INSTITUTE OF FLUID-FLOW MACHINERY
POLISH ACADEMY OF SCIENCES

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114

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GDAŃSK 2003

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Aims and Scope

Transactions of the Institute of Fluid-Flow Machinery have primarily been established to publish papers from four disciplines represented at the Institute of Fluid-Flow Machinery of Polish Academy of Sciences, such as:

- Liquid flows in hydraulic machinery including exploitation problems,
- Gas and liquid flows with heat transport, particularly two-phase flows,
- Various aspects of development of plasma and laser engineering,
- Solid mechanics, machine mechanics including exploitation problems.

The periodical, where originally were published papers describing the research conducted at the Institute, has now appeared to be the place for publication of works by authors both from Poland and abroad. A traditional scope of topics has been preserved.

Only original and written in English works are published, which represent both theoretical and applied sciences. All papers are reviewed by two independent referees.

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Editorial

These Special Issues of the *Transactions of Fluid-Flow Machinery*, Nos. 113 and 114 contain selected papers from the International Conference on *Turbines of Large Output* devoted to commemorate 100$^{\mathrm{th}}$ Birthday Anniversary of Prof. Robert Szewalski. The conference was held in Gdańsk, Poland on September 22-24, 2003.

The Conference is a continuation of previous conferences held at the Institute of Fluid-Flow Machinery PAS in former years dedicated to technology of steam turbines. Series of conferences bearing the same name took place in the years 1962, 1965, 1968, 1993. In 1997 organised has been a conference on steam turbines and related topics, but with a slightly amended title – *Problems of Fluid-Flow Machinery.* At present at the Institute of Fluid Flow Machinery there are conduced research of fundamental character encompassing both the issues related to steam turbines and fundamentals of power engineering.

Organisers of the present conference have returned to the traditional name, i.e. Conference on *Turbines of Large Output* to mark the respect to the memory of Professor Robert Szewalski (1903-1993), the founder and a director of the Institute of Fluid-Flow Machinery for several years, and initiator of the conference series devoted to the problems of steam turbines.

The Editors are very grateful to the referees of the papers presented in this issue of the *Transactions of Fluid-Flow Machinery*: J. Badur, W. Batko, E. S. Burka, J.T. Cieśliński, P. Doerffer, A. Gardzilewicz, B. Grochal, J. Kiciński, G. Kosman, T. Król, J. Krzyżanowski, J. Mikielewicz, A. Neyman, W. Ostachowicz, R. Puzyrewski, R Rządkowski, J. Świrydczuk, M. Trela, T. Uhl and Z. Walczyk.

We appreciate cordially the manifested authors interest in our conference. Special thanks are conveyed to Ms 'Maya' Bagińska, for her fruitful editorial help related to directing the papers to reviewers and correspondence with the authors of contributions.

Prof. Jarosław Mikielewicz
Editor-in-Chief

Dr Edward Śliwicki
Managing Editor

TRANSACTIONS OF THE INSTITUTE OF FLUID-FLOW MACHINERY

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WŁADYSŁAW NOWAK*and ALEKSANDRA BORSUKIEWICZ-GOZDUR

Analysis and assessment of the effectiveness of operation of binary power plant utilising geothermal water with a medium enthalpy

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Abstract

In the work presented are the results of investigations regarding the effectiveness of operation of binary power plant fed by geothermal water with the flow rate of 100 m^3/h and temperature of 90°C. The results of calculations regard the system of binary 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.

Keywords: Binary power station; Geothermal energy; Low-boiling fluid; Thermodynamic cycle

Nomenclature

η_t	–	thermal efficiency of the real cycle, %
A	–	heat transfer surface, m^2
HE	–	heat exchanger,
N_w	–	internal turbine power, kW
T_g	–	temperature of geothermal water, °C
T_n	–	temperature of low-boiling fluid, °C

1 Introduction

In the domestic and foreign literature the knowledge of the problems regarding exploitation of geothermal resources with high enthalpy for production of

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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 energy from the hot geothermal resources for electricity production:

- direct vaporization of geothermal water using the separator,
- indirect vaporization 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.

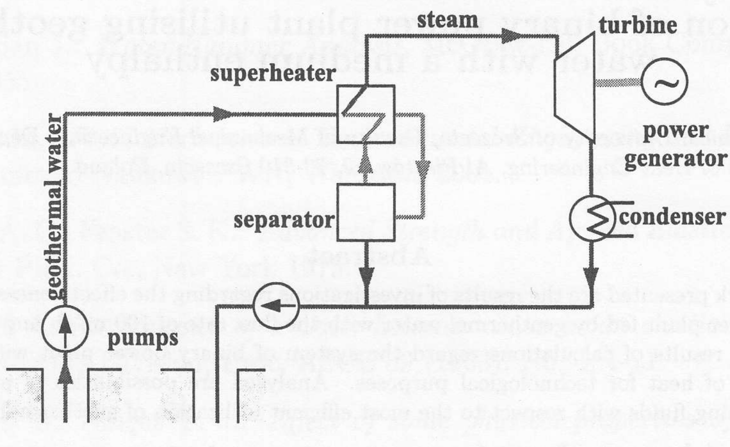

Figure 1. Scheme of a power plant with direct vaporisation of geothermal water.

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 that water. 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].

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 heater, evaporator or sometimes in the superheater. Next, geothermal water is directed to the return well. A sample design of the binary power plant in presented in Fig. 2 [4].

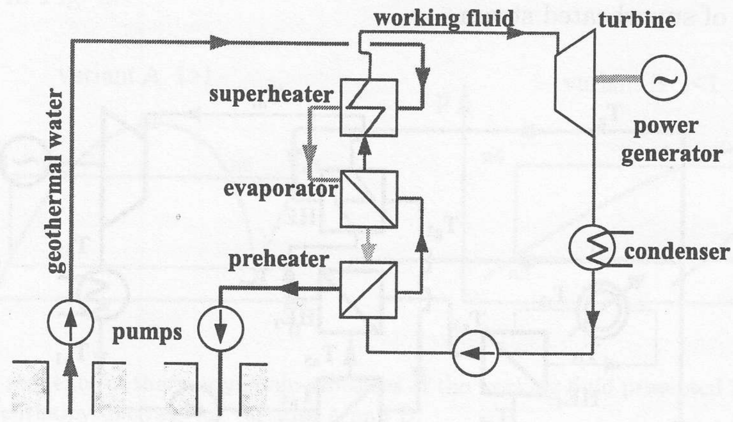

Figure 2. Scheme of a two-component power plant.

2 Characteristics of binary 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 potential (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 steam region and that it starts or terminates on the saturated vapour line. 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 steam and the end of isentropic expansion falls onto the saturate steam line;

- variant B when the entropy index $I < 1$ – the beginning of expansion is on the steam saturation line whereas the end of isentropic expansion is in the region of superheated steam.

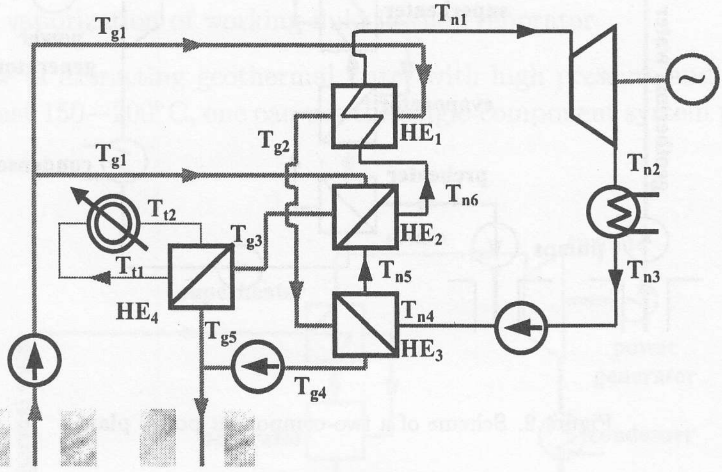

Figure 3. Scheme of the geothermal power plant with steam superheating – variant A.

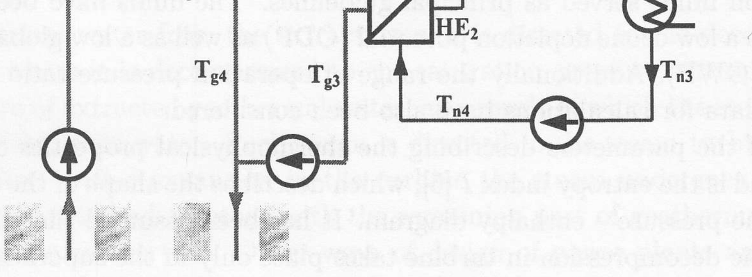

Figure 4. Scheme of the geothermal power plant without steam superheating – variant B.

Schematics of considered variants A and B in the operation of geothermal power plants have been presented respectively in Fig. 3 and Fig. 4 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 realized theoretical Clausius-Rankine cycles in the pressure-enthalpy co-ordinate system for both diagrams have been presented in Fig. 5.

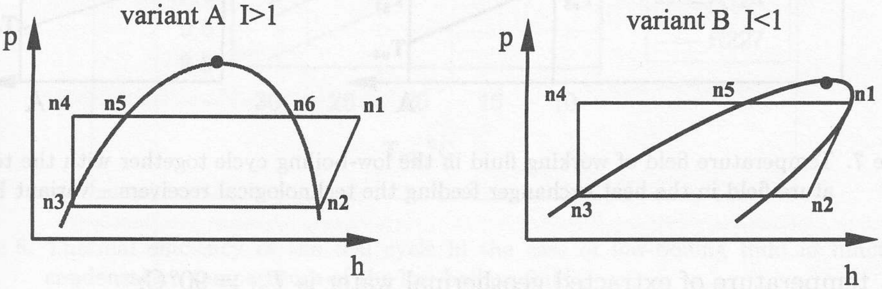

Figure 5. A sequence of thermodynamic processes of the working fluid presented in the pressure – enthalpy diagram for variants A and B.

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

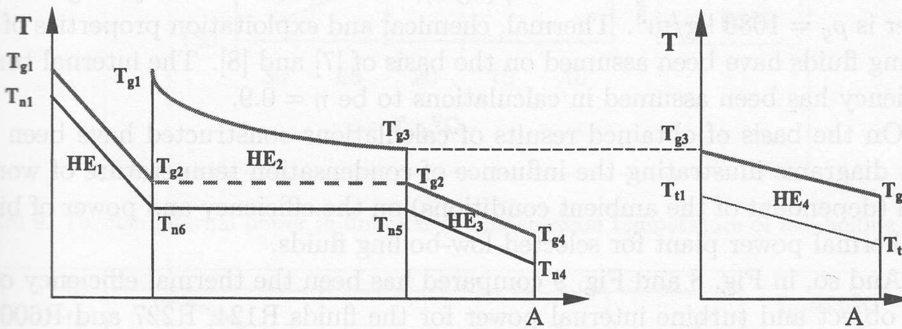

Figure 6. Temperature field of working fluid in the low-boiling cycle together with the temperature field in the heat exchanger feeding the technological receivers – variant A.

3 Results of calculation

In the case of discussed above two variants performed have been calculations of efficiency and power for three low-boiling fluids with entropy index $I < 1$ and various ambient temperatures.

In calculations it has been assumed that:

- volumetric flowrate of geothermal water is $V_g = 100\ \mathrm{m^3/h}$;

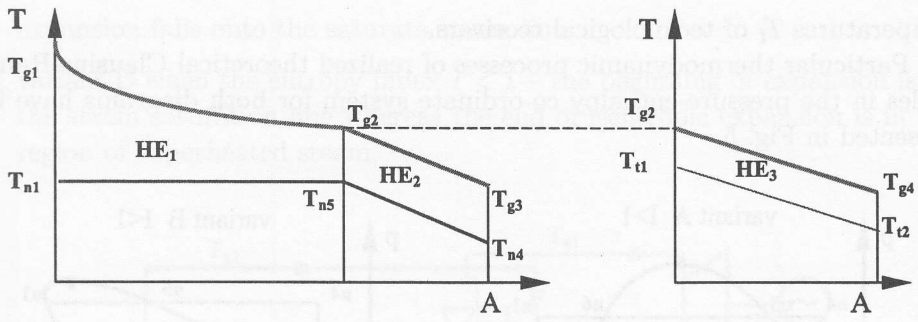

Figure 7. Temperature field of working fluid in the low-boiling cycle together with the temperature field in the heat exchanger feeding the technological receivers – variant B.

- temperature of extracted geothermal water is $T_{g1} = 90°\mathrm{C}$;
- 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 $\rho_g = 1080$ kg/m^3. Thermal, chemical and exploitation 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 $\eta = 0.9$.

On the basis of obtained results of calculations constructed have been relevant diagrams illustrating the influence of 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.

And so, in Fig. 8 and Fig. 9 compared has been the thermal efficiency of the real object and turbine internal power for the fluids R124, R227 and R600A at various condensation temperatures of the working medium.

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 R227 fluid the turbine internal power N_w exceeds the turbine power at two other remaining fluids R600A and R124.

In two subsequent Fig. 10 and Fig. 11 presented has been the influence of external temperature, 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. Some of this results of calculations were presented at the Conference on Sustainable Development of Energy [9].

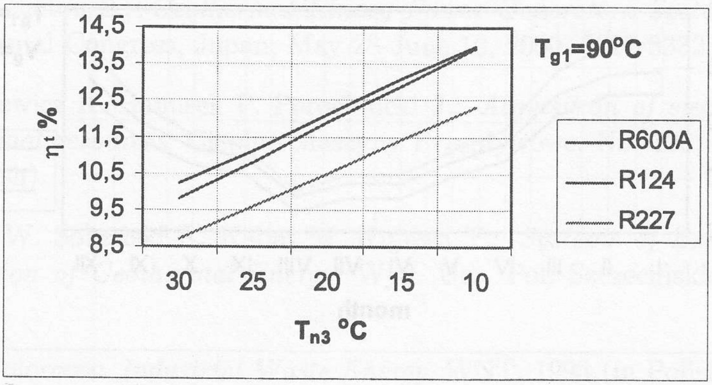

Figure 8. Thermal efficiency of the real cycle in the case of low-boiling fluid in function of condensation temperature of the low-boiling fluid.

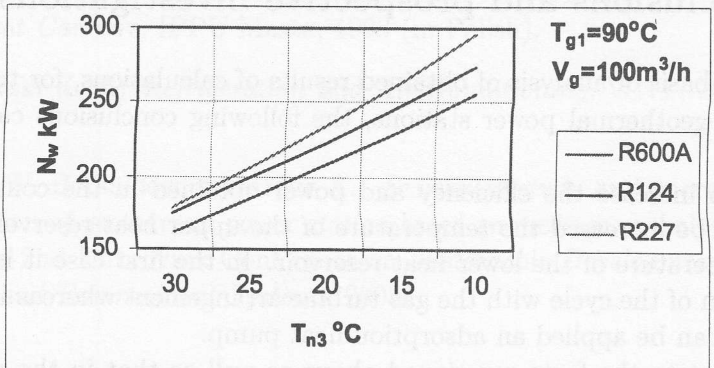

Figure 9. Turbine internal power in function of condensation temperature of low-boiling fluid.

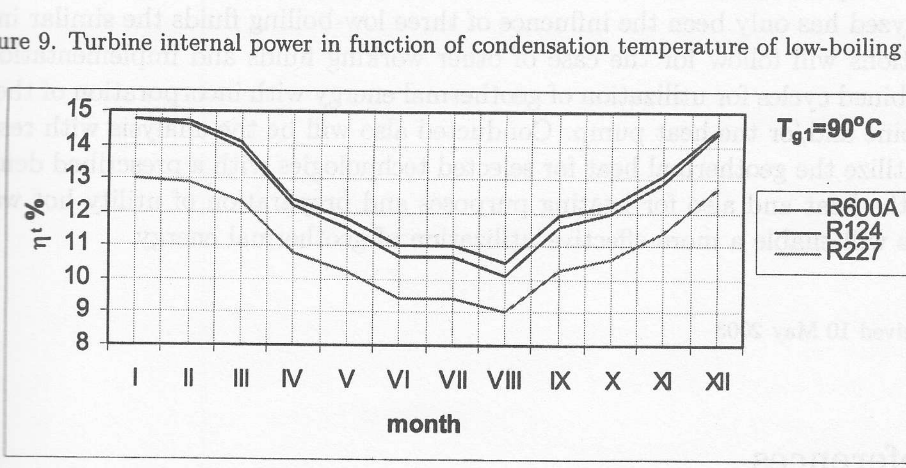

Figure 10. Thermal efficiency of the real cycle for the low-boiling fluid in function of ambient temperature.

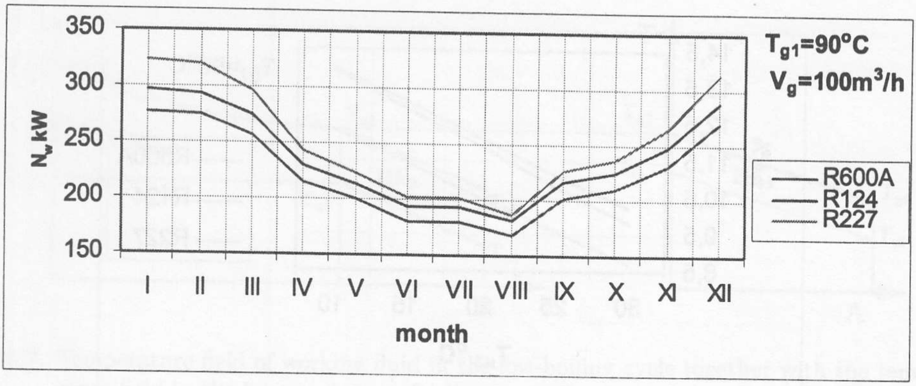

Figure 11. Turbine internal power in function of ambient temperature.

4 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.

With respect to the facts mentioned above as well as that in the present work analyzed 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 cycles 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.

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References

[1] Gawlik K. Hassani V.: *Advanced Binary Cycles: Optimum Working Fluids*, Resources Council, Annual Meeting, California, 1998.

[2] Ura K. Saitou S.: *Geothermal Binary Power Generation System*, Proc. of Geothermal Congress, Japan, May 28-June 10, 2000, 3327-3332.

[3] Chodkiewicz R. Hanusek P. Porochnicki J.: *Acquisition of electricity from geothermal resources*, Cieplne Maszyny Przepływowe, No. 120, 2001, 19-37 (in Polish).

[4] Nowak W. Sobański R. Kabat M. Kujawa T.: *Systems of Extraction and Utilisation of Geothermal Energy*, Wyd. Ucz. Pol. Szczecińskiej, 2000 (in Polish).

[5] Praca zbiorowa: *Industrial Waste Energy*, WNT, 1993 (in Polish).

[6] Główny Urząd Statystyczny, *Statistical Yearbook*, 1997 (in Polish).

[7] Bońca Z. Butrymowicz D. Dembek D. Depta A. Targański W.: *Refrigerants and Heat Carriers*, IPPU Masta, 1998 (in Polish).

[8] Gutkowski K.M.: *Refrigeration and Air-Conditioning*, WNT, 2003 (in Polish).

[9] Nowak W. Borsukiewicz-Gozdur A.: *Feasibility study and energy efficiency estimation of geothermal power station based on medium enthalpy water*, CD Proc. of 2nd Dubrovnik Conference on *Sustainable Development of Energy, Water and Environment Systems*, 2003.