TRIGENERATIVE PLANT WITH ORGANIC RANKINE CYCLE

Marcel DRAGAN, Tanase PANAIT, Krisztina UZUNEANU, Gelu COMAN

"DUNĂREA DE JOS" UNIVERSITY OF GALAȚI, Romania

Abstract. The need of protecting the environment, correlated with the sustainable energetic development has led in the past 15-20 years to an increase in the concerns regarding the promotion of the regenerating energy sources and their adjacent technologies. The European Union's policy in this matter, expressed by the White paper and the European Directive 201/77/CE regarding the energy production from regenerating sources states that, by the year 2010, the European Union is to assure 12% of its energy requirements from the exploitation of regenerating sources. This work presents how to obtain energy into a trigenerative plant using as main energy source the geothermal energy. An energetic study on the tri-regenerative plant that produces hot water, superheated water for electric power and heat is presented.
Keywords: trigeneration, organic Rankine cycle, heating pump, thermodynamic efficiency.

Rezumat. Necesitatea protejării mediului înconjurător, corelată cu dezvoltarea energetică durabilă, a condus în ultimii 15-20 de ani la intensificarea preocupărilor privind promovarea resurselor regenerabile de energie şi a tehnologiilor aferente. Politica Uniunii Europene în acest domeniu, exprimată prin Carta Albă şi Directiva Europeană 2001/77/CE privind producerea de energie din surse regenerabile, prevede ca, până în anul 2010, Uniunea Europeana să îşi asigure necesarul de energie în proporţie de circa 12% prin valorificarea surselor regenerabile. Această lucrare prezintă modul în care se poate obţine energie într-o instalaţie trigenerativă folosind ca principală sursă de energie energia geotermală. Se prezintă un studiu energetic pe instalaţia trigenerativă care produce apă caldă menajeră, agent termic pentru încălzire şi energie electrică.
Cuvinte cheie: trigenerare, ciclul Rankine organic, pompă de căldură, eficienţă termodinamică.

1. INTRODUCTION

Many European countries possessing geothermal resources similar to Romania's have made efforts in designing and applying certain effective and sustainable technologies, leading to a profitable exploration, both in the part regarding the resources' exploitation (geothermal bores extraction and drilling technologies) and in the one regarding the surface energetic devices.

The "low temperature" geothermal resources are used in heating and preparing the domestic hot water of the households, social services, the industrial sector or spaces destined for animal husbandry.

2. GENERAL ASPECTS REGARDING THE GEOTHERMAL ENERGY

The geothermal energy is the heat accumulated in the rocks and the fluids filling their pores.

It represents the thermal energy contained by the organic matter underneath the Earth, known as the sensitive heat and greatly produced by the slow decomposing process of the natural radioactive substances existing in all the rock types. The heat comes from the energy diffused radially from the center towards the exterior of the Earth and is produced on a constant basis. The high temperatures of the center of the Earth can be explained by the Earth's origin and the existence of the uranium (U^{238}, U^{235}), thorium (Th^{232}) and potassium (K^{40}) radioactive isotopes in its composition.

The diffusion process is permanent and it could be stated that the geothermal energy is an inexhaustible energy source.

The geothermal energy is one of the alternatives able to cover mankind's need of energy, also minimizing the impact on the environment.

2.1 The geothermal gradient

The geothermal gradient expresses the depth induced temperature increase, the average being of de 2,5…3°C/100 m, corresponding to an 100 °C temperature, at 3000 m in depth.

There are various zones where the geothermal gradient's value considerably varies from the aforementioned average. For example, in the areas

where the rock plateau has experienced sudden collapses and the reservoir is filled with "very young" sediments (from the geological point of view), the geothermal gradient may be less than 1°C/100 m. On the other hand, in other geothermal areas, the gradient can surpass the average by several times. In general, the gradient's value is of 25 ^{o}C/km, however there are numerous areas where these precise areas are true high potential geothermal energy underground reservoirs, which, in certain favorable conditions, may be explored in order to be used for the heating equipments preparing the domestic hot water.

2.2. Geothermal systems

The geothermal systems can be found in areas with a normal or near normal geothermal gradient and in the areas where the geothermal gradient may be slightly above average. In the first situation, the systems will be characterized by low temperatures, usually reaching 100°C for economically optimal depths. In the second case, the temperature may even reach 400°C. A geothermal system may be described as one where water is used as a heat transport agent, through which the heat is taken from the underground source to the consumer at surface. A geothermal system is made up of three main elements: a heath source, a reservoir and a fluid. The source may be a magmatic rock intrusion of a very high temperature (> 600°C), located rather near the surface (5-10 km). The reservoir is a hot, permeable rock volume, where the transporting fluids extract the heat from the reservoir is usually covered by an impervious rock layer, connected to a surface charging area through which the geothermal fluid originating in the precipitation may partially or entirely compensate for the loss in the reservoir through springs or the extraction process. The geothermal systems may be classified depending on the temperature and pressure of the system, as well as the way the thermal energy is transferred to the soil. Consequently, there are several geothermal systems, listed as follows:

a. Hydro-thermal sources. These sources are based on the circulation of meteoric (surface) waters, which infiltrate from 100 m to 4,5 km into the Earth's crust.The circulation is naturally assured by the difference in the density of the cold and hot water, or of the water vapors.

b. Pressured sources. The water contained in the reservoirs has a low salt concentration and contains dissolved methane. The water and methane are held captive by impervious rock layers in reservoirs at great depths (3-6 km), characterized by extremely high pressure levels. The water's temperature is generally between 90 … 200 °C.

c. Hot rocks. This source type is based on hot rock layers existing on the Earth's crust. Unlike the hydro-thermal sources, in this case there are no underground water reservoirs, nor is there any possibility for the meteoric water to infiltrate.The exploration is carried out through drilling in the hot rocks area. Cold water will be pumped in order to create a reservoir, and the water heated this way will eventually be brought back to the surface through an extraction shaft.

d. Magma. The magma is the greatest geothermal resource, being formed of melted rocks, located at great depths of 3 to 10 km. The magma's temperature is generally situated between 700 and 1200°C. No research has been carried put regarding the use of this resource, due to the difficult access at the depths the magma can be found.

3. SOLUTION FOR TRIGENERATION OF A GEOTHERMAL SOURCE

The great majority of the geothermal reservoirs are characterized by relatively low temperatures, ranging from 100 .. 200°C. In this case, for the conversion of the geothermal energy into electricity and thermal energy, the optimal solution is using the plant from Fig. 1.

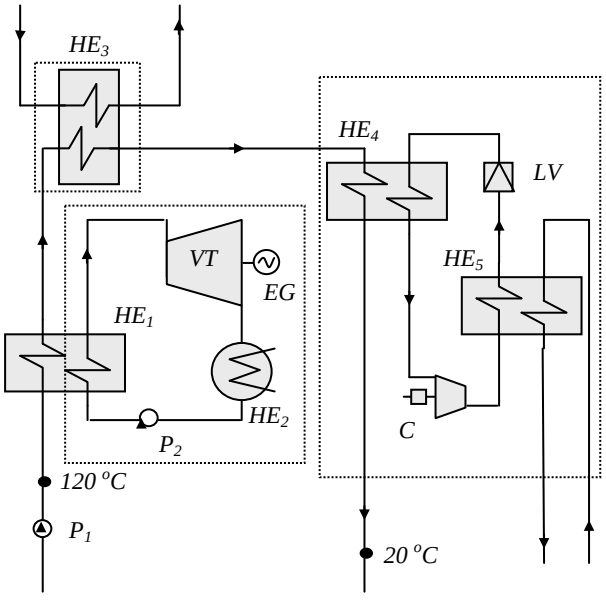


Fig. 1. Trigeneration plant.

The water from the geothermal source, with a temperature of 120 ^{o}C, gives in to the refrigerant agent of the Rankine Cycle (amonia), the heat. The main characteristic of this fluid is the much lower boiling point than water. The vapors formed into the vaporizer HE1 will expands in the vapor turbine VT and will produce electric energy in the electric generator

The water cooled condenser HE2 forms the liquid refrigerant agent, which is pumped out with pump P2, and reintroduced into the vaporizer HE1.

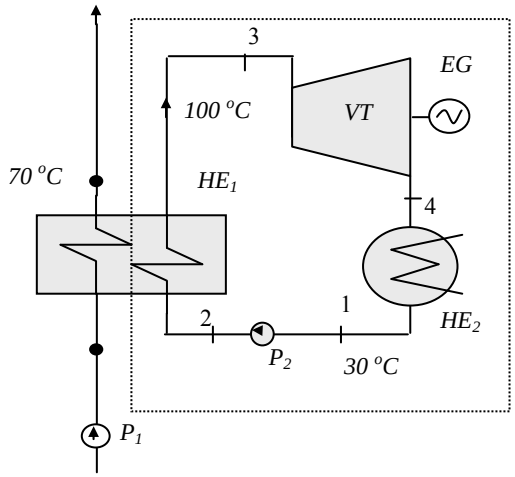


Fig. 2. Electric plant with ammonia Rankine cycle.

The hot water is produced by cooling out the geothermal water, from 70 °C to 40 °C in the heat exchanger HE3.

The water for use is heated from 15 °C to 55 °C.

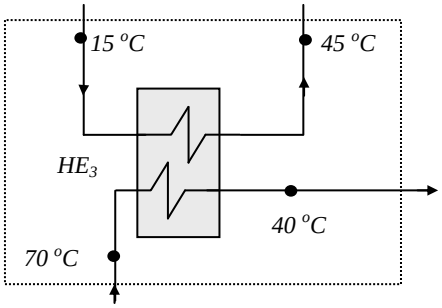


Fig. 3. The generation of hot water for use.

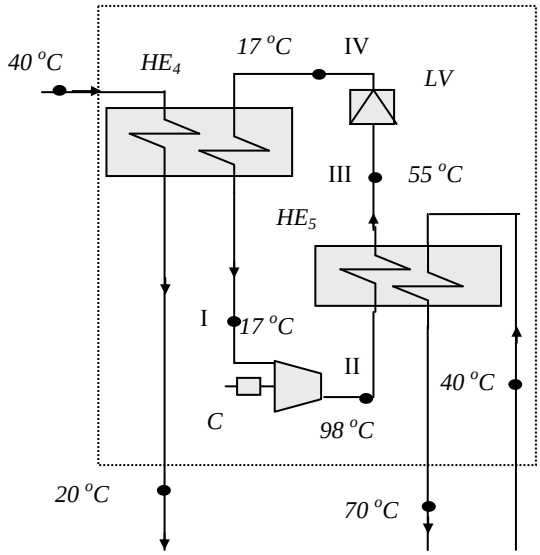


Fig. 4. Producing heat with the heat pump.

The low thermal potential of geothermal water with a temperature below 40 °C is used with an ammonia heat pump installation. Cooling out the geothermal water in the heat exchanger HE4, the ammonia is vaporized at 17 °C. Those refrigerant vapors are compressed in the compressor C and condensate in the condenser HE5. Condensing the ammonia gives in the condensing heat to the water from the heating cycle, generating a useful effect.

The liquid ammonia expands in the laminar valve LV. For the compressor from the heat pump installation the electric energy produced in the Rankine cycle is used.

4. THE TRIGENERATIVE PLANT ENERGETIC ANALYSES

The energetic analysis of the geothermal energy conversion in to useful energy is made on the three selected perimeters.

*In the Rankine cycle with ammonia are the following energy flows (according to fig. 2),

$$q_{0,1} = c_w(120-70)\ [\text{kJ/kg}] \quad (1)$$

$$l_p = v_1(p_2 - p_1)\ [\text{kJ/kg}] \quad (2)$$

The work produced by the turbine:

$$l_{VT} = h_3 - h_4\ [\text{kJ/kg}] \quad (3)$$

The thermal efficiency of the Rankine cycle is,

$$\eta_t = \frac{l_{VT} - l_p}{h_3 - h_2} \quad (4)$$

The specific energy provided by the installation is:

$$ee = \eta_{gen}(l_{VT} - l_p)\ [\text{kJ/kg}] \quad (5)$$

η_{gen} = 0.8 represents the turbo generator efficiency

* For the thermal energy used to warm up the water for use in the heat exchanger HE3, the specific energy consumed is:(according to fig. 3):

$$q_{0,2} = c_w(70-40)\ [\text{kJ/kg}] \quad (6)$$

Supposing that the heat exchanger is adiabatic insulated, the produced energy is:

$$q_{h,w} = q_{0,2} = c_w(70-40)\ [\text{kJ/kg}] \quad (7)$$

* For the thermal energy for heat, according with the heat pump installation from fig. 4 the following energy is used:

- for the refrigerant vaporize

$$q_{0,3} = c_w(40-20)\ [\text{kJ/kg}] \quad (8)$$

- for the refrigerant compressor drive

$$l_c = h_{II} - h_I \text{ [kJ/kg]} \quad (9)$$

The condensation energy generated by the heat exchanger (condenser) HE5:

$$q_h = h_{II} - h_{III} \text{ [kJ/kg]} \quad (10)$$

* The energetic efficiency of the trigenerative plant is mathematically expressed with the relation (11):

$$\eta_{trigen} = \frac{(ee - l_c) + q_{hw} + q_k}{q_{0,1} + q_{0,2} + q_{0,3}} \quad (11)$$

4.1. The energy studies result

* From ammonia Rankine cycle, the thermodynamic parameters of the main characteristic points are:

Table 1

Numerical results

Point	*t* [°C]	*p* [bar]	*i* [kJ/kgK]	*x* [kg/kg]
1	30	11.67	-620.6	0
2	31.4	62.53	-612.14	-
3	100	62.53	473	1
4	30	11.67	291.24	0.79

The thermal efficiency of the ammonia Rankine cycle (equations 4) is 16 %.

The plant generates the following specific energy (equations 4):

$$ee = 138.64 \text{ kJ/kg.}$$

* From heating pump cycle. the thermodynamic parameters of the main characteristic points are:

Table 2

Numerical results

Point	t [°C]	p [bar]	i [kJ/kgK]	x [kg/kg]
I	17	7.78	514.78	1
II	98	23.09	671.1	-
III	55	23.09	-496.12	0
IV	17	7.78	-496.12	0.156

For the drive of the refrigerant compressor from the installation with heating pump, according to equation (9), the following specific energy is consumed: $l_c = 156.32$ kJ/kg

We will observe that the specific work necessary for the compression in the heat pump installation is bigger than the specific electric energy obtained in the Rankine cycle. In these conditions for the installation to work properly is necessary that between the required electric power for the heat pump installation and the electric power produced by the energetic installation with ammonia, to exist the relation:

$$P_{EE} = m_{Rankine} \cdot ee \geq P_c = m_{hp} \cdot l_c \text{ [kJ/kg]} \quad (12)$$

Therefore the function terms are connected to the relation between the two flows:

$$m_{Rankine} \geq 1.282 \cdot m_{hp}$$

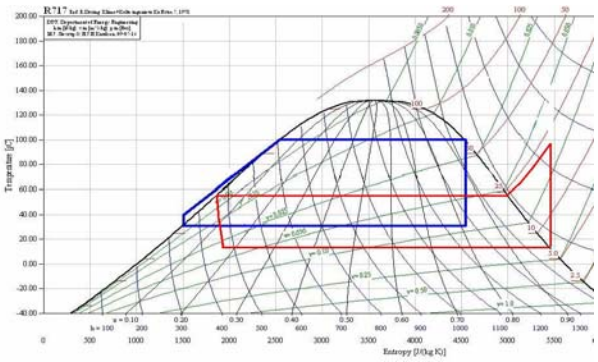


Fig. 5. *Ammonia Rankine cycle and ammonia heating pump cycle.*

The trigenerative plant in the limit function situation will become a cogenerative plant with the following efficiency:

$$\eta_{cogen} = \frac{q_{hw} + q_k}{q_{0,1} + q_{0,2} + q_{0,3}} \quad (13)$$

$$\eta_{trigen} \geq \eta_{cogen} = 0,6$$

5. CONCLUSIONS

Using the geothermal energy in trigenerations, in order to produce electricity and thermal energy has certain advantages, among which:

* The thermal efficiency compared with the efficiency of the Rankine cycle of the nuclear plants;

* It is a local primary energy source able to reduce the importation of expensive fossil fuels (natural gas, petroleum);

* It has a positive impact on the environment by replacing certain extremely polluting fossil fuels (charcoal); it represents a reliable primary energy source, not needing any storing equipment.

REFERENCES

[1] Dubin F.S. *The heat pump centered integrated Community energy system* ASHRAE, 1999, vol.86, p.979-990.
[2] *Geothermal Energy. Resources, Production, Stimulation,* Stanford University Press, 2002.
[3] Hickel W.T*.*, *Geothermal energy, A special report,* University of Alaska, Fairbanks, 2002.