FEASIBILITY STUDY AND ENERGY EFFICIENCY ESTIMATION OF GEOTHERMAL POWER STATION BASED ON MEDIUM ENTHALPY WATER

by

Aleksandra BORSUKIEWICZ-GOZDUR and Wladyslaw NOWAK

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In the work presented are the results of investigations regarding the effectiveness of operation of power plant fed by geothermal water with the flow rate of 100, 150, and 200 m^3/h and temperatures of 70, 80, and 90 °C, i. e. geothermal water with the parameters available in some towns of West Pomeranian region as well as in Stargard Szczecinski (86.4 °C), Poland. The results of calculations regard the system of geothermal power plant with possibility of utilization of heat for technological purposes. Analysed are possibilities of application of different working fluids with respect to the most efficient utilization of geothermal energy.

Key words: *geothermal power plant, low-temperature power plant, organic Rankine cycle, organic working fluid*

Introduction

A non-efficient economy regarding natural resources, fast depletion of fossil fuels, extensive energy consumption and resulting devastation of natural environment form the factors which serve at present as basis for restructurisation of power engineering market to include an increasing share of renewable energies. Amongst the resources of renewable energy in Poland a significant share goes to geothermal energy, which is available almost in the entire country, and which can be used for heating purposes. At present in Poland there are geothermal power plants operated in Banska Nizna, Biaty Dunajec, Pyrzyce, Mszczonów, and Uniejów. In the domestic and foreign literature the knowledge of the problems regarding exploitation of geothermal resources with high enthalpy for production of electricity is quite extensive [1-3]. There is however a lack of data regarding utilization of geothermal energy with medium enthalpy for production of electricity.

There are two ways for utilization of steam from the hot geothermal resources for electricity production:

- direct vaporisation of geothermal water using the separator, and
- indirect vaporisation of working fluid in the evaporator.

In the case of extracting geothermal water with high pressure and temperature, say at least 150-200 °C, one can use the single-component system presented in fig.1.

Geothermal water from the extraction well is directed to the decompressor-separator, where it is decompressed to the saturation pressure corresponding to temperature of extracted geothermal water, as a result of which the steam will be generated from steam. Such steam is directed to the steam turbine driving the generator. After expansion in the turbine the steam undergoes transition to the liquid state and together with the remaining part of geothermal water is pumped to the return well. Other ways of design of power plants and thermal power plants with direct vaporization of geothermal water, which ensures better utilization of geothermal water have been presented in [4].

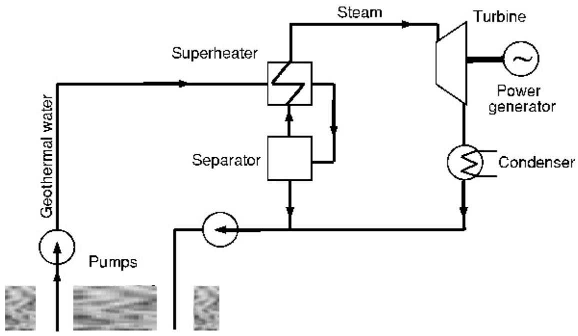

Figure 1. Schematic of a power plant with direct vaporisation of geothermal water

If temperature of geothermal water is smaller than 150 °C then a two-component system consisting of a primary circuit with the extracted geothermal water usually is used, which transfers heat to the working fluid in the secondary circuit in the preheater, evaporator or sometimes in the superheater. Next, geothermal water is directed to the return well. A sample design of the low-temperature power plant in presented in fig. 2 [4].

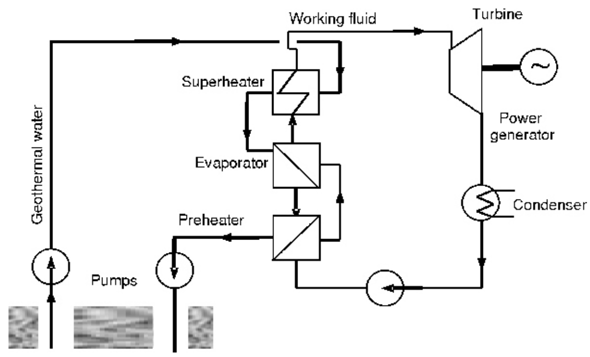

Figure 2. Schematic of a two-component power plant

Characteristics of geothermal power plants and their principles

In the case of low-temperature cycles a key issue is the adequate selection of the working fluid. In the course of selection of working fluids, for which the calculations have been performed, the ecological indicators for the assessment of refrigeration fluids served as principal guidelines. The fluids have been selected which have a low ozone depletion potentiel (ODP) as well as a low global warming potential (GWP). Additionally the range of operation pressure ratio and availability of data for calculations have also been considered. One of the parameters describing the thermophysical properties of the low-boiling fluid is the entropy index I [5], which describes the shape of the saturation curve in the pressure – enthalpy diagram. It has been assumed that the process of isentropic decompression in turbine takes place only in the superheated vapour region and that it starts or terminates on the dew point curve. It results from that assumption that all considered in the work cycles can be divided, with respect to the entropy index, into two variants:

– variant A, when the entropy index $I > 1$, in such case the beginning of expansion is in the area of superheated vapour and the end of isentropic expansion falls onto the dew point curve, and
– variant B, when the entropy index $I < 1$ – the beginning of expansion is on the dew point curve whereas the end of isentropic expansion is in the region of superheated vapour.

Schematics of considered variants A and B in the operation of geothermal power plants have been presented in figs. 3 and 4, respectively, with marked temperatures T_{n} of a low-boiling fluid, temperatures T_{g} of geothermal water, and temperatures T_{t} of technological receivers.

Particular thermodynamic processes of realised theoretical Clausius-Rankine cycles in the pressure-enthalpy co-ordinate system for both diagrams have been presented in fig. 5.

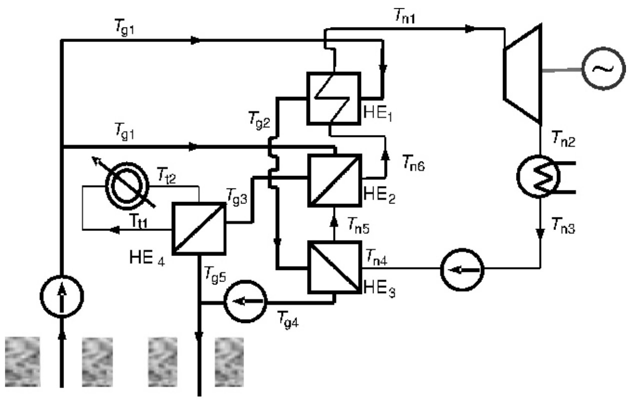

Figure 3. Schematic of the geothermal power plant with vapour superheating – variant A

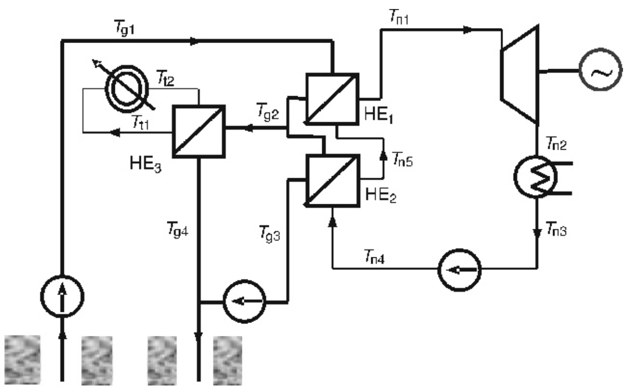

Figure 4. Schematic of the geothermal power plant without vapour superheating – variant B

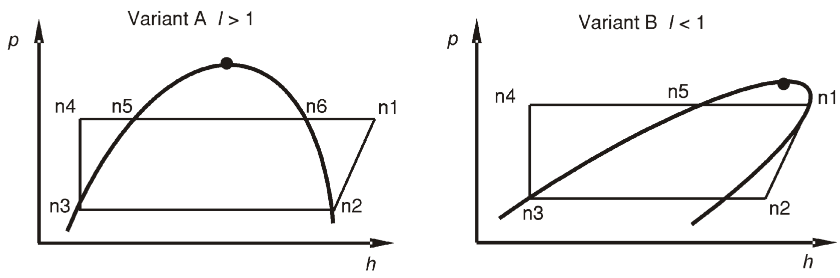

Figure 5. A sequence of thermodynamic processes of the working fluid presented in the pressure-enthalpy diagram for variants A and B

In figs. 6 and 7 are presented temperature fields of fluids in heat exchangers with denoted temperatures at inlet and outlet according to the nomenclature given in figs. 3 and 4.

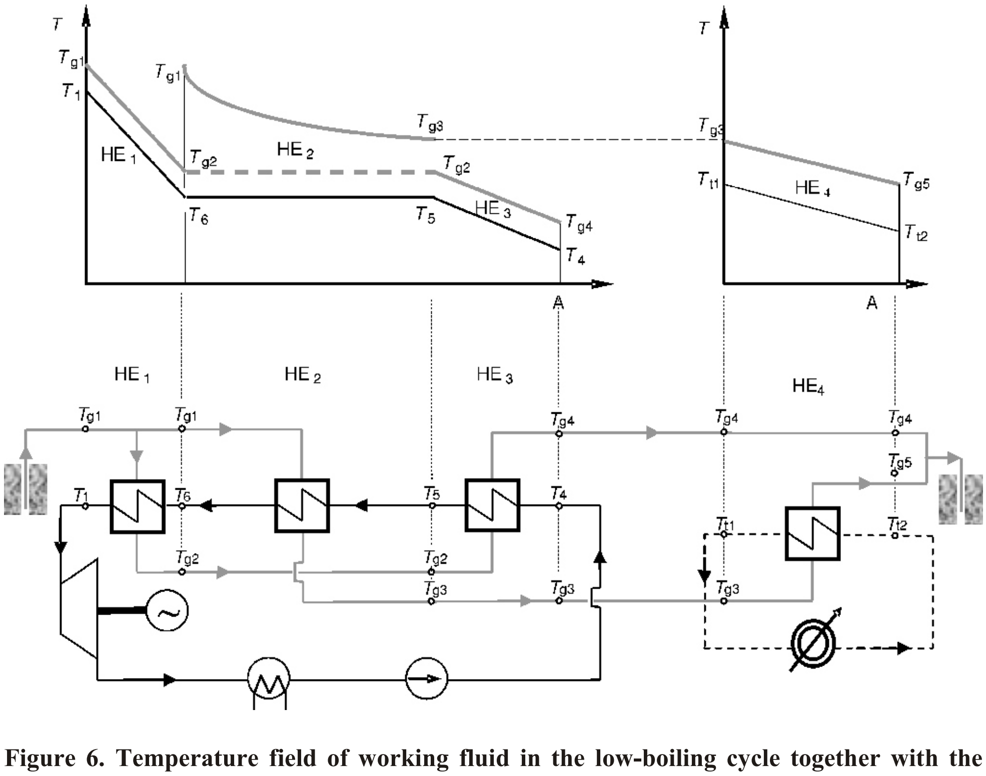

Figure 6. Temperature field of working fluid in the low-boiling cycle together with the temperature field in the heat exchanger feeding the technological receivers – variant A

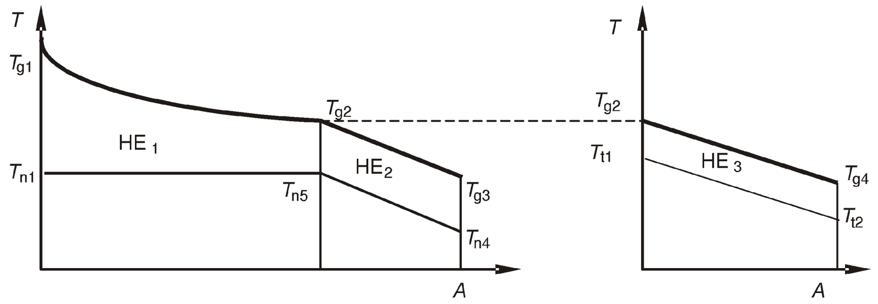

Figure 7. Temperature field of working fluid in the low-boiling cycle together with the temperature field in the heat exchanger feeding the technological receivers – variant B

Results of calculations

In the case discussed above two variants of calculations have been performed for efficiency and power, taking in account the influence of parameters of geothermal water for three low-boiling fluids and various ambient temperatures.

In calculations it has been assumed that:

– maximum volumetric flowrate of geothermal water is V_g = 100 and 200 m^3/h,
– maximum temperature of extracted geothermal water is T_{g1} = 70, 80, and 90 °C, and
– condensation temperature of the low-boiling fluid varies in the range from 10 to 30 °C and is linked to the ambient temperature, which in the case of West Pomeranian region ranges from –4.1 to +18.4 °C [6].

For simplicity of calculations it has been assumed that the mean specific heat of geothermal water is c_g = 3.8 kJ/kgK, and the mean density of geothermal water is ρ_g = = 1080 kg/m^3. Thermal, chemical, and exploitational properties of low-boiling fluids have been assumed on the basis of [7] and [8]. The internal turbine efficiency has been assumed in calculations to be η = 0.9. Detailed mathematical model has been presented in [9]. It should be emphasised that the main purpose of this study is to select comparable operating conditions for all fluids, regardless of their different thermodynamic characteristics

On the basis of obtained results of calculations constructed have been relevant diagrams illustrating the influence of temperature of geothermal water, a volumetric rate of geothermal water, and condensation temperature of working fluid (dependent of the ambient conditions) on the efficiency and power of binary geothermal power plant for selected low-boiling fluids.

In figs. 8 and 9 the thermal efficiency of the real object and turbine internal power for the fluids R124, R227ea, and R600A are compared, obtained for the case of geothermal water with temperature of 90 °C and volumetric flowrate of 100 m^3/h at various condensation temperatures of the working medium.

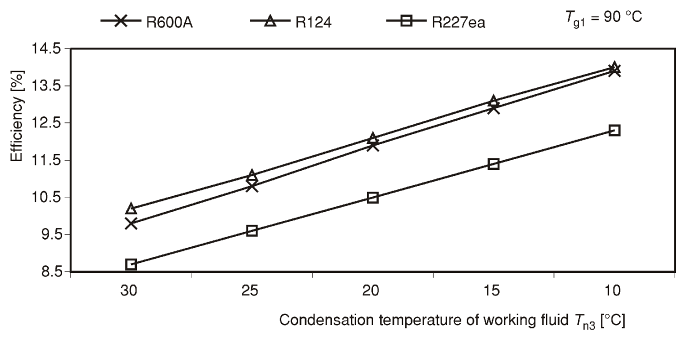

Figure 8. Thermal efficiency of the real object in the case of a low-boiling fluid in function of condensation temperature of the low-boiling fluid

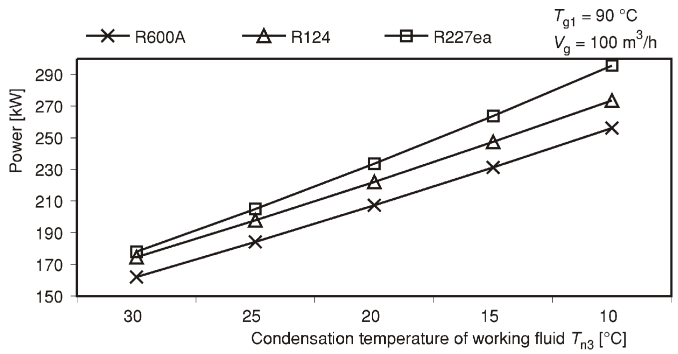

Figure 9. Turbine internal power in function of condensation temperature of low-boiling fluid

From the diagrams stems a clear influence of reduction of condensation temperature (ambient temperature) both on the thermal efficiency of the real cycle η_t as well as on the turbine internal power N_w as well as the influence of the kind of applied low-boiling fluid. In the case of the R227ea fluid the turbine internal power N_w significantly exceeds the turbine power at two other remaining fluids R600A and R124.

In figs. 10 and 11 the influence of external temperature has been presented, which varies in specific months, using the data from 1997, on the thermal efficiency of the real cycle η_t and turbine internal power N_w.

Conclusions and prospective investigations

On the basis of analysis of obtained results of calculations, for two presented variants of geothermal power stations, the following conclusions can be formulated.

In order to increase the efficiency and power obtained in the considered cases there must be increased the temperature of the upper heat reservoir and/or reduced temperature of the lower heat reservoir. In the first case it is possible by combination of the cycle with the gas turbine arrangement whereas in the second case there can be applied an adsorption heat pump.

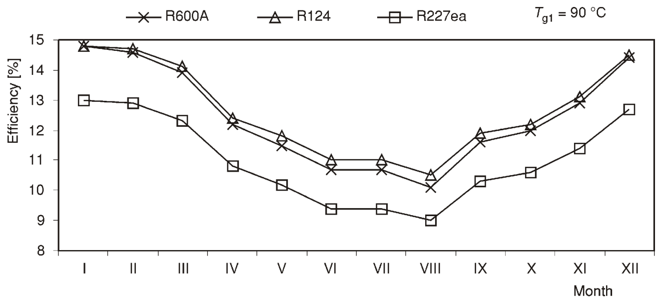

Figure 10. Thermal efficiency of the real cycle for the low--boiling fluid in function of ambient temperature

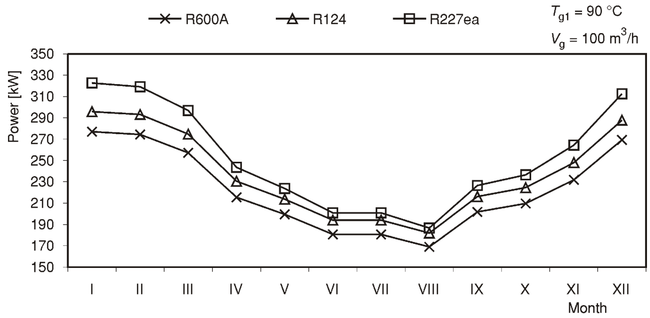

Figure 11. Turbine internal power in function of ambient temperature

With respect to the facts mentioned above as well as that in the present work analysed has only been the influence of three low-boiling fluids the similar investigations will follow for the case of other working fluids and implementation of combined cycled for utilization of geothermal energy with incorporation of the gas turbine and/or the heat pump.

Conducted also will be the analysis with respect to utilize the geothermal heat for selected technologies with a prescribed demand for the heat and also for heating purposes and preparation of utility hot water. This will enable a more effective utilization of geothermal energy.

Nomenclature

A – heat transfer surface, [m^2]
N_w – cycle power, [kW]
T_g – temperature of geothermal water, [°C]
Tn – temperature of low-boiling fluid, [°C]
η_t – thermal efficiency of the real cycle, [%]

Abbreviation

HE – heat exchanger

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Authors' address:

A. Borsukiewicz-Gozdur, W. Nowak
Szczecin University of Technology, Chair of Heat Engineering
19, al. Piastów, 70-310 Szczecin, Poland

Corresponding author A. Borsukiewicz-Gozdur
E-mail: aborsukiewicz@ps.pl

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