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MUTNOVSKY GEOTHERMAL POWER COMPLEX IN KAMCHATKA

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1. INTRODUCTION

Modern development of energy in Russia is characterised by an abrupt increase in requirements for fuel and materials, and correspondingly electric power.

The greatest increased cost of energy takes place in remote area of the Far East, Kamchatka and the Kurils Islands, which use mostly imported fuel. Recently the cost of 1 kWh of electric power in these areas exceeds world prices and reaches 0.1-0.25 dollars USA for 1 kW/h.

Russia has a unique reserve of geothermal energy in Kamchatka. This region may secure itself with energy independence by generating energy at the warm Earth's expense.

Russia has a rich experience in mastering geothermal resources with many explored Russian geothermal fields. There are about 1000 drilled geothermal wells within Russia. Today in Europe and throughout the world the intensive utilisation of non-traditional renewable types of energy is observed. In particular, the use of geothermal energy in Russia is part of a strategic plan of moving whole regions to securing them cheaper and ecologically clean geothermal energy. This plan is being realised for the first time in Kamchatka.

2. GEOTHERMAL RESOURCES IN MUTNOVSKOYE

The volcanic regions of Kamchatka have various types of geothermal resources. An available potential of the high-temperature (more than 150°C) geothermal fields in Kamchatka area totals about 1130 MW_e and potential of low-temperature fields (temperature lower 150°C) equals 1345 MW_t for a period of 100 years [1,2]. Currently, more than 20 geothermal fields in Kamchatka have been explored.

The Mutnovsky geothermal field is the most significant among the well-studied ones. Mutnovsky reserves were estimated and measured in 1988 and 1990, and now the field is completely ready for industrial use.

The Mutnovskoye site is located 70km Southwest from Petropavlovsk-Kamchatsky. About 60 wells have been drilled at this site, and one third of them are production wells. Reserves of geothermal fluids are capable to drive geothermal power plants with capacity of more than 250 MW.

Geothermal production from the Mutnovskoye site is both dry and wet steam with temperature up to 240°C and enthalpy up to 660 kcal/kg. Chemical composition of Mutnovskoye steam/water thermal sources is characterised as chloride, chloride-sulphate, and sulphate-chloride anions with the main cations being sodium and calcium [3].

Gas composition of the noncondensibles mainly consists of carbonic acid (up to 70% vol. CO_2). In addition, there is hydrogen sulphide, nitrogen, oxygen, methane, and hydrogen. Volume content of hydrogen sulphide is 10% on average.

3. UTILIZATION EXPERIENCE OF GEOTHERMAL RESOURCES IN KAMCHATKA

The first power generation experience on a base of geothermal resources was in the Paratunsky geothermal field, Kamchatka, Russia, in 1967, where the first of the experimental binary power plants, with capacity of about 600 kW was constructed [4].

The first industrial geothermal power plant in Russia was also constructed in 1967 in the Pauzetsky field, Kamchatka. The installed capacity of the first phase of the plant was 5 MW. After installation of the second phase of the plant in 1982, the total capacity was increased up to 11 MW [5]. An experimental back-pressure turbine was installed in the Mutnovsky field in 1987, and it produced about 300 kW of electricity.

The low-temperature geothermal resources are mainly used for district heating and health resorts (Paratunka, Esso, Anagvai) as well for greenhouses (Termalny, Ozernoye), and for fish farming (Malki, Paratunka).

Recently, in Russia, there is an active development of geothermal energy utilisation, which is realised within the frames of RF Ministry of Science projects (Department of Science of Russia), in a structure of GNTPR "Environmentally pure power" [5].

4. VERKHNE-MUTNOVSKY GEOTHERMAL POWER PLANT

More recently, in order to solve energy problems using geothermal resources of the Mutnovsky deposit in Kamchatka, "Geotherm" SC with participation of RAO "UES of Russia", Kamchatka Administration, "Kamchatskenergo" SC, and "Nauka" SC was founded [1,7].

The design, creation, equipment production and construction of the first multi-module geothermal power plant – Verkhne – Mutnovskaya GeoPP (VM GeoPP) with a capacity of 12 (3x4) MW (Fig.1) was organised by "Geotherm" SC with RF Ministry of Science support. VM GeoPP is the pilot geothermal power plant of GeoPP series, which are being constructed in Kamchatka. The equipment for this power plant has been manufactured at "Kaluga Turbine Works" SC ("KTZ" SC), "Podolsky Mashinostroitelny Plant" SC, etc. [8]

The creation of VM GeoPP was based on new approaches to power plant construction:

1. Modular steam preparation system manufactured completely assembled was introduced.
2. GeoPP, also modular (Fig. 1) with 100% factory assembly of major units-modules (turbogenerators, electrotechnical equipment, main control panel and etc.) was introduced.
3. Ecologically clean cycle of geothermal fluid utilisation with an air condenser that prevents direct contact of the working medium with the environment was incorporated.

Two phase flow from three production wells is carried through the pipeline to the collector and then after a two stage system of separation comes to three power units with a capacity of 4 MW each (Fig.2)

Steam entering the turbine at the pressure of p_0=0.8 MPa and correspondingly at the temperature of about 170 ^{0}C is practically completely dried (humidity rate is not higher than 0.05%) and therefore sufficiently clean. Steam quality at the turbine inlet is similar to common, medium-pressure thermal power plants.

In order to increase efficiency of utilisation of geothermal carrier energy, hot water (brine with appr. t=170 ^{0}C) after the separators is transported to the flash unit, where steam at a pressure of about 0.4 Mpa is produced. This steam (about 10 t/h) is used in ejectors for removal of non-condensable gases, specifically hydrogen sulphide (H_2S). Hydrogen sulphide removed from the condenser enters the adsorber where it dissolves in the steam condensate, which is then piped to the injection well without any contact with the environment. The condensate is sufficiently clean water with low admixture of salt content. Therefore, a lower condensate temperature was taken (t=50 ^{0}C appr.) allowing its injection without deposition in pipelines and injection wells.

The control of three energy units is carried out from the General Control Panel module.Six air condenser modules are located at a six-meter height from the turbo-generator platform (Fig.1). The condenser modules with water-cooler are designed and manufactured at "KTZ" SC. Every air condenser module of hipped type consists of 8 sections (packages) of 38X3 diameter steel zinc-plated pipes wrapped around with aluminium ribbing with 15 mm height.

The Steam Preparation Installation (SPI) for VM GeoPP has been developed in "Nauka" SC with MPEI, ENIN, VNIIAM and CNIIEP for engineering design. It was manufactured at Podolsky Mashinostroitelny Plant as a module, and is completely factory assembled. After plant tests the module has been delivered to Kamchatka by AN-124 airplane, having been mounted and tested under real working geothermal fluid conditions.

In the pump module there are separate reinjection system pumps, fire and auxiliary pumps, and electrical control panels. In addition there is the SPI system and the whole station protection system for corrosion and erosion-corrosion protection of metal during the idle and repair time of equipment. During the exploitation process the protection system allows to removal of salt deposits in turbines and air condensers.
Turbo-installations for VM GeoPP were developed and manufactured at "KTZ"SC on "Geotherm" SC assignment. The turbine and generator are installed on a single chassis, which also contains the lubrication tank and system. The turbine is connected directly (without the reduction gear) through the sleeve with the generator and has a rotation frequency of 50 rotations/sec. Every turbo-set is mounted separately in a module (carriage). A longstanding "KTZ" SC experience from ship and industrial turbines creation has been used in the design of VM GeoPP turbines.

The features of these turbines are the following: flexible support on the front frame, hydraulic regulation unit directly on the front frame, superposition of support-persistent bearing with the oil pump in the front frame [6].
The VM GeoPP turbine has some differences from the ship and industrial turbines: 1) steam control at the inlet pipeline is executed with "butterfly" type rotary damper, 2) steam entering the unit is carried out from above through the module roof. All ten-turbine stages have band and well developed moisture separation system.

VM GeoPP is intended for 2 versions of commercial operation of electric power production for "Kamchatskenergo" SC and construction-erection works provision under the GeoPP series creation at the Mutnovsky geothermal deposit.

5. MUTNOVSKY GEOPP (1^ST^ STAGE)

The project of creation of the Mutnovsky GeoPP 1st stage development with capacity 50 (2x25) MW is under construction now by "Geotherm" SC. Its start–up is scheduled in 2001 (Fig.3, 4). The financing of the project is carried out through a European Bank for Reconstruction and Development loan and Russian investors: Kamchatka Region Administration, RAO "UES of Russia" and "Kamchatskenergo"SC.

At present the GeoPP site civil preparatory and advance steam field works are being completed. The works under the major contract of design, manufacture, supply and "turn-key" construction of geothermal power plant have been started. Mutnovsky GeoPP 1st stage project includes (Fig.5): the main building with facilities for turbines, unit control panel, separators, electrotechnical equipment and a hostel for watch personnel [9]. At the GeoPP site there are also civil-engineered facilities such as power delivery equipment and treatment facilities.

Under the contract for drilling and repair of wells on the project, the supply of geothermal steam at the rate of not less than 320 t/h and at a pressure of 7 bar for the GeoPP separators 2nd stage is provided. The GeoPP Steam Preparation Installation includes separators, muffler, and other equipment, which should ensure the moisture outlet value not more than 0.05%.
The condensate and brine reinjection system includes provision for a snow melting system within the technological scheme. "Kamchatskenergo" SC has finished the construction of a 220 kV transmission line consisting of a 70km extension from the Mutnovsky GeoPP to Avacha electric substation in Elizovo. SC "Kamchatskenergo" has built the road between Petropavlovsk-Kamchatsky and Mutnovsky geothermal deposit. It was the route for delivery of the turbo-generator and technological modules weighing up to 50 tone each to the Verchne-Mutnovsky Site.

6. VERCHNE-MUTNOVSKY GEOPP 4TH UNIT WITH COMBINED CYCLE

In 1965 the Soviet scientists S.S. Kutateladze and A.M. Rozenfeld took out a patent for power generation from hot water with the temperature of more than 80 ^{0}C [10].

In order to design and test the combined cycle GeoPP equipment under the field conditions of Mutnovsky, (low temperatures, high snowfall up to 12 m, frequent and strong wind, and seismicity factor of 9 according to the MSK-64 scale), "Geotherm" SC started the work on the 4th unit for the Verchnye-Mutnovsky GeoPP. The combined cycle 4th unit construction is now being commissioned [11].

From the existing wells surplus two-phase fluid not used by the first three power units will be transported to the 4th power unit of Verchnye-Mutnovsky GeoPP. At the upper part of the cycle a modular back-pressure steam turbine with the capacity of 3 MW will be used. Such turbines are manufactured by "Kaluga Turbine Works" SC.

Geothermal two phase fluid (steam-water mixture) passes two stages of separation. Separated steam is transported to the steam turbine. Wet steam exiting the turbine condenses and condensate additionally cools in condenser-evaporator tubes. Exhaust pressure of the steam turbine is within the range of 0.11-0.03 MPa; i.e. a back-pressure turbine is used.

The scheme of a combined power unit providing GeoPP operation during wintertime was developed and patented (Fig.6) [11]. Turbines, generators, and heat exchange equipment are mounted on a five-meter high platform and are enclosed for protection from snow. The panels of the air condenser are outward inclined preventing snow collection and icing of heat transfer surfaces. Exhaust fans and driving electomotors will be located in the flow of already preheated air. Electrotechnical equipment and devices of automated control system will be located in a heated enclosure.

Total capacity of the power unit will be 9 MW. The binary installation will be designed, constructed and tested under nominal capacity of 6.8 MW, as a pilot model of serial binary power modules. These power modules will be used in future combined power units of the second stage of Mutnovsky GeoPP, and for the extensive application of binary GeoPP with the capacity of 6 and 12 MW for other new projects.

Under design, construction and testing of the combined power units several scientific-technical problems are addressed. These include: selection of optimal low-boiling medium, determination of the minimal temperature of brine cooling to prevent silica depositions, optimal method of non-condensable gases disposal from the condenser-evaporator and finally, taking into account the necessity of meeting the environmental requirements for hydrogen sulphide disposal.

The climatic conditions of the Mutnovsky area are rather unique due to the location in a northern region at a substantial elevation above the sea level. The average annual air temperature is -1.5 ^{0}C. The average temperature over the duration of eight months (from October till May) is lower at -5 ^{0}C. This low ambient temperature allows reducing the design condensate temperature in the power cycle to 10-20 ^{0}C yielding considerable power output increase (by 20-40%) compared to GeoPP located in hot or moderate climate.

Another advantage of low condensate temperature is that only a minimal reduction of a power plant output would result from any future decline of wellhead pressure of production wells. Utilisation of only turbines using geothermal steam is not profitable because of the required considerable steam flow rates and the height of blades of last turbine stages. There is also considerable power expense for gas removal from the condenser under pressure of water saturation corresponding the temperature of 10-20 ^{0}C. Application of a combined cycle eliminates these imperfections.

The working medium of the binary power unit has a low freezing temperature that ensures normal operation in wintertime and prevents freezing under emergency stops.

7. COMBINED POWER UNITS FOR MUTNOVSKY GEOPP 2ND STAGE

In accordance with the Geothermal Energy Development Program in Kamchatka [12] the next phase implementation – (2X30) 60.0 MW Mutnovsky GeoPP 2nd stage has already begun. The construction of a 3rd stage with a capacity of up to 100 MW is also planned.

Planning for 2nd and 3rd stage expansions became a most important matter since the Mutnovsky deposit reserves are well studied and sufficient, the road and transmission line are available, and with the experimental-industrial Verchne-Mutnovskaya GeoPP in operation, electrical power is available to the GeoPP construction sites during these expansion stages.

As to the preliminary data, Mutnovsky GeoPP 2nd stage will consist of two combined power units with total steam consumption of 320 t/h and brine of 640 t/h.

"Geoterm" SC has already completed the feasibility study of Mutnovsky GeoPP construction with combined cycle of appr. 60 MW_e capacity. This feasibility study has been approved by the European Bank for Reconstruction and Development (EBRD) and has been confirmed by international experts. [9]

Every power unit contains a back-pressured steam turbine with a capacity of about 12 MW and three binary power modules of 6 MW. Total capacity of the combined power unit shall be, at least, 20% higher than that of the 1st stage condensation units and correspondingly the economic indexes will be improved.

The transfer of Kamchatka to geothermal power supply will allow saving annually approximately 900 thousand tones of conditional fuel.

8. REFERENCES

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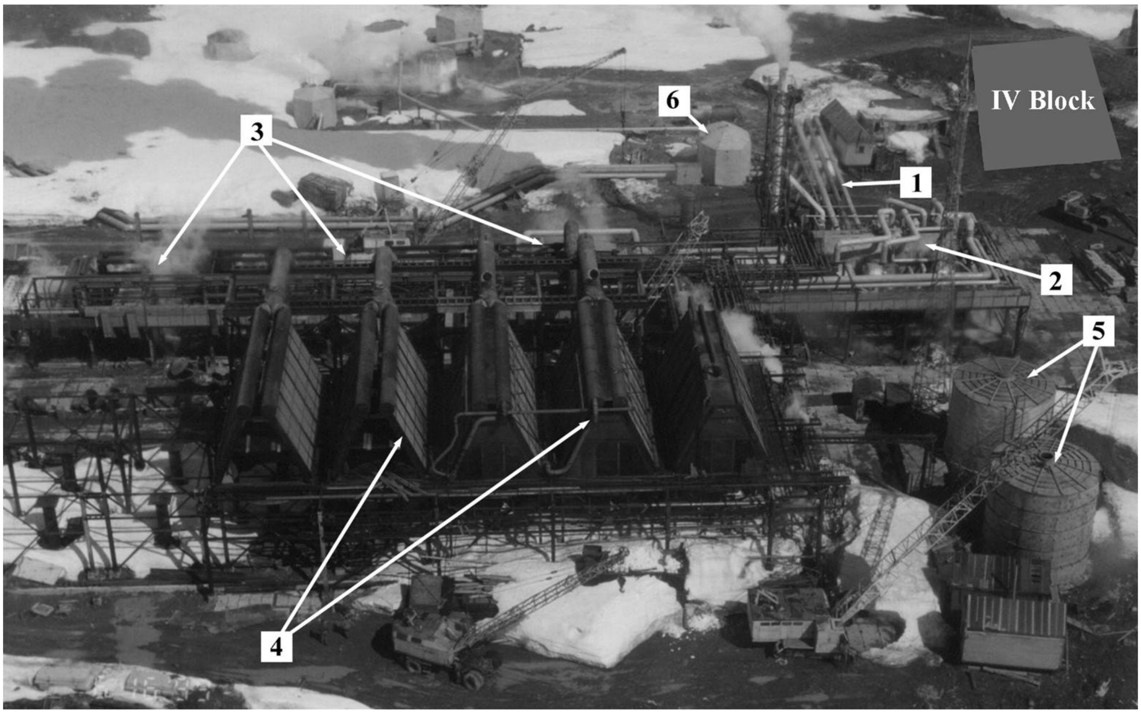

Fig.1. Verhnye-Mutnovsky power plant with a capacity of 12 (3x4) MW:
1 – geothermal heat-carrier supply; 2 – steam preparation unit; 3 – turbogenerator modules; 4 – air condensers; 5 – fire protection tanks; 6 – UTP

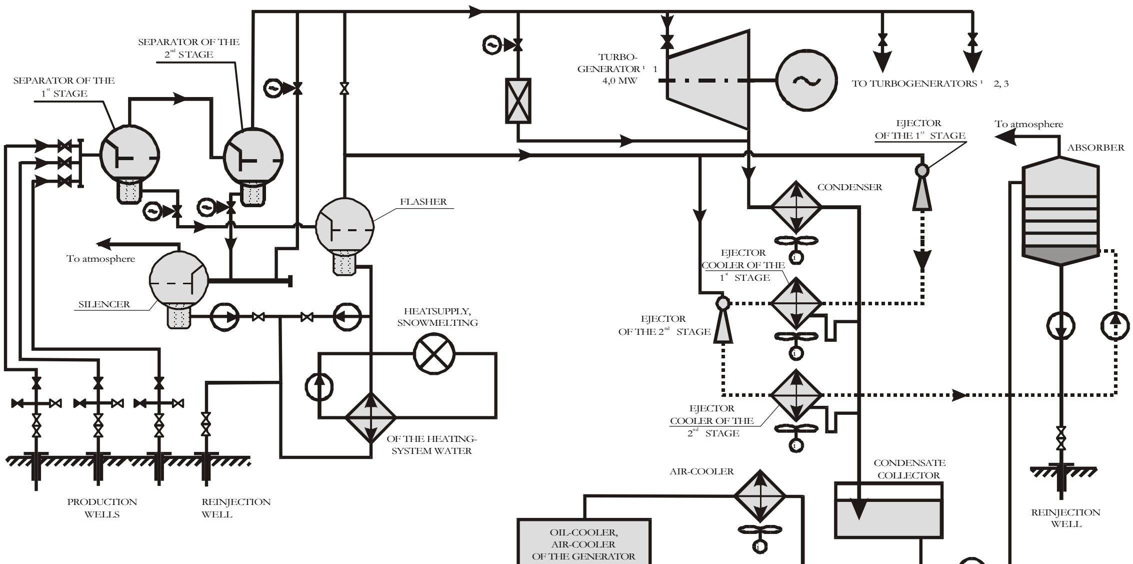

Fig.2. Flow diagram of Verchnye-Mutnovsky GeoPP

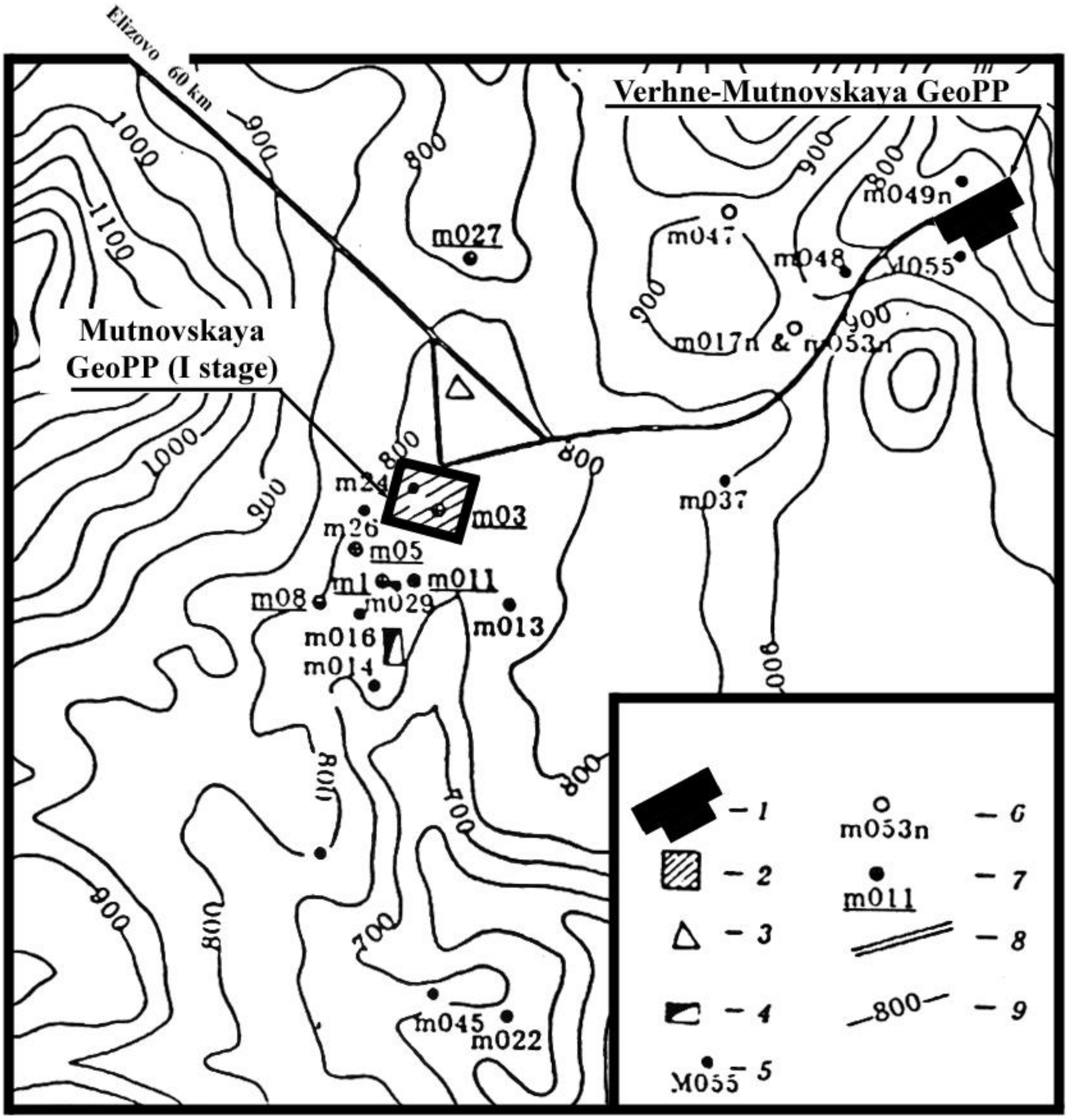

Fig.3. 1 – Verchne-Mutnowsky GeoPP site; 2 – site of the first 40 (2x20) MW stage of Mutnowsky GeoPP; 3 – temporary site forelectric sub-station; 4 – construction yard and administrative biulding; 5 – production well; 6 – untested wells; 7 – low pressure wells; 8 – roads; 9 – hight above the sea level

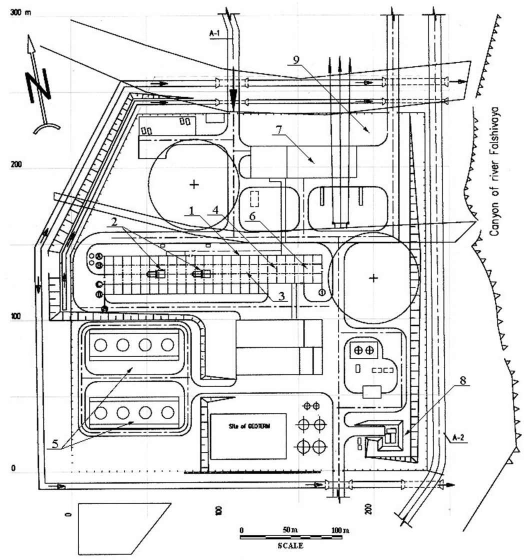

Fig.4. Layout of equipment of the first stage of Mutnovsky GeoPP:

1 - Main Building; 2 - Steam Turbine Room; 3 - Separator Room; 4 - Unit Control Room; 5 - Dry Cooling Towers; 6 - Hotel With Store House; 7-220 kV SF 6 Factory-Assembler Switchgear; 8 - Waste Water Treatment Facilities; 9-220 kV Overhead Power Transmission Line

Fig.5. Location of main facilities of geothermal power complex at Mutnovsky steam field

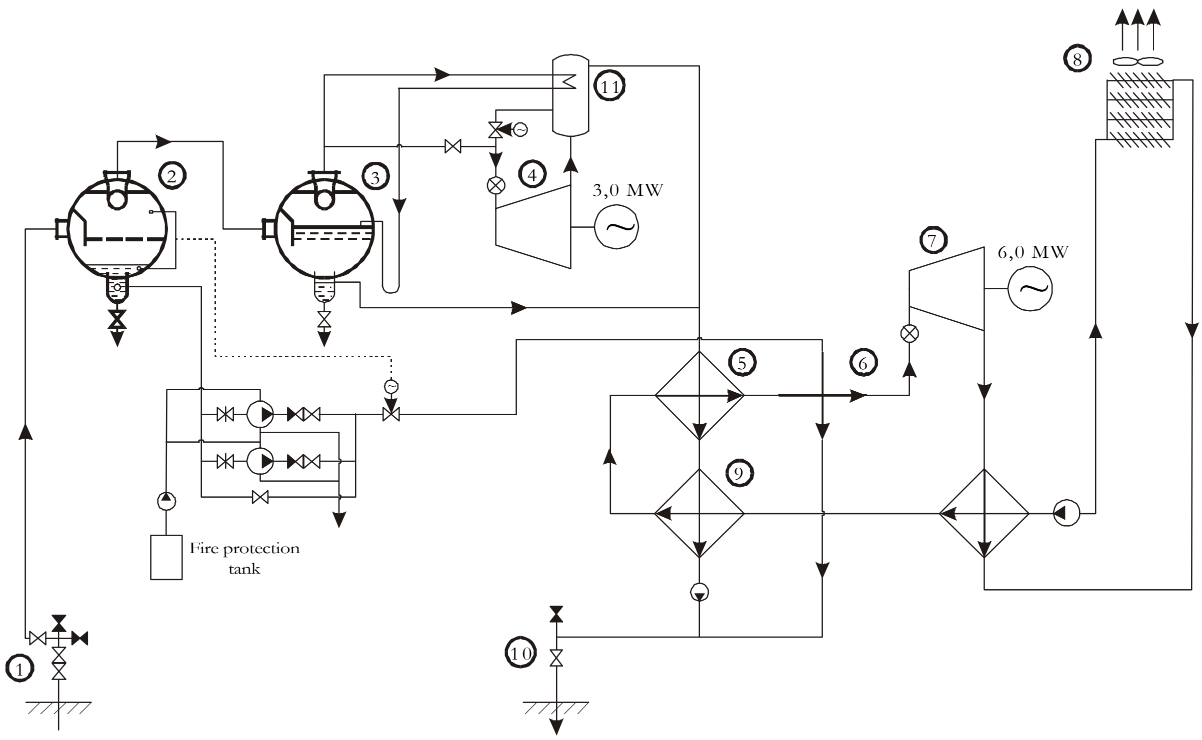

Fig.6. Flow diagram of the fourth power unit with a combined cycle (capacity – 9 MW) of Verchnye-Mutnovsky GeoPP:

1 – production well; *2* – separator of the first stage; *3* – separator of the second stage; *4* – steam turbine; *5* – evaporator; *6* – superheater; *7* – pentanoic turbine; *8* – air condenser; *9* – heater; *10* – injection well; *11* – condenser of the backwashing system.