Experience of creation and operation of geothermal power plants at Mutnovsky geothermal field, Kamchatka, Russia

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Abstract

The energy development strategy of the Kamchatka Region lies in its entire conversion to use of geothermal resources. The Mutnovsky geothermal reservoir is well-studied and found adequate to ensure the operation of a geothermal power plant with more than 300MWe total capacity. The program of construction of the geothermal power plant series at the Mutnovsky steam-field is under active implementation by Geotherm SC. In 1999, a 12 (3x4) MWe Verchne-Mutnovsky geothermal power plant was put into operation, and in 2002, the 1st stage of the 50 (2x25) MWe Mutnovsky geothermal power plant was constructed. It is planned to construct the 2nd stage of the Mutnovsky geothermal power plant with a capacity of 100 MWe and to start works on the creation of the 4th geothermal power unit with 4.0 MWe capacity utilizing binary cycle at the Verchne-Mutnovsky geothermal power plant.

***Keywords**: geothermal, electric power generation, condensing, binary cycle.*

1 Introduction

Russia possesses a unique reserve of geothermal heat in Kamchatka and Kuril Islands. They are adequate for generation of electric power and heat of more than 2000-MW_e total capacity. The first experience of obtaining electric power based on geothermal heat use was gained at the Paratunsky geothermal reservoir (Kamchatka) at Russia in 1967. Geothermal binary two-circuit pilot power plant with capacity of about 500-kW_e was created here for the first time in the world.

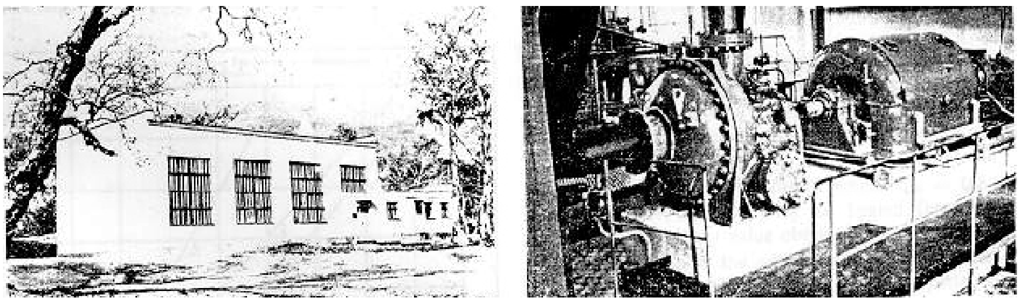


Figure 1: General view and the turbogenerator of the first world binary cycle Paratunsky GeoPP.

In 1967 the industrial production of electric power at the first Russian geothermal power plant got under way at the Pauzhetsky reservoir (Kamchatka). The installed capacity of the 1st stage of the Pauzhetsky Geothermal Power Plant was equivalent to

5 MW_e, and in 1982 it was brought to 11 MW_e. Even nowadays the Pauzhetsky plant is a sustainable producer of one of the cheapest electric power in Kamchatka.

In recent years the works on commercializing geothermal power technologies in Russia were liven up. Russian companies Geotherm SC, Nauka SC, and others in cooperation with RAO "UES of Russia" and by financial support of European Bank for Reconstruction and Development and the Savings Bank of the Russian Federation have organized a full-scale production of the equipment (turbo-generators, separators, and others), and implemented the program of developing geothermal power technologies:

1. In 1993 the modular geothermal power plant of 500-kW_e was put into operation in Kunashir island.
2. Within 1992-1996 Kaluga Turbine Works SC manufactured 9 geothermal power units of 1.7-4.0-MW_e capacity.
3. In 1999 the first environmental friendly Verchne-Mutnovsky Geothermal Power Plant (Kamchatka) of 12 (3x4)-MW_e capacity was commissioned.
4. In 2002 the construction of the 1^{st} stage of 50 (2x25)-MW_e Mutnovsky Geothermal Power Plant was completed and its exploitation started.
5. The construction of combined IV unit of the Verchne-Mutnovsky Geothermal Power Plant with binary cycle of 6.5-MW_e capacity is underway.
6. The preliminary activities on the creation of the 2^{nd} stage of the Mutnovsky Geothermal Power Plant of 100-MW_e capacity are in progress.

Now in Kamchatka seven geothermal power units of 73-MW_e total installed capacity are operational. By 2010 it is proposed to construct several geothermal power plants at the Mutnovsky reservoir thereby bringing their total capacity to 300-MW_e.

Figure 2: First environmental friendly 12 MW_e (commissioned in 1999) Verchne-Mutnovsky GeoPP and the 1^{st} stage 50 MW_e (commissioned in 2002) Mutnovsky GeoPP.

2 Mutnovsky GeoPP project description

The Mutnovsky Geothermal Power Plant Project (MGeoPP) is implemented by the Russian company – Geotherm S.C. Grant funds received from the European Bank for Reconstruction and development (EBRD) in 1997 were used to appoint consulting companies WestJEC (Japan) and GENZL (New Zealand). In association with Nauka S.C. (Russia) they produced the Feasibility Study based on which the EBRD provided loan funds for the project implementation. The EBRD loan is to the government of the Russian Federation and on-lent to Geotherm S.C. Other financing is from State Budget funds and Russian co-investing companies: RAO "UES of Russia", "Kamchatskenergo" S.C. and the State Property Committee for the Kamchatka region. The total project budget is US$ 154 million with shareholders and loan funds at 35% and 65% respectively.

A Project Management Unit (PMU) consisting of Geotherm's Moscow and Kamchatka based staff was set up by Geotherm S.C. The Moscow team is responsible for project funding and financial issues, preparation of procurement documentation, procurement activities for various project implementation contracts and for all work associated with consultancy contracts. Project site activities, including managing the three main construction contracts and plant operation and maintenance fall under the responsibility of the Kamchatka team.

The 1st phase of the MGeoPP comprises 2 x 25 MW_e power units installed at the Dachny site, a Fluid Collection and Disposal System, drilling of two new production wells and work-over of existing wells. Due to the severe climatic conditions all plant and equipment is located inside four main buildings. Other site facilities include two induced draught cooling towers, water and fuel storage tanks, water treatment facilities and a brine emergency holding pond. To ensure safe plant operation and access in winter when snow cover can be up to 6 metres, enclosed air bridges interconnect all buildings. The Main building provides a 24 room hostel for plant operating staff and plant and equipment comprises: secondary separators; turbine generators and condensers; cooling water circulation pumps; cooling water chemical treatment plant; plant control room and control system; 10 kV and 400V switchgear/ transformers; non condensable gas removal system.

Figure 3: Turbine and separator buildings of the 1st stage 50 MW_e Mutnovsky GeoPP.

Separate pipelines deliver two-phase fluid with between 30-100% steam content (by weight) from 7 production wells to primary separators installed in the separator building (Figure 3). Wells M5Э; M016, M29W and A2 are connected to the separator of Unit No 1, whereas wells M026, M4Э and A3 wells are connected to the separator of Unit No 2. The M016 and M026 pipelines are interconnected by means of a crossover pipe to allow balancing the output from Unit 1 and 2 separators.

The design features horizontal type separators, which also function as a header and collect the fluid (steam-water mixture) from different wells. Horizontal type separators are very efficient in terms of moisture removal and achieve near-dry steam at the outlet (not less than 99.98% by weight).

The separators are provided with overpressure and brine carry-over prevention systems. Brine re-injection pumps fitted with variable frequency drives control the brine level in the separators. Exceeding the high level point in the separator opens the emergency valve to discharge brine into the noise silencer. Steam blocking float valves prevent water discharge into the steam pipelines when separator fills with water in an operating emergency. Part of the brine is first used for power plant heating purposes before all brine is re-injected into wells M027, M028 and M044. The minimum allowable brine temperature is 145°C to avoid re-injection system silica scaling.

Steam from the primary separators is delivered into the main header from where two pipelines deliver steam to the turbines located in the main building. Rated steam pressure in the header is 6.5 bara and steam pressure is controlled by vent valves equipped with fast acting electrical drives. The pressure control system is designed to maintain pressure in the steam system even after one or both turbine generators have tripped. Steam washing and separation in the secondary separators located in the main building is carried out before delivery of steam to the turbines. Pure condensate extracted from moisture removal stages in the turbines is used for steam washing.

The steam turbines were manufactured at Kaluga Turbine Works (Russia) and are of the double flow type with 8 stages. The turbines are very efficient and designed to operate with a specific steam consumption of just 6.2 tonne/kWh. This is partly due to the very cold ambient conditions, which allows a very low condenser pressure of 0.05 bara.

Special turbine separator stages, developed by research and engineering staff of the Moscow Power Engineering Institute together with Kaluga Turbine Works' personnel are used to achieve effective blade peripheral/internal moisture removal.

Application of moisture separation devices in the turbine flow path allows removal of almost all moisture, thus minimising erosion of turbine blades and resulting in a nearly 2.0% efficiency improvement of the turbine unit.

Mutnovsky GeoPP is designed for future unmanned and remotely controlled operation, due to the severe climatic winter conditions and the plant's remote location. Plant design also features maximum reliability of all equipment and minimal O&M staff based at the plant site.

The power plant and steam field are controlled by a Teleperm ME distributed control system (DCS) supplied by Siemens. All systems are fully automated and the DCS design enables starting, stopping, and operating the plant both from the control room, as well as remotely by transmission of plant control signal via the transmission line, fiber-optic cable or satellite communication system.

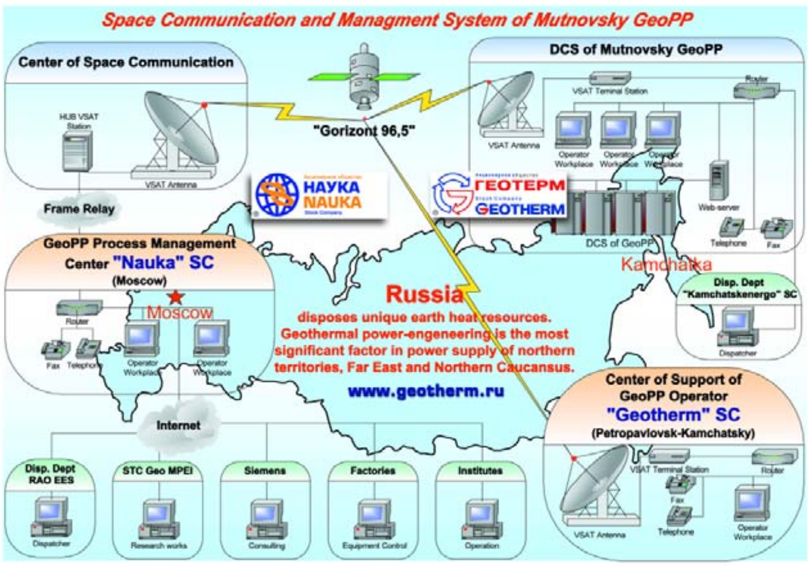


Figure 4: Satellite system for communication/control of the Mutnovsky Geothermal Power Plant.

To provide permanent technical assistance and back up control of the power plant, SC "Nauka" (Moscow) is setting up a satellite communication system with direct communication between Moscow and the power plant. A satellite dish on the roof of the Main Building transmits a (128 kb/s information content) signal to a Russian satellite in heliocentric orbit, from where the signal is picked up 7,000 km away at the satellite dish of SC "Nauka" in Moscow, where the plant control centre has been set up. Control centre operators can contact equipment designers and manufacturers in Russia, Germany, and USA by email at any time and are able to provide quick expert feedback to plant operating staff in Kamchatka

3 Binary cycle power plant development

Russian experience of the Paratunsky Geothermal Power Plant with binary cycle creation and successful exploitation of the Verchne-Mutnovsky Geothermal Power Plant since 1999 underlay the project on development of combined IV unit of the Verchne-Mutnovsky Geothermal Power plant with binary cycle, and Geotherm SC and Nauka SC with financial support of RAO "UES of Russia" have commenced its implementation.

Creation of the 4th power unit with binary cycle will enable the increase of the capacity, reliability, and effectiveness of the geothermal power plant on the whole.

Scientific and technical developments of Geotherm SC and Nauka SC for the purpose of creation of the 4th combined Verchne-Mutnovsky Geothermal Power Plant power unit with binary cycle identified an optimum heat scheme, technological modes, organic working fluid, and the main equipment structures.

The analysis indicates the following unused at the Verchne-Mutnovsky Geothermal Power Plant components: waste geothermal fluid (hot water) of 140°C temperature; 170°C temperature unused geothermal fluid of No. 049 substandard well.

The creation of the 4th combined power unit with binary cycle will enable:

1. to increase considerably (more than for 10%) the effectiveness of geothermal fluid usage at the Verchne-Mutnovsky Geothermal Power Plant with no additional drilling of wells while utilizing the heat of waste and substandard geothermal fluid.
2. to increase the Verchne-Mutnovsky Geothermal Power Plant capacity per 6.5-MW_e (more than per 50%).
3. to raise reliability, fail-safety, and security of the Verchne-Mutnovsky Geothermal Power Plant operation under extreme conditions of winter (strong wind –over 40m/sec, hard frost of up to minus 25°C, snowdrifts to 10-m height) at the expense of applying non-freezing (up to minus 140°C) organic working fluid in the binary cycle of the 4th power unit.
4. to work through binary technologies, possessing of the unique viability in the North conditions, in order to their perspective implementation at the Mutnovsky Geothermal Power Plant and the wide spreading in Russia and abroad.

Relatively low cost of the 4th power unit of the Verchne-Mutnovsky Geothermal Power Plant and an opportunity of its construction in such short space of time as 22-28 months are provided with the following factors:

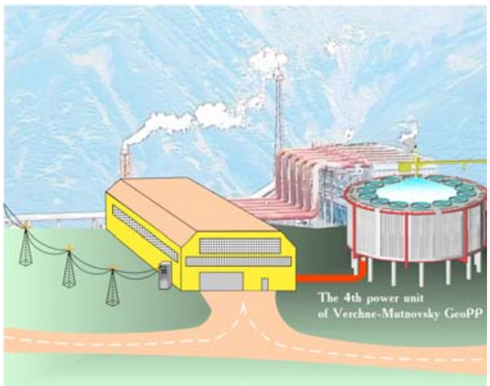
1. The 4th power unit completion is possible using domestically stock-produced equipment (up to 85%).
2. It is planned to be deliver the main equipment (turbo-generators) at 100% factory readiness, being fully preliminarily tested under load at the factory.

3. Possibility of conducting accelerated construction-and-assembling operations within short summer periods (3-4 months) at the expense of today's well-developed Verchne-Mutnovsky Geothermal Power Plant infrastructure available, and the experience of geothermal power plant building in these climatic conditions.
4. Deficiency of expensive sophisticated and long-term drilling and well constructing works.

Technological scheme of the 4th power unit (Fig 3.2) of the Verchne-Mutnovsky Geothermal Power Plant constitutes an aggregate of the 1st and 2nd circuit inseparably linked with each other.

The 1st circuit of the 4th power unit operates using geothermal fluid. Two-phase mixture from 049 well enters the separator and falls into steam (the Russian up-to-date separators enable to achieve steam with x=0.9995) and brine. The steam operates in the turbine and moves to the condenser-evaporator. There in the beginning the steam is condensed, and then the steam condensate cools and directs into the re-injection well. Thus, the 1st circuit is environmentally friendly.

In the 2nd circuit of the power unit wit a capacity,of 2.5-MW_e a low-boiling working fluid is used. Since the 2nd circuit is closed and leak-free, therefore it is environmentally friendly, as the whole 4th power unit. The 2nd circuit working fluid after the feed-pump comes into the condenser-evaporator, where it is firstly preheated and evaporated at the expense of the worked out steam heat after the 1st circuit turbine, and enters the super-heater. There the fluid is overheated owing to the brine heat and enters the 2nd circuit turbine. After the steam expanding in the turbine the worked out steam comes to the air-condensing installation, condenses, and enters the feed-pump inlet.



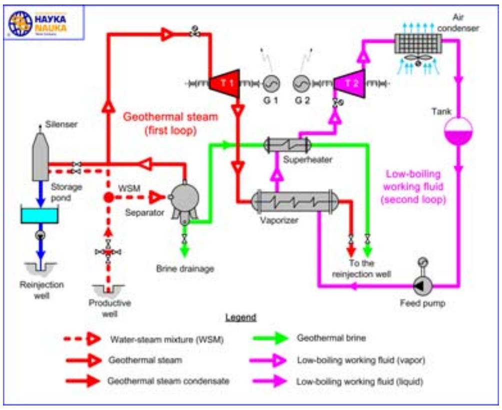


Figure 5: Location and heat scheme of the 4th power unit

The layout and main elements of the 4th power unit are designed taken into account the climatic conditions of Kamchatka: strong snowdrifts, minus 30°C temperature in winter, and at last, the permanent wind, which speed varies from 5 to 40 m/sec.

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