot 8320$$

$$E_{net1} = 12\ 300\ 000\ kWh_e$$

Equivalent annual quantity of natural gas which could be saved with geothermal power production:

$$G_{gas} = E_{net} \cdot D_{sp\ gas}$$

$$G_{gas} = E_{net} \cdot \frac{1}{Q_{en\ gas} \cdot \eta_o} = \frac{E_{net}}{\frac{Q_{gas}}{3600} \cdot \eta_{oe}}$$

$$G_{gas} = \frac{12{,}3 \cdot 10^6}{\frac{33300}{3600} \cdot 0{,}33} \approx 4\ 029\,000\ \ m^3$$

4.1.1. Potential of Power Production from Dissolved Gas

Geothermal water from the Kutnjak-Lunjkovec reservoirs contains gaseous phase with the Gas-Water ratio of 4,5 m^3/m^3, at the wellhead conditions. Most of the gas mixture is carbon-dioxide and nitrogen, with the share of methane/ethane phase at 12,9%. Pre-investment study suggests two possible water injection regimes; a) gas and geothermal water are not separated, yet from production to the injection well continuously flow bubble phase; b)gas is being separated from the liquid at the production well and then again being injected in the stream at the compressor station near the injection well. Designing the system with separation of the liquid and gas phase would improve heat transfer at the heat exchangers and separated methane/ethane could be used for production of electricity via gas turbine, covering in that way part of the power plant internal energy consumption. Production of the gas phase, alongside the water production of 6050 m^3/day, would be 27225 m^3/day, respectively methane/ethane of 0,04065 m^3/s. With known lower calorific value of the dominant methane phase (33,34 MJ/m^3) it is possible to determine produced electricity via gas turbine with standardized efficiency of 37%.

$$P_{gas} = 33{,}34 \cdot q_{CH4} \cdot \eta oe = 33{,}34 \cdot 0{,}04065 \cdot 0{,}37$$

$$P_{gas} = 0{,}5014\, MJ/s = 0{,}5014\, MW_e = 501\, kW_e$$

4.2. Second Circulation Cycle – Production of the Heat Energy with Cascade Principle of Utilization

Installed geothermal heat power in the second circulation cycle could be written as:

$$P_{heat} = q_g \cdot c_{pg} \cdot (\Delta T)_2 \cdot \eta_{he} \quad (kW_t)$$

Due to outlet temperature of the geothermal water from the power plant of 70℃ and planned temperature drop till 30℃, installed heat power would be:

$$P_{heat2} = 70 \cdot 4{,}20 \cdot (343{,}15 - 303{,}15)_2 \cdot 0{,}95 = 11\,170 \quad kWh_t$$

With assumed annual capacity factor of 3 950 hours (β=0,45) it is possible to provide annual heat energy of:

$$E_{net2} = P_{heat2} \cdot \beta$$

$$E_{net2} = 11170 \cdot 3950 = 44\,121\,500 \; kWh_t$$

Quantity of natural gas that could be saved, equivalent to calculation shown for power production, with comparison to gas furnace with efficiency of η_{oh}=0,9:

$$G_{gas} = \frac{44{,}12 \cdot 10^6}{\frac{33300}{3600} \cdot 0{,}90} \approx 5\,300\,000 \;\; m^3$$

Through utilization of electricity and heat energy in the cascade principle of two circulation cycles, with temperature drop to the 30℃, total annual saved amount of natural gas would be 9 329 000 m^3, or 0,3% of total annual consumption of natural gas in the Republic of Croatia.

4.2.1. Space heating in the hotel-recreational centre

In the case of health recreational complex construction, or for heating purposes in the industry, considering climate conditions at the location and standard insulation material, when dimensioning space heating it is needed to take into account mean heating factor of:

$$f = 50\ W/m^2$$

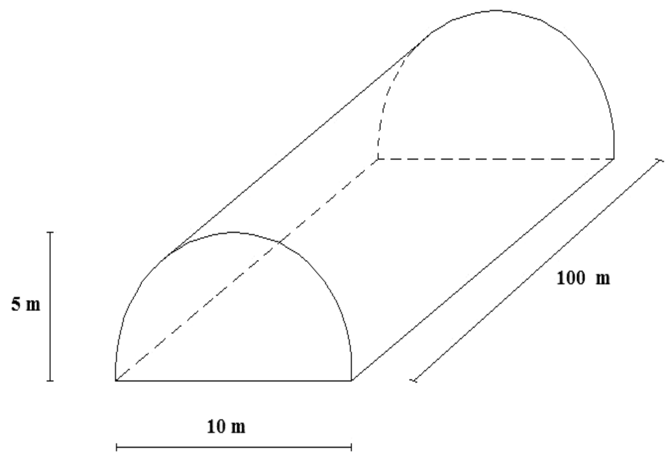
With calculated installed power of the second circulation factor of 11,17 MW_t, it is possible to quickly estimate total area that could be heated with geothermal energy at the location:

$$A_{sp} = \frac{P_{heat2}}{f} = \frac{11170000}{50} \approx 223000\ m^2$$

4.2.2. Greenhouses heating

If geothermal energy should be utilized as well in the greenhouses, considering available heat power at the site, it is possible to determine maximum area of installed greenhouses. Analysis of the greenhouses requires determination of peak heat energy loss in function of inside and outside design temperatures as well as characteristics of geothermal source. For purpose of numerical example, quonset hut design with polymer insulation will be considered with standardized dimensions as shown on figure 4-2.

Figure 4-2: Standardized quonset-hut greenhouse example



Heat loss for a greenhouse is consisted of two components [5][6]:

a) transmission heat loss through the walls and roof of the greenhouse

b) heat loss caused by ventilation losses and intrusion of cold outside air

$$Q_{grh} = Q_{hl} + Q_{ai}$$

Transmission heat losses Q_{ot}, considering greenhouse material (glass, plexiglass or other polymers) and wind speed at the location could be expressed as:

$$Q_{hl} = \left(A_{roof} \cdot \Delta t_{grh} \cdot k_m\right) + \left(A_{wall} \cdot \Delta t_{grh} \cdot k_m\right) \ (W_t)$$

Due to standardized greenhouse dimensions as shown on figure 4-2, designed inside temperature of 26℃ (vegetables growing), designed outside temperature at the site of -12℃, mean wind speed of 4,1 m/s, coefficient of heat transfer for double layer foil of 3,80 W/m^2℃, total transmission heat losses are equal to [5] :

$$Q_{hl} = (1\,570 \cdot 38 \cdot 3{,}80) + (78{,}5 \cdot 38 \cdot 3{,}80) = 238\,043\, W_t = 238\, kW_t$$

Heat loss caused by ventilation losses and intrusion of cold outside air depends upon the number of times per hour that the air in the greenhouse is replaced by cold air leaking in from outside. Greenhouse air change rate depends on the type of the construction, wind velocities and temperature difference between outside cold air and inside design temperature. For chosen greenhouse this value is 0,25 [5]:

$$Q_{ai} = Q_{a\,i} / h \cdot V_{grh} \cdot \Delta t_{grh} \cdot 0{,}102 \quad (W_t)$$

$$Q_{ai} = 0{,}25 \cdot 3925 \cdot 38 \cdot 0{,}102 = 3\,803\, W_t = 3{,}8\, kW_t$$

Therefore, peak heat requirement or total heat loss of the greenhouse is:

$$Q_{grh} = Q_{hl} + Q_{ai}$$

$$Q_{grh} = 238 + 3{,}8 = 241{,}8\, kW_t$$

With available heat power at the second circulation cycle of 11,17 MW_t, number of possible installed greenhouses at the location would be:

$$n_{grh} = \frac{P_{heat\,2}}{Q_{grh}} = \frac{11\,170}{241{,}8} = 46\ greenhouses$$

Expressed in area units, available heat power would be sufficient for heating of 46000 m^2 greenhouses area.

5. CONCLUSION

Aim of the Government of the Republic of Croatia is increase share of renewable energy in total energy consumption to 5,8% till 2010. Moreover, increase in energy consumption must not cause increase in emission of greenhouse gases which goes in favour to geothermal energy. In *Strategy of mineral resources management*, done by Faculty of Mining, Geology and Petroleum Engineering for Ministry of Economy, Labour and Entrepreneurship in 2006., principle of sustainable development means mutual functional connectivity of variables which needs to comply with technological, ecological, economical and sociological requirements, with engagement of local resources and municipality. Because the *Project of Geothermal Energy Commercial Utilization at the Lunjkovec-Kutnjak Locality* is in compliance with national development priorities (promoting renewable energy, production of food, employment), Government of the Republic of Croatia supports this project as demonstrational one which should start during 2008. With calculation of installed power through specific thermodynamics laws and cascade principle of utilization it is shown how to properly design geothermal project, which method could be applied to other potential geothermal localities for electric power production.

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List of used symbols:

A_{roof} - greenhouse roof area, m^2
A_{wall} - total wall area of the greenhouse, m^2
c_{pg} - specific heat of geothermal fluid, kJ/kg K
$D_{sp\ gas}$ - specific consumption of natural gas, kg/kWh_e
E_{net1} - total annual electricity produced, kWh_e
k_m - coefficient of heat transfer, W/m^2 K

n_{grh} - number of greenhouses at the location
p_{gu} - pressure of geothermal fluid at the wellhead, Pa
p_o - pressure of geothermal fluid at standard conditions, Pa
P_{ex} - geothermal exergy power at the wellhead conditions, kW_e
P_{heat} - installed heat power, kW_t
$T_{g\ in}$ - temperature of geothermal fluid at the inlet of the heat exchanger, K
$T_{g\ out}$ - temperature of geothermal fluid at the outlet of the heat exchanger, K
T_{gu} - temperature of the geothermal fluid at the wellhead, K
T_o - sink temperature 10,3 °C
V_{grh} - volume of the greenhouse, m^3
q_g - geothermal fluid flow, l/s
q_{CH4} - methane phase flow, m^3/day
Q_{air}/h - air change per hour in the greenhouse
$Q_{en\ gas}$ - energy of the natural gas, kWh/kg
Q_{gas} - lower calorific value of the natural gas, kJ/m^3
Q_{hl} - transmission heat loss through the walls and roof of the greenhouse, kW_t
Q_{tot} - total heat energy of the geothermal fluid with inlet temperature $T_{g\ in}$, kW_t
Q_{ai} - greenhouse heat loss caused by ventilation losses and intrusion of cold outside air, kW_t
Δi - change in enthalpy, kJ/kg
Δs - change in entropy, kJ/kg K
Δt_{grh} - outside/inside temperature difference in the greenhouse, ^oC
ΔT - temperature difference at the primary side of power plant heat exchanger, K
$(\Delta T)_2$ - temperature difference of the second circulation cycle, K
β - annual utilization factor, h/year
η_{carnot} - efficiency of the Carnot cycle
η_{cycle} - thermodynamic cycle efficiency according to the first law of thermodynamics
η_{oe} - heat energy to electrical energy conversion factor
η_{oh} - efficiency of the gas boiler
η_{he} - efficiency of the heat exchanger at the primary side
η_{util} - utilization efficiency according to second law of thermodynamics

UDK	ključne riječi	key words
550.367	geotermalni izvori energije	geothermal power resources
553.7	geotermalno ležište	geothermal reservoir
536.717	kružni proces	circular process
536.77	slobodna energija	free energy
.001.24	gledište tehničkog proračuna	technical calculation
.003.1	gledište ostvarivosti	feasibility viewpoint
697.1	grijanje zgrada	house heating
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