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Russian Geothermal Power Plants Equipped with ORC-units

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ABSTRACT

In 1967, 1st in the world (750 kW) binary power plant was built and successfully tested in Russia on Paratunskiy (Kamchatka) site. Use of ORC technology allows increasing the installed capacity of the existing geothermal power plants (GeoPP) without drilling additional wells due to more efficient use of geothermal fluid. Nowadays JSC "RusHydro" (Russian largest power-generation company) completes the construction of Russian pilot binary power plant 2.5 MW installed capacity, utilizing waste geothermal brine with temperature 120 °C. Heat balance diagram and equipment of this ORC-unit adopted to meet the physical and chemical properties of the organic and geothermal working fluid as well as the severe climatic conditions of Kamchatka region. Installing of such ORC-units on Russian GeoPPs will greatly improve the efficiency of geothermal fluid utilization. For example, the new project of upgrading Mutnovsky GeoPP with ORC units will increase its total capacity on 30%. Currently completed project Feasibility Study allowed identifying engineering proposals providing its high efficiency.

1. INTRODUCTION

The method for producing electric energy from hot water by means of a binary installation using Freon R12 low-boiling organic substance as working fluid for the Rankine cycle was patented for the first time in the world in the Soviet Union, and the technology was approbated at the Paratunskaya experimental geothermal power plant (GeoPP) in Kamchatka in 1967, Moskvicheva and Popov (1970). Since that time, this technology has been actively used outside of Russia. According the data from Larjola et al. (2011) by the end of 2011 the global number of built power plants with binary power units exceeded 300 (including power units utilizing geothermal heat) with the total installed capacity of about 2000 MW (Figure 1).

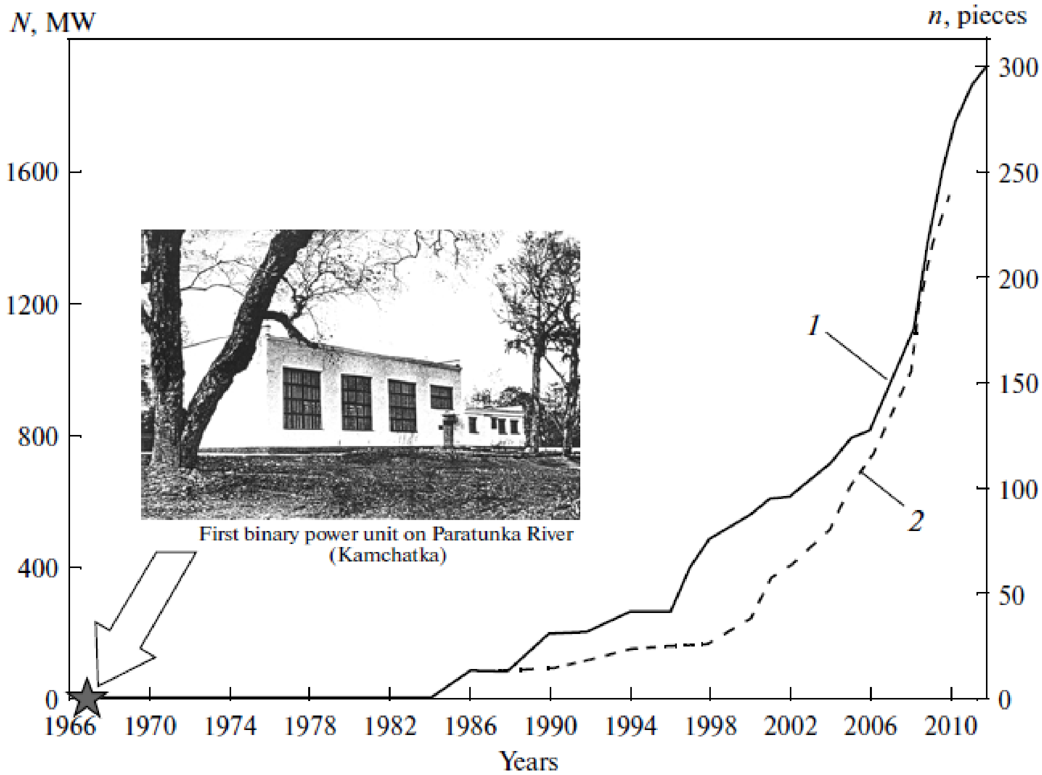

Figure 1: Growth in the total installed capacity *N* and (*2*) the amount of *n* of the built binary power units in the world.

2. PAUZHETSKAYA GEOTHERMAL BINARY POWER PLANT

At present, we are witnessing a revival of Russian binary technologies, Povarov et al. (2003) and Tomarov et al. (2009). The project of constructing a 2.5 MW pilot binary power unit is being implemented at the Pauzhetskaya GeoPP in Kamchatka. This project, ordered by JSC Engineering Center of Renewable Energy, takes financial support from JSC "RusHydro". Specialists of JSC "Geotherm-EM" have carried out a set of research and experimental design works on selecting the working fluid, developing the concept and technical solutions for the project, determined the technical parameters and designs of the main equipment, and are conducting scientific-technical supervision of the project.

Central to the project is construction of a binary-cycle power unit intended for producing electric energy by using the waste geothermal brine from Pauzhetskaya GeoPP, which has a temperature of about 120°C. The objective of the project is to refine the technology, reveal problems, and prepare the basis for construction of binary power plants at other sites, including those equipped with power units of larger capacity.

The Pauzhetskaya GeoPP was commissioned in 1966 and now has two power units with a combined capacity of 12 MW (6.0 + 6.0); however, due to a shortage of geothermal steam, they altogether produce not more than 5.5–6.0 MW. At the same time, a big volume of geothermal brine with a temperature of 120°C is not used in the technological cycle of the Pauzhetskaya GeoPP and is discharged onto the relief.

Selection of a low-boiling organic working fluid for Organic Rankine Cycle (ORC-fluid) is one of the most important problems determining how efficiently and reliably the binary installation will operate. In solving this problem, various factors should be taken into account: the environmental safety of the technology, the thermal–physical properties of the working fluid (heat conductivity and heat capacity, viscosity, and critical parameters), thermal–chemical characteristics, cost of ORC-fluid, its availability in the market, extent to which its properties have been studied, etc., Pirson (2004).

The selection of ORC-fluid for the Pauzhetskaya GeoPP is based on a multilevel comparative analysis of the entire set of properties and determination of their interrelation with the thermodynamic characteristics of the cycle, thermal engineering, and mass and dimensional parameters of the main and auxiliary equipment, Boyarskii et al. (2005).

An R-134a refrigerant has been selected as working fluid for the Pauzhetskaya GeoPP as a result of calculation and analytical studies. A detailed substantiation of this choice is given in Boyarskii et al. (2005). The numerical modelling has carried out for the main power performance characteristics of binary GeoPP and the parameters of its scheme determination at the base points with varying the temperature and flowrate of geothermal brine serving as heating medium, as well as during variations of the temperature and flowrate of cooling water in the condenser. Central to this calculation, which is carried out using the method of successive approximations, is finding the correspondence between the thermal balance of the evaporator and economizer and their thermal characteristics. Thus, the flowrate and temperature of heating separated moisture are the main parameters influencing the performance of the binary installation. A change in these parameters leads to the corresponding change in the flowrate of ORC-fluid and turbine output. At the same time, changes in the temperature and flowrate of cooling water in the condenser must be taken into account. The study results were used to construct a simplified nomographic chart for estimating the gross power output produced by the binary turbine of the Pauzhetskaya GeoPP at variable parameters of geothermal brine and cooling water (Figure 2). Thus, the described studies of variable operating conditions of the Pauzhetskaya GeoPP, which were carried out in a wide range of the parameters of heating and cooling media and flowrates of brine and cooling water, made it possible to reveal the changes in the performance indicators of the power plant that may occur during its operation.

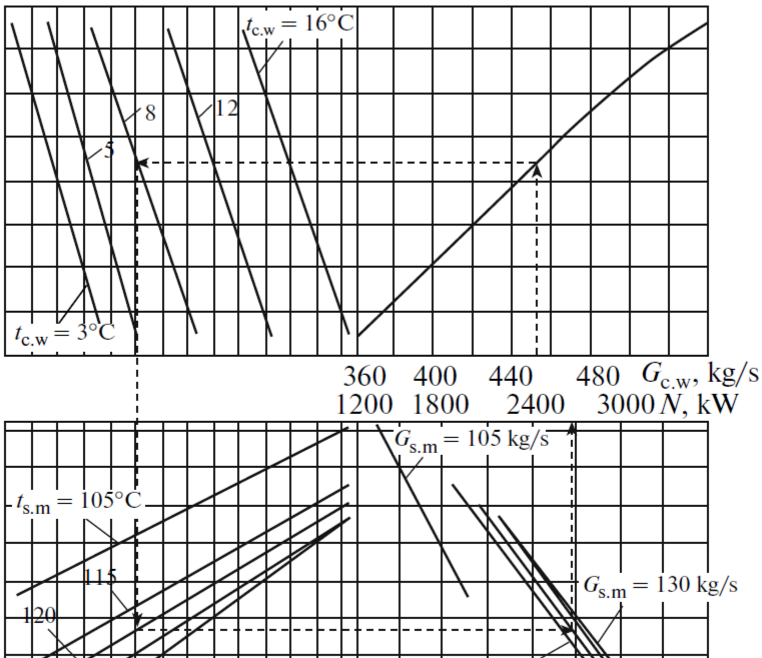

Figure 2: Simplified nomographic chart for estimating the power output produced by the binary turbine at the Pauzhetskaya GeoPP at variable parameters of geothermal heat carrier and cooling water. $G_{c.w}$ and $T_{c.w}$ are the flow rate and temperature of cooling water, and $G_{s.m}$ and $t_{s.m}$ are the flowrate and temperature of geothermal brine.

3. POWER EQUIPMENT OF PAUZHETSKAYA BINARY POWER PLANT

All equipment of the binary power unit is accommodated in a standalone building with in-plan dimensions 18 × 36 m. The vertical layout solutions for the project are determined primarily by the requirements of ensuring the necessary net positive suction head (NPSH) for the feed pumps and providing sufficient space for maintenance of the turbine generator and condenser. In accordance with these conditions, the height elevation of the maintenance platform and the second floor of the stack for electrical, administrative, and amenity rooms was taken equal to 4.65 m.

The layout of the main equipment and pipelines of the binary installation in the machine hall is shown in Figure 3. In 2012, works on erecting the equipment of the pilot binary-cycle geothermal power unit at the Pauzhetskaya geothermal power plant were completed. In 2013 start-up tests of binary GeoPP were successfully completed.

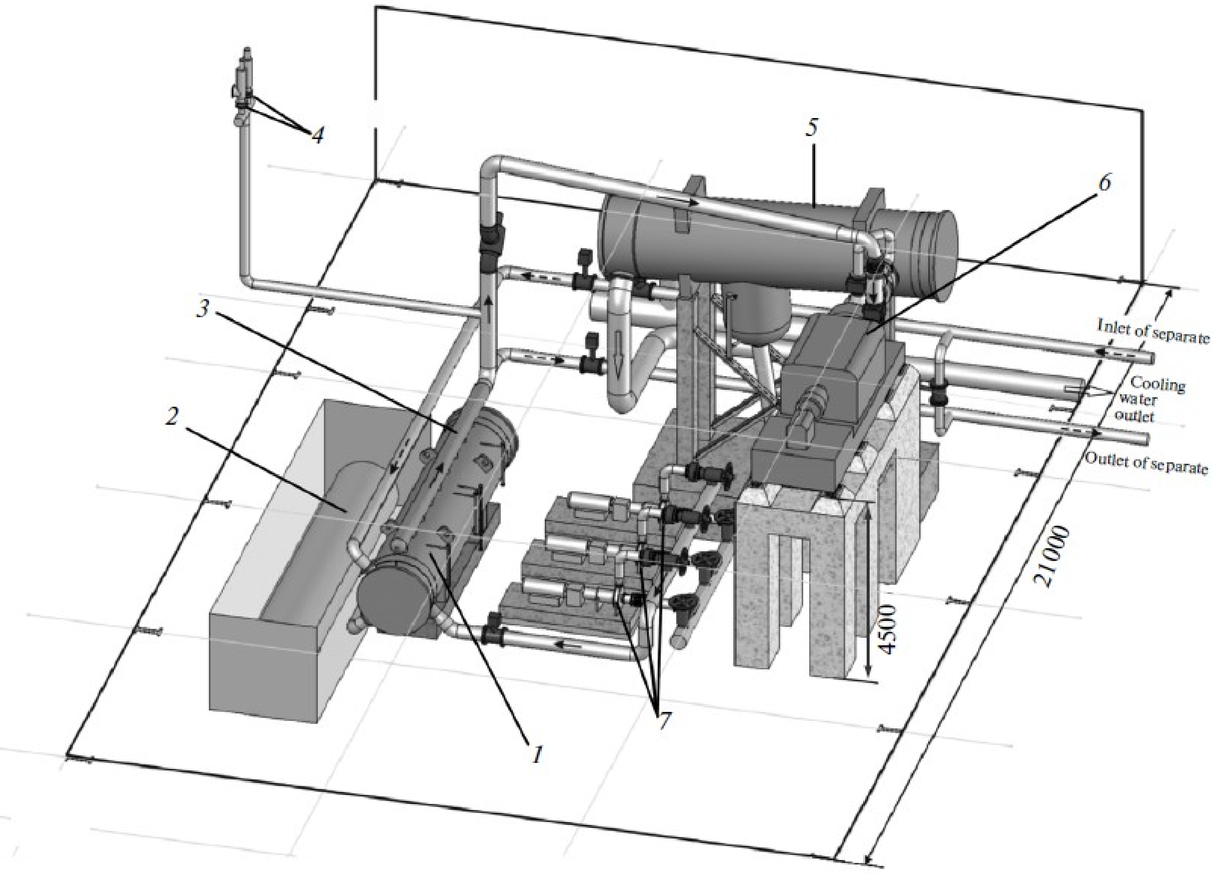

Figure 3: Layout of main equipment and motion directions of organic low-boiling working fluid, geothermal brine, and cooling water in the process loops of the binary-cycle 2.5 MW power unit at the Pauzhetskaya GeoPP. (*1*) Evaporator-superheater, (*2*) storage tank, (*3*) vapour collector, (*4*) safety valves, (*5*) condenser, (*6*) turbine generator, and (*7*) feed pumps.

One of the most complicated and responsible machines of any power plant is the turbine, Tomarov et al. (2014). The researchers from the Kaluga Turbine Works (Russia) explored the production of turbines for geothermal power plants of different plants, including the steam turbines and the ones with back pressure, which work on geothermal steam.The first Russian ORC-turbine on the organic working fluid (Freon R-134a) was produced in 2010 for the binary power unit of capacity 2.5MW (Figure 4). The binary turbine for the Pauzhetskaya GeoPP is a single-stage one placed in a cantilever manner at the turbine generator free end and is made as a radial-axial unit. One of the design features of the binary turbine is that the system of its end seals can operate both under vacuum and at increased pressure in emergency situations. To compensate for temperature expansions, a bellows compensator (D_{nom} = 600 mm) is inserted in the between the binary turbine and condenser.

Spent vapour from the turbine axial exhaust hood is forwarded into the condenser. There is also possibility to dump the ORC-vapour into the condenser in bypass of the turbine. The condenser is essentially a shell-and-tube heat exchanger designed to maintain the condensation temperature equal to 28°C with the cooling water temperature equal to 8°C (Fig. 5). The condenser is installed with a 4° slope to the horizontal plane to reduce the influence of tube bundle flooding by condensate from the upper tubes, thus achieving more efficient heat transfer.

In 2013 functional tests of the process cycle of the pilot industrial binary 2.5 MW power unit at the Pauzhetskaya GeoPP were carried out. These works were finished with carrying out the first start of the binary turbine unit, and the correctness of the adopted basic technical solutions, of the selected main equipment, and the serviceability of the binary power installation were confirmed.

Figure 4: Pauzhetskaya GeoPP turbine unit equipped with the binary turbine produced by the Kaluga Turbine Works.

Figure 5: Condenser of the binary turbine unit at the Pauzhetskaya GeoPP.

4. ADVANCED BINARY GEOTHERMAL PROJECTS IN RUSSIA

Besides Pauzhetskaya Binary Power Plants JSC “RusHydro” has many other prospective plans of geothermal development, among them the project to increase the installed capacity of the Mutnovsky geothermal power plant (MGeoPP) by using the waste water heat (geothermal brine). The idea underlying this technology is in utilization of geothermal brine heat from the Mutnovsky geothermal power plant. At the present time, only geothermal steam with a pressure of 0.6MPa is used in MGeoPP, while the brine (about 1000 t/h) with a temperature of 150–170°C is pumped into the reinjection wells and, then, dropped on the relief. The project involves expansion of the geothermal brine at a pressure of 0.2 MPa with forming the so-called secondary steam, which is directed into two steam turbines with air condensers of 4MW of power. The geothermal brine that is left after boiling with temperature 120°C is used in two binary turbines of 2.5MW power.

Realization of the project will allow one to improve the efficiency of using the extracted geothermal heat carrier by 26% and obtain the additional power of 13 MW in MGeoPP. Currently, the technological decisions and draft designs of basic equipment are being worked out by the specialists of JSC “Geoterm- EM”, the substantiation of the investment is being carried out, and the design of the project has already been started. Figure 6 shows the thermal diagram of the constructed system for utilization of waste brine of MGeoPP.

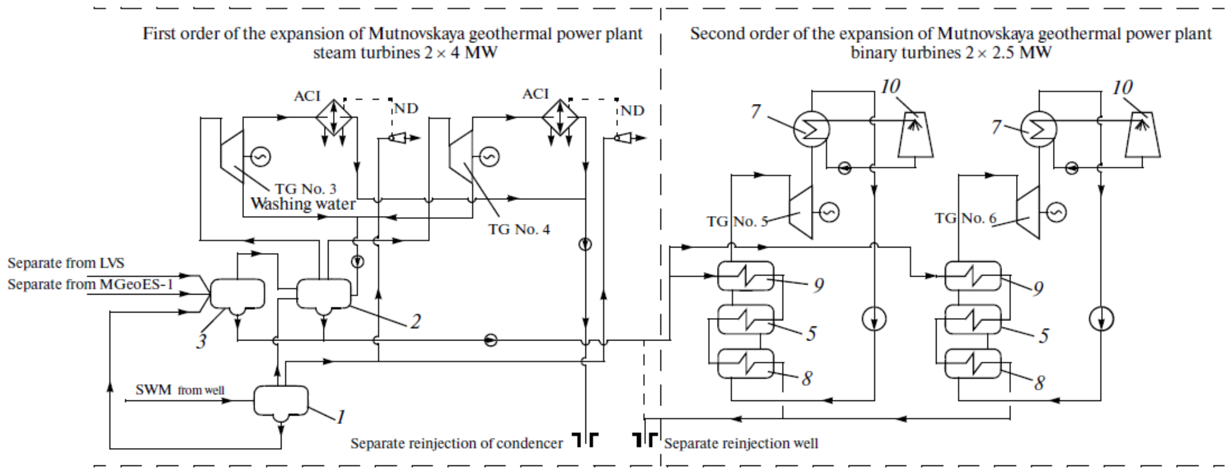

Figure 6: The thermal diagram of the utilization system of waste geothermal brine of the Mutnovsky geothermal power plant: (*1*), (*2*) separators of first and second stages; (*3*) expander; (*4*) muffler; (*5*) evaporator; (*6*) feed pumps; (*7*) condenser; (*8*) economizer; (*9*) vapour superheater; (*10*) water cooling tower; TG Nos. 3–6 are turbogenerators; SWM is the steam–water mixture; LVS is the linear vertical separator; ACI is the air condenser installation; and NCG are noncondensables.

CONCLUSION

A domestically produced 2.5 MW pilot binary-cycle geothermal power unit operating on geothermal brine discharged at the Pauzhetskaya GeoPP has been constructed for the first time. The results of commissioning works have confirmed serviceability of the equipment selected for the binary geothermal power unit at the Pauzhetskaya GeoPP. The mastering of binary power technologies on the pilot commercial model of the binary power unit at the Pauzhetskaya GeoPP opens prospects for wide-scale use of binary power technologies in Russia for recovering heat discharges from power-generating and industrial enterprises.

It is planned to introduce the geothermal power supply with the help of binary power plants in Russian regions (Kamchatka, Kuril Islands, Krasnodar region etc.). The basic increase of power plant capacities will be ensured due to large-scale exploration of low-temperature geothermal sources with using the binary technologies.

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