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3. PROPOSALS OF SMALL SCALE BINARY GEOTHERMAL POWER PLANT WORKING IN THE POLISH LOWLAND CONDITIONS

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1. INTRODUCTION

European Union requires from the countries in the pre-accession state to increase energy share from the renewable resources in their energy mix from 7.5% in 2010 up to 14% in 2020 in their structure of primary energy consumption. In the report "Strategy for the development of renewable energy", prepared by the Department of Environmental Protection (September 2000) [1], amongst the scenarios of the growth of RES technologies in Poland the share in production of electricity using the geothermal resources is not taken into account. Geological conditions of presence of geothermal resources in Poland and potential of contained there thermal energy have been extensively discussed in the papers by Gorecki [2] and Sokolowski [3]. According to Sokolowski, on the territory of Poland there is approximately 6600 km^3 of geothermal waters with temperature ranging from 25°C to 150°C. The resources are more or less evenly distributed across Poland in specified geothermal basins and sub-basins belonging to selected provinces and geothermal periods. Advantageous geological surroundings, mentioned above, lay out possibilities of its utilization not only for heating purposes but also for production of electricity.

In the paper presented are different concepts of management of thermal waters with temperature of 80°C for production of electricity based on a low-temperature Clausius-Rankine cycle.

2. EFFECTIVENESS OF LOW-TEMPERATURE CLAUSIUS-RANKINE CYCLE

Thermal efficiency of the Carnot cycle operating in the temperature range 100-25°C is about 20%. The corresponding efficiency of Clausius-Rankine in the specified above temperature range will be adequately lower. Several factors influence the effectiveness of organic Clausius-Rankine (ORC) and primarily:

- temperature of the upper heat reservoir (temperature of geothermal water)
- temperature of lower heat reservoir (condensation temperature of working fluid – usually dependent on ambient temperature),
- thermodynamical parameters and physical and chemical properties of the working medium),
- efficiency of equipment and devices used for realization of the cycle (particularly heat exchangers, turbogenerators).

Increase of temperature of the upper reservoir without supply of energy from external resources can be achieved for example through incorporation to the system of a heat pump fed with geothermal water. Preliminary calculations of modified in such a way systems have not given satisfactory results. In [4] presented have been suggestions of solutions aimed at increase of cycle effectiveness through the decrease of temperature of the lower reservoir.

Considered has been a possibility of implementation of absorption cooler, where the energy source would be geothermal water. However also in that case the obtained results are not very satisfactory. It seems that the biggest possibilities are offered to the cycle optimization through consideration of applied working fluid. Up to date the ORC cycles operated using single-component organic fluids. At present an increased interest in application of multi-component mixtures [5] can be observed. From several advantages resulting from application of a mixture as a working fluid there can be mentioned the possibility of adjustment of saturation curves as well as values of critical parameters. In figure 1 presented has been the isobaric process of boiling of zeotropic solution. Another important feature of multi-component fluids is the existence of so called temperature slip, which is advantageous in the case of clockwise C-R cycles.

3. CHARACTERISTICS OF ZEOTROPIC WORKING MEDIA

Transition of the two-component solution from one state of the matter to another takes place in a completely different way than in the case of single-component media [6]. Implementation of multi-component fluids in the Clausius-Rankine cycle requires knowledge of their behaviour during processes occurring in the evaporator and condenser. In figure 2 presented have been thermodynamic processes of working fluid in the Clausius-Rankine cycle. On the other hand the schematic presenting the binary power station operating according to such cycle in the superheated vapor region together with the temperature field in the heat exchanger is shown in figure 3.

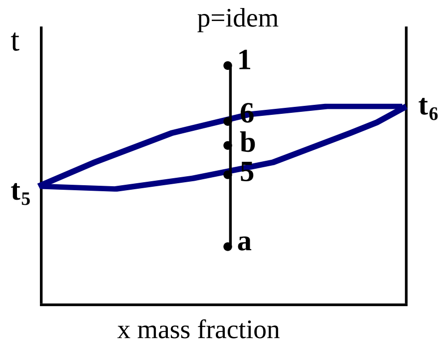

Figure 1. Isobaric pro ropic solution

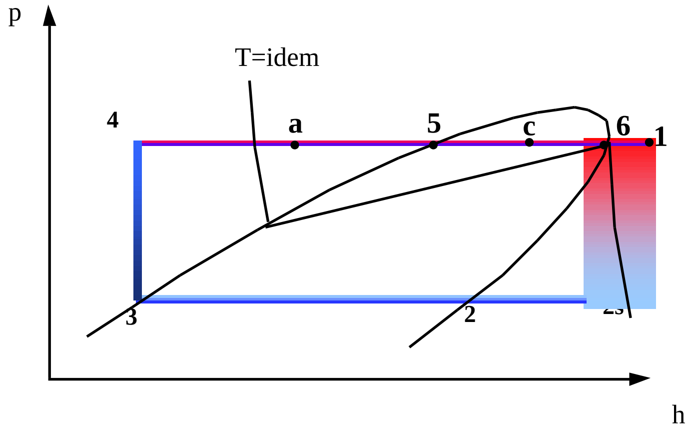

Figure 2. A cycle of thermodynamic processes of working fluid in the Clausius-Rankine cycle

4. RESULTS OF CALCULATIONS

Calculations of efficiency and power of the C-R cycle have been made at the assumption that the upper heat reservoir is geothermal water with temperature 80°C and a volumetric flowrate 100m^3/h where the working medium is a two-component propane-ethane mixture with mass composition presented in Table 1. It has been assumed that the fluid is superheated to temperature of 77°C and undergoes condensation in temperature of 25°C. It has also been assumed that the isentropic fluid expansion in turbine takes place in the region of superheated vapour.

Table 1. Mass composition of fluids considered in calculations

working fluid	fluid composition (mass fraction)	critical temperature °C	remarks
propane/ ethane	propane	96.7	pure fluid
	0.9 propane / 0.1 ethane	90.7	two-component zeotropic mixture
	0.8 propane / 0.2 ethane	84.6	

	0.7 propane / 0.3 ethane	78.4	
	0.6 propane / 0.4 ethane	72.1	
	0.5 propane / 0.5 ethane	65.7	

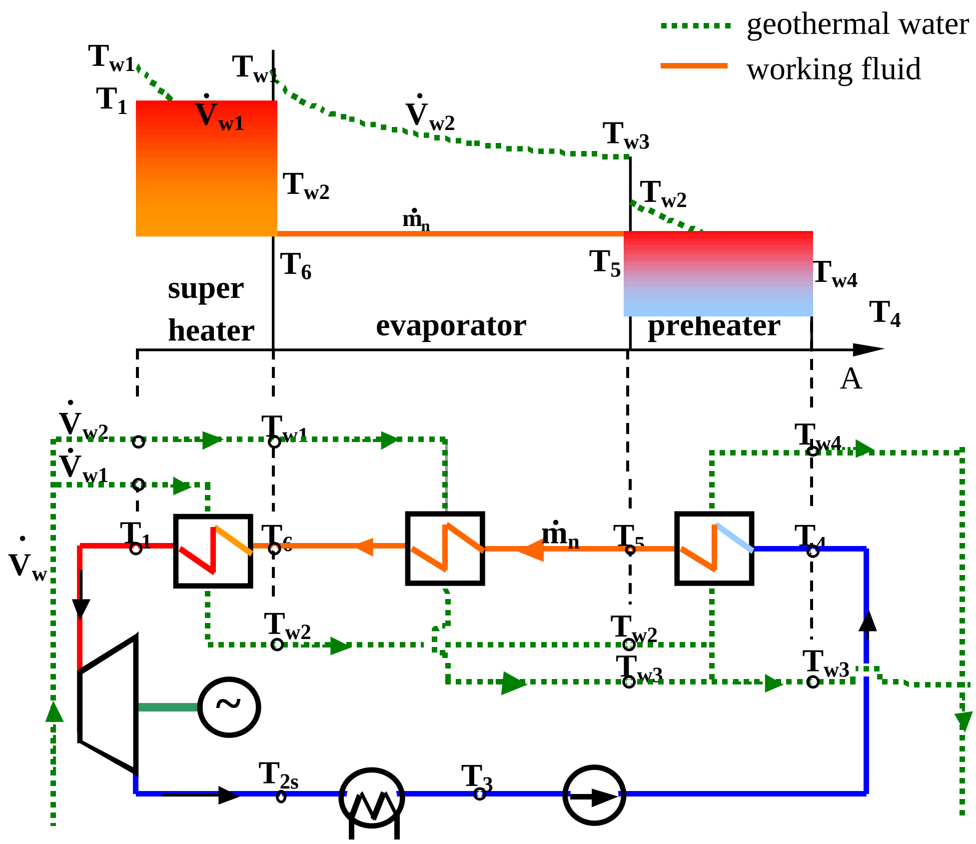

Figure 3. Binary power station operating according to such cycle in the superheated vapor region together with the temperature field in the heat exchanger

5. RESULTS OF CALCULATIONS AND THEIR ANALYSIS

In fig. 4 presented have been values of obtained the cycle powers and theoretical efficiencies for the parameters of geothermal water and assumptions given above.

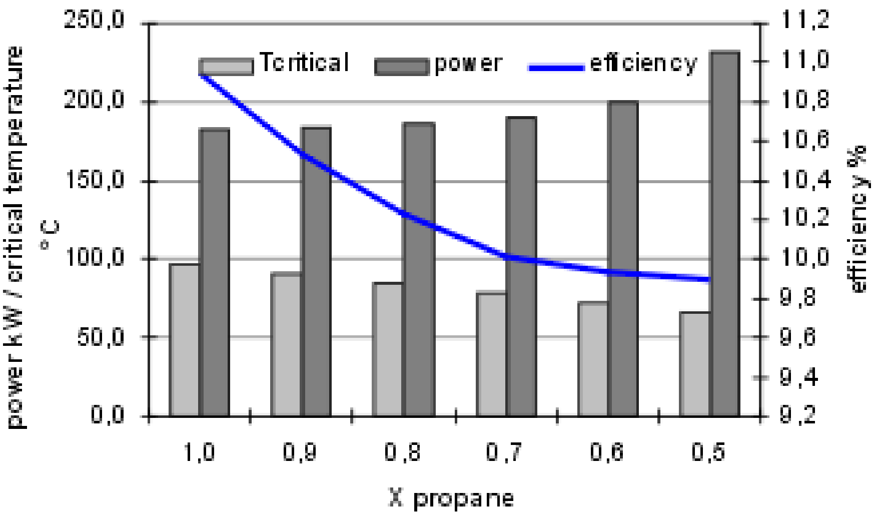

Figure 4. R-C cycle efficiency and power for the propane-ethane mixture

Analysing the above diagram it can be noticed that the highest cycle efficiency has been obtained for the pure propane and that it decreases with the increase of the share of ethane in the mixture. A different relation is observed when we focus our attention on the function of the cycle power in function of the working fluid composition. The highest value of power has been obtained in the case of a 50/50 propane/ethane mixture. A tendency of power increase with decrease of the critical fluid temperature has also been noticed. That can be explained due to the fact that the enthalpy of fluid evaporation decreases with increase of pressure (a temperature) to achieve a value of zero in the critical point. The lower the latent heat of evaporation the more of it can be introduced to the cycle at a constant flowrate of geothermal water (fig. 5 and 6).

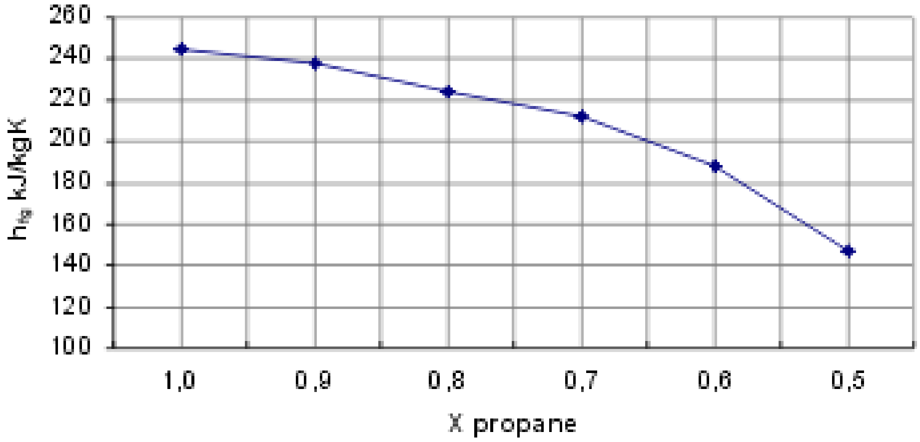

Figure 5. Enthalpy of fluid evaporation in function of composition of working fluid

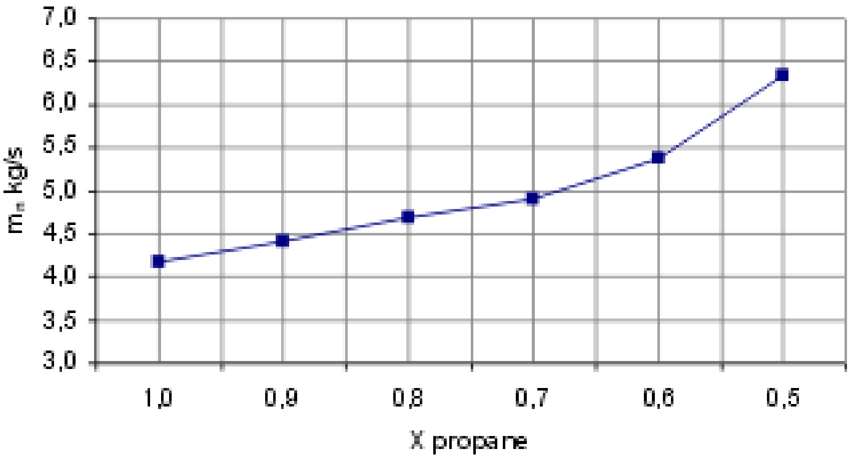

Figure 6. Cycle fluid flowrate in function of composition of working fluid

6. CONCLUSIONS

In the paper presented have been the results of calculation of theoretical efficiency and power of Clausius-Rankine cycle for a zeotropic mixture propane-ethane of different mass composition.

On the basis of analysis of obtained results of calculations there can be formulated the following final conclusions:

- determination of C-R cycle efficiency in operation with a low boiling point fluid as a working fluid proved to be insufficient in the course of energetical assessment of fluid; for similar efficiencies (10.9 - 9.9%) for different mass compositions of propane-ethane mixture obtained have been different values of power (182.3 - 231.2 kW).
- highest values of power of C-R cycle are obtained for the fluid, which critical temperature is mostly approaching the temperature of the upper heat reservoir.

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REFERENCES

[1] *Strategy for the development of renewable energy*, Department of Environmental Protection http://www.mos.gov.pl/1materialy_informacyjne/ raporty_opracowania/energetyka/

[2] Gorecki W., 1996 - *Atlas of resources of geothermal energy in Polish Lowland*, Wyd. Towarzystwo Geosynoptykow GEOS. Krakow (in Polish)

[3] Sokolowski J., 1997 - *Methodology of assessment of geothermal resources and conditions of their presence in Poland,* Notes of the Polish Geothermal School, 3rd edition, PGA i CPPGSMiE PAN Publishers, Krakow-Straszecin (in Polish)

[4] Nowak W., Borsukiewicz-Gozdur A., 2004 – *Binary Geothermal Power Plant with Absorption Cooler,* XIV Internationale Tagung Forschung, Didaktik und Praxis im modernen Maschinenbau, Stralsund, Germany.

[5] Angelino G., Colona di Paliano P., 1998 - *Muiitcomponent Working Fluids for Organic Rankin Cycles*, Energy, Vol.23, No.6.

[6] Czapp M., 2002 - *Phase changes of fluids in coiled refrigeration heat exchangers,* Koszalin University of Technology Publisher.