

Experience of Creation and Operation of Geothermal Power Plants in Cold Climate Conditions

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ABSTRACT

The greater part of Russia's territory is situated in the cold climate zone with low temperatures, huge amounts of falling snow and strong winds. Creation and operation of geothermal plants in such conditions requires taking special measures when designing buildings, construction, technologies and equipment.

Verkhne-Mutnovsky and Mutnovsky geothermal power plants (GeoPP), built over the last 10 years in Russia, are successfully operating in severe climatic conditions, where the average annual temperature is minus 2°C, the snow-level reaches 10 meters and wind speed reaches 45 m/sec.

At the same time, properly taking into consideration climate peculiarities while designing, it is possible to achieve high indices of efficiency of the geothermal power plants at the expense of the low temperature of heat abstraction from the cycle.

The operational experience of the geothermal power plants built in Kamchatka, possibilities to increase efficiency factors of geothermal power plants, potential problems of operation during wintertime and necessary safety measures are examined in the article.

1. INTRODUCTION

The first geothermal power plant – Pauzhetsky GeoPP built in 1965, is still generating the cheapest electric power at Kamchatka. The increase in prices for fossil fuels and heat again stimulated interest in use of geothermal heat in Russia for electric power generation.

Russia, together with enormous mineral resources, is very rich in geothermal resources that may and must be used for the welfare of the population. 47 geothermal reservoirs are explored in Russia with thermal water reserves allowing use of more than 240×10^3 m³/day of water and steam-water fluid reserves with a capacity of 105×10^3 m³/day. Throughout most of Russia, there are reserves of geothermal heat with temperature of 30-40°C, and in some regions there are geothermal reservoirs with temperature up to 300°C. Use of geothermal heat for electric power generation, heating and hot water supply allows the saving of considerable resources of fossil fuel and reduction in discharges of contaminants and CO₂ into the atmosphere.

Over the past 10 years new geothermal power plants at Kamchatka and Kuril islands were constructed. Principal equipment for these power plants was designed and manufactured in Russia. This became possible due to

unification of efforts of newly created companies "Intergeotherm" SC, "Nauka" SC, "Geotherm" SC, "Energy" SC which, in cooperation with scientific centers – SEC Geo of Moscow Power Engineering Institute (MPEI), VNIIAM and factories – "KTW" SC, "PMZ" SC, "Privod" SC, "ChMZ" SC, foreign companies – "Siemens" etc. designed and created modern energy equipment for geothermal electric power and heat plants.

Research, technologies and production capabilities of enterprises producing equipment for NPP, shipbuilding and other branches of industry formed the base for these developments.

Important features of GeoPPs in Russia are the climatic conditions in which these plants are constructed and operated. Remoteness and difficult access to GeoPP construction sites in winter create special requirements for equipment reliability, and low ambient air temperatures, strong winds and large amounts of snow determine architectural and layout peculiarities and building design. At the same time, low average annual ambient air temperatures enable use of geothermal heat more effectively. This article describes the arrangements that permitted operating GeoPP more reliably in severe climatic conditions in Kamchatka.

2. CLIMATIC CONDITIONS OF MUTNOVSKY RESERVOIR AND MEASURES FOR PROVIDING RELIABLE OPERATION OF MUTNOVSKY GEOPP.

The Mutnovsky geothermal reservoir, where the Mutnovsky and Verkhne-Mutnovsky GeoPPs are located, is situated in a mountainous area 70 km to the South of the regional center – Petropavlovsk-Kamchatsky city (Fig. 1). The Power plant is connected to the city by a 140 km road and a 220 kV power transmission line. The climate in the GeoPP area is characterized by long winters, large amounts of snow (height of snow cover at the site is 5-7 m, and in relief depressions up to 10 m), low average annual temperatures (-2°C) and strong winds – speed reaches 45 m/s. There is snow at the site from October to July. The trip from city to the GeoPP takes 2-2.5 hours in summer and at least 5-8 hours in winter, and often weather conditions allow no access to the plant for several days. Such severe climatic conditions determine the shift method of power plants operation. Operative personnel are changed twice a month. Premises for accommodation, meals and rest are provided at the GeoPP.



Fig. 1 Location map of Mutnovsky GeoPP

General views of Mutnovsky and Verkhne-Mutnovsky in winter are shown in Fig. 2 and Fig. 3.

Severe climatic conditions also determined the specific features of architectural and layout solutions and level of process automation.

Covered passage bridges connect all GeoPP buildings; this permits operative personnel to get to any building without going outside.

A distributed control system provides entire GeoPP automation, including steam field control equipment.



Fig. 2. Mutnovsky GeoPP 50 (2x25) MW



Fig. 3. Verkhne-Mutnovsky GeoPP 12 MW(3x4)

Climatic conditions also determined requirements for covered locations of high-voltage gas-insulated switchgear equipment (in a separate GIS-220kV building), as well as the power transmission line operational regime. Under certain weather conditions snow and ice may accumulate on power transmission line wires. The thickness of the ice crust may reach 100 mm and lead to short circuit or wire breakage. To avoid emergency situations, equipment specially installed at GeoPP is used which permits heating the wires by short circuit current and melting the ice on power transmission line wires.

In such complicated operational conditions reliability of main GeoPP equipment is of special importance.

3. STEAM PREPARATION SYSTEM EQUIPMENT.

The working fluid of geothermal power plants (GeoPP) and heat plants (GeoHP) is geothermal fluid, the chemical composition of which is formed in deep layers of the earth. This circumstance defines the specific quality and diversity of its operational and environmental properties. [O. Povarov and G. Tomarov, 1997].

Peculiarities of physical-chemical properties of geothermal fluid create a number of technical problems that must be solved during design and manufacturing of geothermal power equipment. First of all, there is the danger of erosion-corrosion effect upon material of main and auxiliary equipment and salt deposits in turbine flow parts, pipelines and reinjection wells.

Reliability and effectiveness of the GeoPP is to a great extent determined by the quality of steam to the turbine. Purity of steam depends mostly on effectiveness of phase separation as the dissolubility of admixtures in the steam phase at pressure of about 1,0 MPa typical for GeoPP is negligibly small (coefficient of distribution $10^{-15} - 10^{-4}$), and for the most part is concentrated in the liquid phase [M. Styrikovich et al., 1955]. So the extent of steam dryness as the index of salt content is used as the criterion of steam purity. It should be noted, however, that high steam dryness and even small superheating can be reached not only by phase separation but also by predrying in the throttling process, for example due to pressure losses in the pipeline. At the same time, in spite of the absence of considerable amounts of moisture in steam, its salt content can prove to be high enough.

Vertical cyclone separators widespread worldwide have little effectiveness for separation (steam wetness at outlet can reach 1,0%). In the practice of GeoPP operation

separating ability of long pipelines from separators to turbine is often used. Moisture containing salts, moving in the steam flow, forms sediment on pipeline sides as skin and is drained along the length of pipe. Such methods of purification undoubtedly decrease the salt contents of steam downstream of the turbine but can not be controlled to provide reliable operation of the turbines.

Highly effective separators (steam humidity extent at outlet is 0,05% at the most), extenders and steam-collectors, worked out in "Nauka" SC with the participation of SEC Geo of MPEI, VNIIAM, are principally new horizontal type separators; their design is based on the experience in designing similar devices in nuclear power engineering using mechanism of gravitational sedimentation of liquid particles.

With greater moisture removal efficiency the installed separators are an improvement over the comparable foreign types with regard to compactness and steel intensity.

Design of a gravitational type separator is presented in Fig. 4. Unlike cyclone type separators that are as a rule provided with separate separator-collectors (vertical or horizontal) and float safety valve, in this separator all devices are located in single case.

Efficiency of such separators may be increased by a change of vessel length. The process regime of the separator is chosen so that at nominal flow rate the steam humidity doesn't exceed 0,05%.

Specific requirements for purity of steam entering the turbine are determined by the fact that admixtures contained in it form a sediment in the flowing section and lead to a decrease of its economy, and a danger of corrosive-erosive effect on the metal of the turbine and other equipment appears.

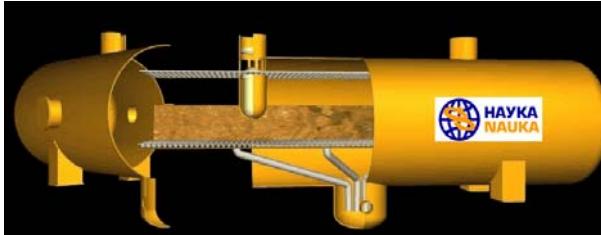


Fig.4 Horizontal gravitation type separator

A considerable decrease of admixture amounts in steam may be reached using a two-stage separation system, with steam rinsing by pure condensate in the second stage separator.

Such a scheme of steam preparation with two-stage separation and steam rinsing is realized at the Mutnovsky GeoPP (Fig. 5).

In steam preparation systems of modern GeoPPs, primary separators are often installed directly at steam fields near production wells and secondary separators (scrubbers) – directly in front of the turbines. In cold climatic conditions, with high snow level on site, such a design solution is unacceptable due to difficulties with operator access for maintenance of primary separators, so the primary separators at Mutnovsky GeoPP as well as silencers, reinjection pumps, pressure regulation system for steam system and other equipment are located in a separate

building connected with the GeoPP main building by a covered passage.

Steam-water mixture with weight contents of steam from 30 to 100% comes from 7 production wells by separate pipelines into two stage-I separators located in the separator building (Fig. 6).



Fig. 6 I stage separators of Mutnovsky GeoPP in separator building.

Separators are provided with protection systems against pressure excess and level excess. Level in separators is regulated by separate reinjection pumps having variable-frequency drive.

In case of an excess level in a separator over the admissible level the emergency valve of the separator discharges into the silencer which is opened automatically. To prevent water discharge into steam pipelines the separator design includes float valves which close the steam outlet when there is emergency filling of the separator by water.

Steam after the stage-I separators, with humidity $x > 0,9998$, flows into the collector from which two pipelines on the scaffold bridge supply the power units located in the main GeoPP building. Nominal steam pressure in the collector is -6,5 bar. Steam pressure in the system is regulated by relief valves having a fast-acting electric drive. The pressure regulation system maintains pressure in the steam system even during complete switch-off of one or two turbo-generators. At this moment pressure deviation in the transition process doesn't exceed $\pm 0,4$ bar.

Before supply to turbines the steam passes the rinsing and secondary separation in stage-II separators located in the GeoPP main building. Pure condensate formed in the flowing section of the turbine is used for steam rinsing.

Separated water with a temperature of about 160°C is used for heating network water in the MGeoPP heat supply system and then is injected into reinjection wells at a temperature 145°C .

4. UNIT-MODULAR VERKHNE-MUTNOVSKY GeoPP

"Geotherm" SC, established to execute geothermal projects at the Mutnovsky reservoir began developing Verkhne-Mutnovsky GeoPP as the pilot project which was put into operation in 1999 (Fig. 7).



Fig.7 Unit-modular Verkhne-Mutnovsky GeoPP in summer

Difficulty of access to the construction area, short construction period (4 months a year), absence of infrastructure and severe climatic conditions determined the concept of Verkhne-Mutnovsky GeoPP construction – unit-modular power plant with location of all equipment in coach-type module-containers connected to each other by covered passages [O. Britvin et al., 1999, O. Povarov, Yu. Lukashenko et al., 2001].

A technological schematic of Verkhne-Mutnovsky GeoPP is presented in Fig. 8.

Steam-water mixture from three wells at a pressure of 8 bar enters the steam preparation device consisting of four modules manufactured by “ZIO-Podolsk” SC; they include stage-I and II separators, steam extender and silencer. The separated brine after primary separators comes into the extender where it boils at a pressure of 4,0 bar. Steam acquired in the extender at 4 bar is used in the NCG bleed ejectors and the brine from the extender is directed to the injection well.

By manifold, steam after the stage-II separators comes to three turbo-generators with a capacity of 4 MW each that are also located in coach-type containers.

The peculiarity of the unit-modular GeoPPs manufactured at “KTV” SC is the presence of the starting oil pump with drive from a separate minor turbine operating on geothermal steam, and negligible auxiliary loads. This permits implementation of autonomous starting without external power sources and their use as emergency starting generators for GeoPP with large capacity. Starting turbine (turbo-pump) supplies, without external electricity feeding, lubrication system and system of oil regulation under pressure sufficient for starting main turbine which has its own oil pump-regulator immediately on the rotor. The main pump starts operating after reaching certain rotation frequency.

Turbine steam exhausts upwards. Waste steam from the turbine comes by exhaust pipelines into air-cooling condensers where it is condensed by flowing inside tubes. Condenser tubes have external finning and are grouped into sections. The condenser has a pyramidal design. Fans installed at the bottom cool the tubes in which condensation of geothermal steam takes place. Use of surface-type air-cooled condensers created an environmentally friendly GeoPP where all geothermal fluid extracted from the earth

and used in the GeoPP scheme, including separate, steam condensate and non-condensable gases, is injected into the geothermal reservoir.

Air condensers are equipped with special screening structures to decrease sectional cooling and reduce the danger of water freezing in tubes depending on wind direction and speed.

Experience of power unit operation at VMGeoPP showed high reliability of air condensers both in summer and in winter. During operation there were no cases of tubes freezing. The problem with icing and damage to fan blades was successfully solved by replacement of aluminium blades for fiberglass plastic. Despite large steel use in the structure, air condensers have environmental advantages in comparison to traditional cooling towers due to absence of moisture and non-condensable gas discharge into the atmosphere

5. MUTNOVSKY GeoPP

Experience from the creation and operation of the pilot Vrkhne-Mutnovsky GeoPP, construction of 220 kV power transmission line, electric substation “Avacha” and road allowing delivery of heavy and large dimension equipment to the construction site, facilitated implementation of the Mutnovsky GeoPP project. Long-term geological exploration work enabled the estimation of power potential of the Mutnovsky reservoir as 300 MWe minimum.

The Investment Feasibility Study carried out in 1997 at the request of EBRD confirmed economical feasibility and technical realizability of the project by dividing its implementation into two stages. The first stage of construction envisaged construction of a 40 MW power plant in the Dachny area using 320 t/h of geothermal steam. Provision of credit for construction by EBRD and investments of Russian Project participants allowed the creation of a modern, entirely automated geothermal power plant.

In October 2002 the Mutnovsky GeoPP was put into operation. At a calculated steam flow rate from the geothermal field of 320 t/h, the electric capacity generated by MGeoPP is 50 MW. (Fig. 9)

Low average annual temperature of ambient air on site permitted design and manufacturing of a highly cost-effective turbine with deep vacuum in the condenser [Yu. Lukashenko et al., 2002].

In Fig. 10 the results of analysis of effectiveness of various GeoPPs are presented. Power units with turbo-generators of 15-35 MW capacity were analysed. The following indices were chosen as the effectiveness indices:

- specific “net” steam flow rate for electric power generation determined as a proportion of steam flow rate per power unit and “net” capacity (power generated by generator minus power unit auxiliary loads)
- “gross” power unit efficiency determined as a proportion of electric power at generator clamps and available heat capacity of geothermal steam supplied to power unit

It can be seen from Fig.10 that Mutnovsky GeoPP power units have the best indices for efficiency and specific steam flow rate for electric power generation. Reaching such high

indices became possible due to the creation of a new double-flow steam turbine working reliably at major vacuum in the condenser (Fig. 11).



Fig. 11 25 MW steam turbine designed and manufactured by "KTZ" SC for Mutnovsky GeoPP.

Design and creation of such a turbine became possible due to long-term active creative links of Kaluga Turbine Works with the Chair of Steam and Gas Turbines of Moscow Power Engineering Institute which carried out scientific research on optimization of "KTZ" SC turbine flowing parts. As a result of this research design decisions allowing increase essentially to the economy of flowing parts and its reliability at work in wet steam were found, theoretically substantiated, experimentally confirmed and introduced at "KTZ" SC turbines [M. Deych, G. Filippov, O. Povarov, 1973 and 1979].

The peculiarity of turbines for GeoPP is the following: as a rule the whole steam expansion process takes place in the two-phase zone, and humidity extent in the last stage of about 10% is considered extreme due to risk of erosion damage to blades. Deepening of vacuum in the condenser leads to increase of steam humidity in the last stage, so special devices for moisture removal are used in the KTW turbine allowing for removal of up to 80% of large drops and liquid skins from the flowing part.

Except for decreasing risk of erosion deterioration, use of these devices increased turbine efficiency by 2%.

Main technical characteristics of turbine:

Turbine type	K-25-06-Geo
Nominal electric power at generator clamps	25,0
Nominal calculated steam parameters:	
steam flow rate, t/h	160
steam pressure, MPa	0,62
- steam dryness extent upstream of turbine	0,9998
- non-condensable gas contents in steam (by mass), %	0,4
- steam pressure in condenser, kPa	5,0

6. RUSSIAN BINARY TECHNOLOGIES.

Creation of Paratunka GeoPP – the first binary cycle power plant in the world - by Soviet scientists in 1967 opened the possibility of getting electric power from low-potential heat sources [S. Kutateladze, L. Rosenfeld, 1965]. This idea became wide-spread, and today all over the world hundreds of units using binary cycle technology work at geothermal fields. After more than 30 years works on creation of binary power plants are carried on actively again in Russia.

Use of organic working fluids that do not freeze at low temperatures in binary cycles allows use of the severe Russian climatic conditions to increase the thermal efficiency. "Nauka" SC designed the new binary power plant project (Fig. 12) that can use low-potential heat from various sources (geothermal water, hot water of heat supply system, waste heat of industrial enterprises, etc.) for electric power generation, and at present is designing a combined cycle IV power unit of Verkhne-Mutnovsky GeoPP which will allow increase in plant capacity of up to 18 MW [O. Povarov, A. Nikolski et al., 2002].



Fig. 12 Binary power plant

The peculiarity of BPP designed in "Nauka" SC is the circular location of the air condenser sections allowing use of wind power for optimal cooling, regardless of its direction.

The energy plant is completely automated and controlled by unmanned technology from a remote control panel.

7. FIRST SATELLITE COMMUNICATION AND GeOPP CONTROL SYSTEM

The Mutnovsky GeoPP is a completely automated power plant supplied by a distributed control system based on the Siemens company programme-technological complex Teleperm ME. Algorithms and step-by-step programs designed by the Russian company "Interautomatics" allow for start-up or shutdown of power units by pressing one key.

On the other hand, high automation levels and complexity of technological processes at GeoPP require adequate competence from operative personnel. As was mentioned before, the Mutnovsky GeoPP is located in a difficult access region with severe climatic conditions, 10 thousand km from the center of Russia, and possibilities to render scientific-technical support to personnel by specialists of

manufacturers, scientists and designers are quite limited, which is why “Nauka” SC proposed, and together with specialists of United Design Bureau of MPEI and Siemens company, created the space communication and MGeoPP control system (Fig. 13) allowing the monitoring of the technological process and power plant equipment and geothermal field status in real time [A. Nikolski et al., 2002].

The system consists of:

- Operators' workplaces and local process control center (PCC Geo) networks in Moscow (“Nauka” SC) and Petropavlovsk-Kamchatsky (“Geotherm” SC).
- WEB-server included into distributed control system of power plant and connected with space communication station “VSAT”;
- Space segment made on the basis of small earth data transmission network station using satellite “Horizont 96,5”
- “Virtual connection” – local PCC Geo – Center of space communication network “Medvezhyi ozera”

The system allows, except for transmission of data on technological process, transmission of the image from 16 dirigible video cameras located at the power plant, and provides telephone communication by two channels.

PCC Geo operators can receive any information on their computer monitors in the form of videograms similar to those that operators at the power plant have.

The system allows provision of constant support to GeoPP operators, especially necessary during the period of mastering of new equipment and technologies, by leading specialists of manufacturing works, design and scientific organizations.

8. CONCLUSION

Experience in designing and operation of geothermal power plants in Russia shows that with the help of special arrangements it is possible to provide reliable and effective operation of GeoPP in severe climatic conditions.

Long-term fundamental research and scientific-technical developments by Russian scientists, unification of efforts of leading institutes, companies and manufacturing works (MPEI, VNIIAM, “Nauka” SC, “KTZ” SC, “ZIO-Podolsk”

SC etc.) again launched Russia into the list of countries able to independently develop and produce all equipment for geothermal power and heat plants and most advanced geothermal technologies.

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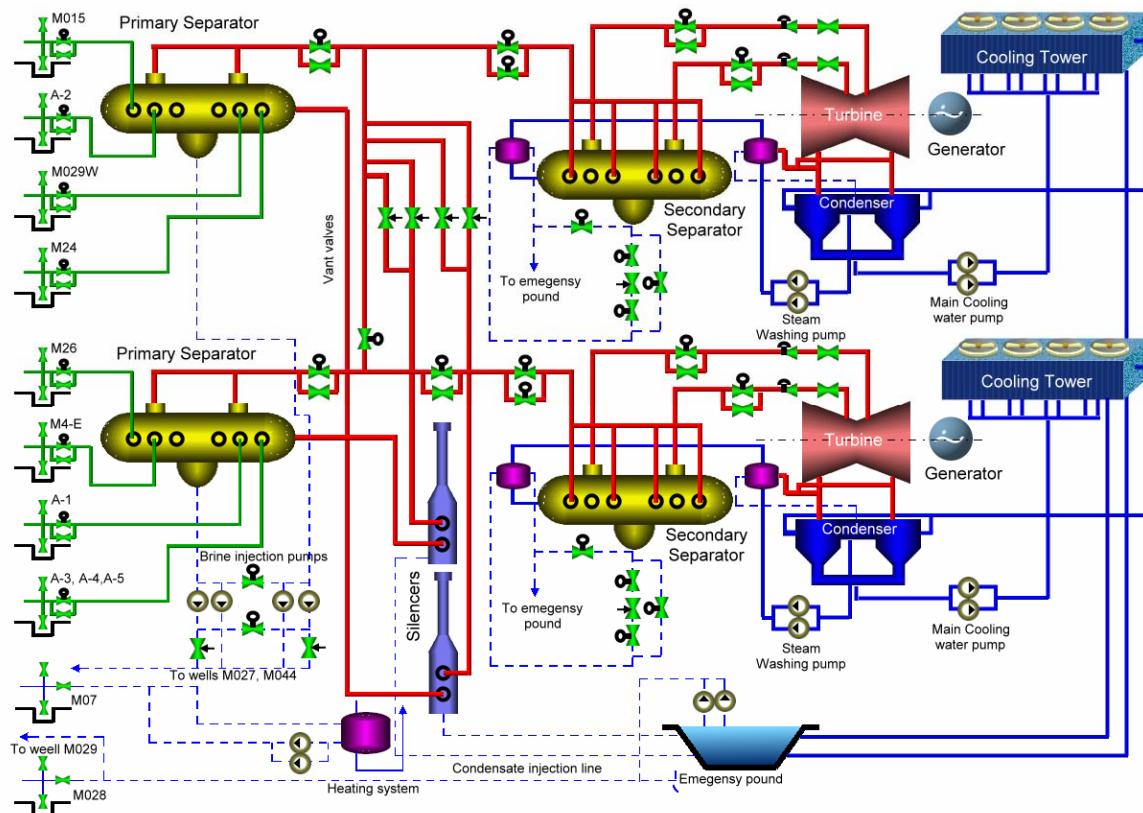


Fig. 5. Technological schematic of MGeoPP-1

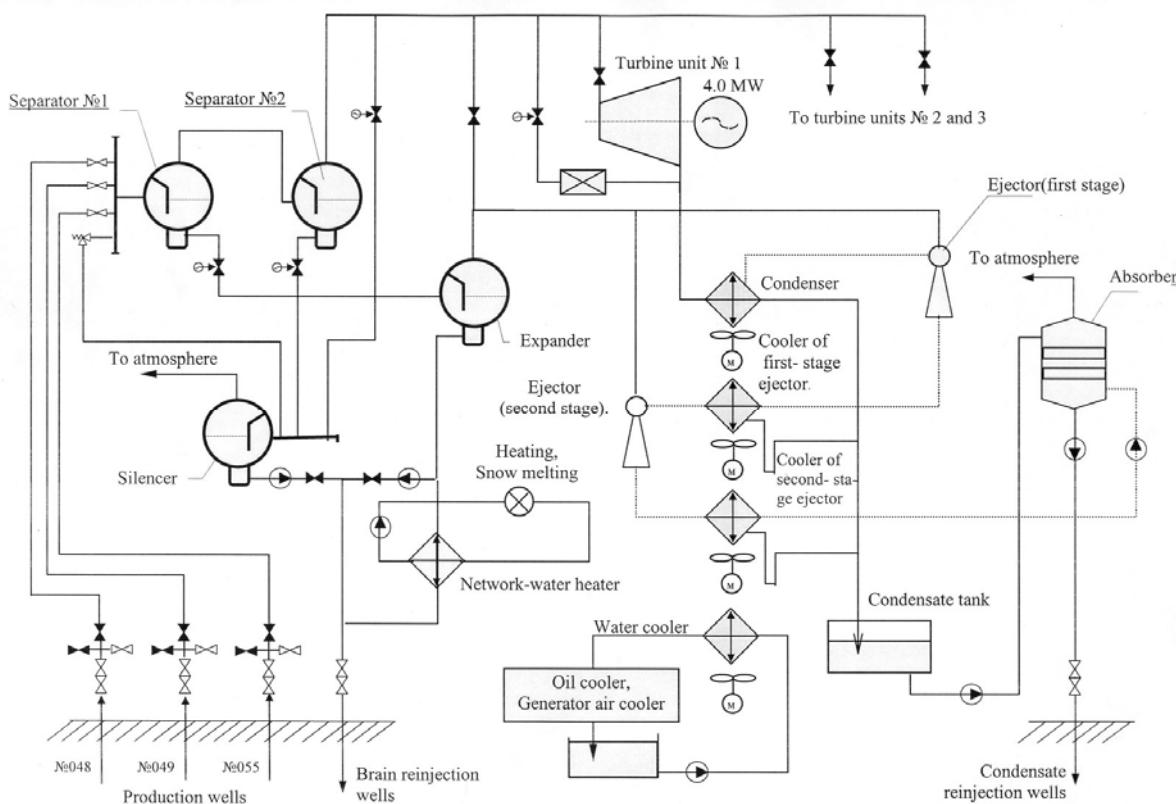


Fig.8 Technological schematic of Verkhne-Mutnovsky GeoPP



Fig. 9 Mutnovsky GeoPP 50 MW(2x25 MW) in summer

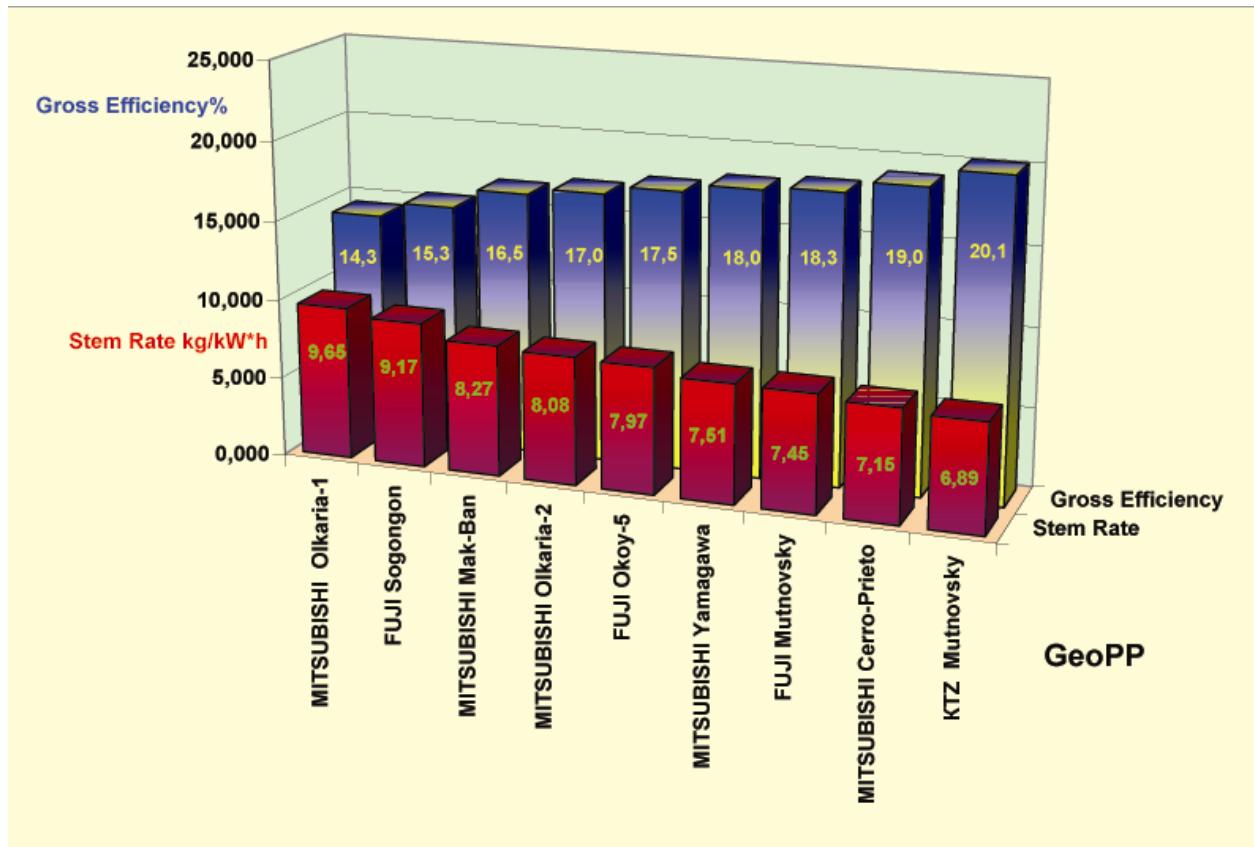


Fig. 10 Indices of effectiveness of various GeoPPs

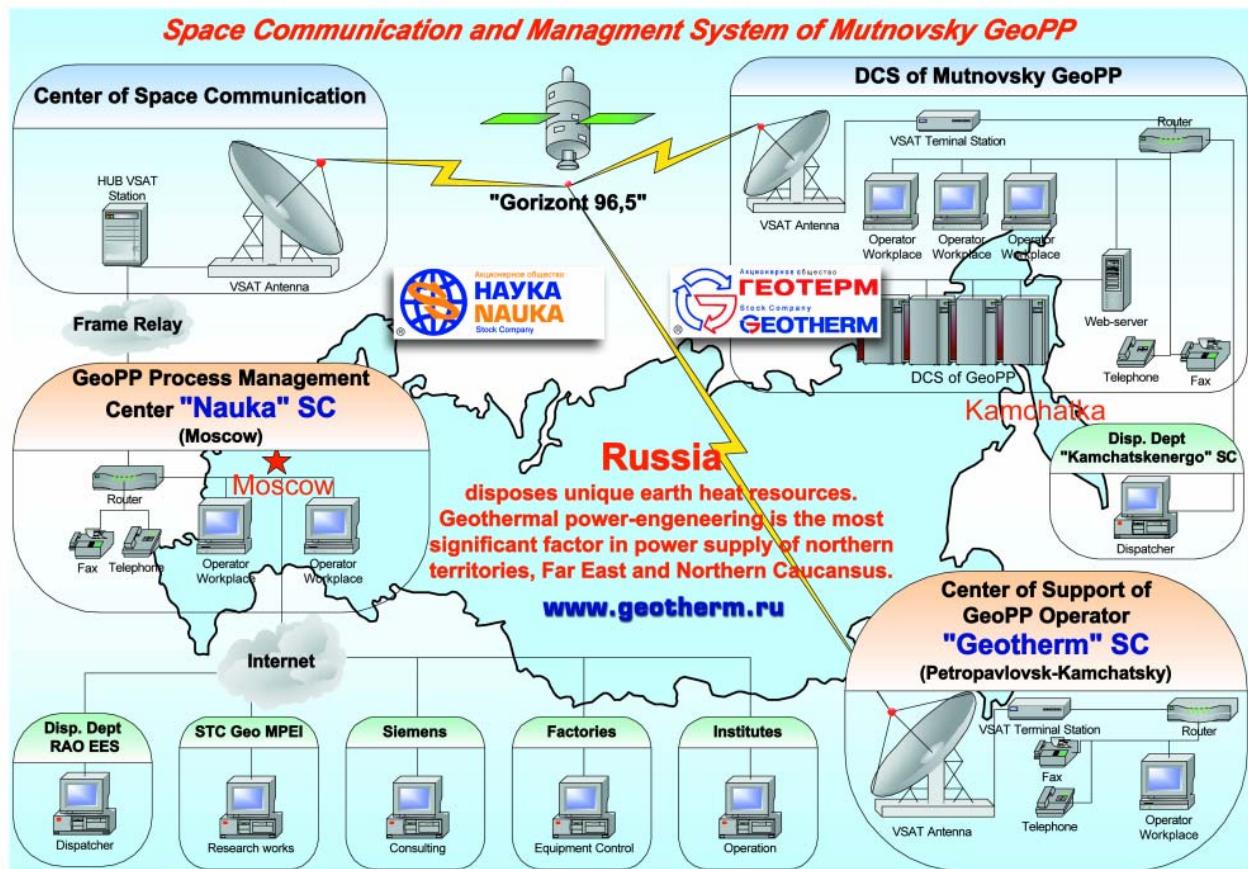


Fig.13 Satellite communication and control system of Mutnovsky GeoPP.