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Creation of Pilot Binary Geothemal Power Plant on Pauzhetsky (Kamchatka) Site

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ABSTRACT

The newest stage of Russian geothermal development includes both serial binary cycle geothermal power plant construction and low-enthalpy resource utilization to supply heat and electricity. A number of Russian regions (Northern Caucasia, Kaliningrad and Baikal region) possess low-temperature geothermal resources that are sufficient to meet their total demand for power and district heating. According to the Federal Hydro-generating Open Joint-Stock Company (JSC “RusHydro”) strategy, the approval of binary geothermal applications using northern (Kamchatka) and southern plant design is expected.

The JSC Geothermal Engineering Company (JSC “Geoencom”) is developing a pilot binary geothermal power plant called the JSC “New Binary Power Plant” on the Pauzhetsky GeoPP site. This work is based on research and development, design, and experimental investigations concerning the heat exchangers, turbines, the automatic-control system, and the selection of working fluids.

1. INTRODUCTION

It is well-known that about 70% of the world’s geothermal resource potential lies in reservoirs with fluid temperatures less than 130^{o}C (Povarov and Tomarov 2006). The tendency to actively use low-potential resources in local geothermal heat and electricity supply systems including binary power plants (BPPs) and heat pumps is a recent development.

In 1967, Russia built the first binary cycle geothermal power plant in the world at Paratunsky, which used hot (90^{o}C) water for electricity generation. The rated electric capacity of the unit was 750 KW. Scholars from Institute of Thermal Physics at the Siberian branch of the Academy of Sciences of the USSR chose Freon R12 as the working fluid (WF) for this unit. An image of this binary cycle power plant and its thermal circuit diagram are shown in Figure 1a) and 1b), respectively.

Geothermal water at 90^{o}C and a flow rate of about 200 m^3/h was run through a Freon superheater, an evaporator, and three heaters in series, as shown in Figure 1b). Liquid Freon R12 was boiled and superheated by the water at a pressure of 1.4 MPa. The superheated vapor was then run to a turbine, which rotated the turbo-generator rotor. Freon steam with low pressure (0.5 MPa) from the turbine was routed to two condensers, where it condensed and transferred its heat to the cooling water. The maximum flow rate of the cooling water was 1500 m^3/h (with a condenser inlet temperature of 5 ^{o}C). Liquid refrigerant from the condenser drained into a condensate storage tank from which it was sent to the steam generator by two centrifugal pumps.

The success of this application led to widespread use abroad, and there are currently more than a thousand binary plants with various capacities are in operation worldwide

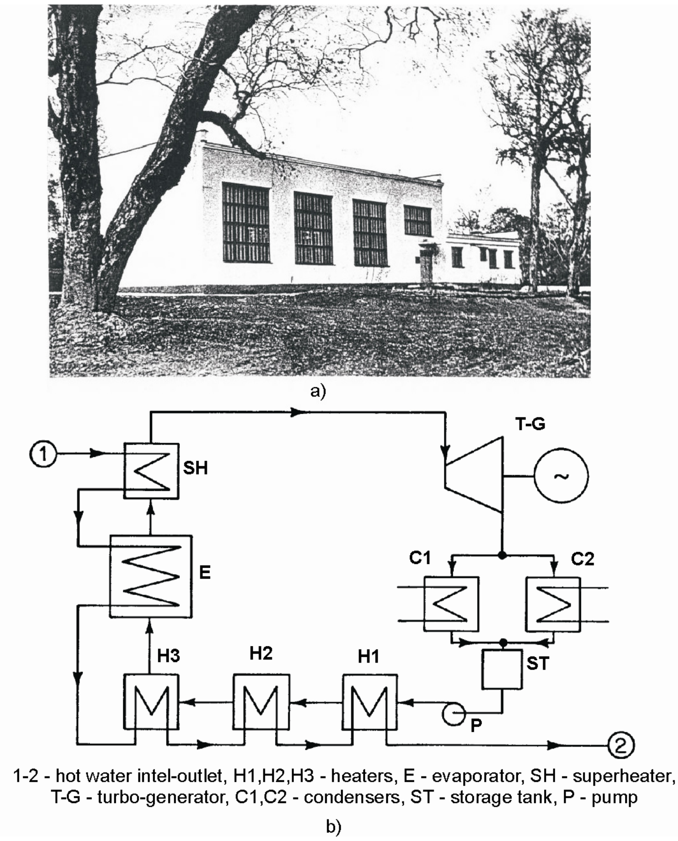

Figure 1. (a) Image of the Paratunsky binary GeoPP and (b) thermal circuit diagram

2. PROSPECTIVE PLANS TO CONSTRUCT BINARY GEOTHERMAL POWER PLANTS IN RUSSIAN REGIONS

Disregarding Kamchatka and the Kuril islands, low-temperature geothermal fields are available in many regions of Russia such as Northern Caucasus, the Kaliningrad region, and Transbaikalia. The potentials in these areas of application are sufficient for supplying heat and electricity to these regions.

SC “GEOENCOM” has developed a design for the standard binary GeoPP, where refrigerant R-134a is used as the working fluid.

The revival of Russian binary energy technologies and arrangement of serial BPP production should become a basis for large-scale use of geothermal resources and other heat sources in various regions of the country. SC “RusHyrdo” plans to play its part in Russian geothermal development by designing and implementing binary geothermal power plants for various climatic operational conditions.

BGeoPPs in Northern variant (Kamchatka, Kuril islands) are characterized by:
- Stability in severe climatic conditions (low temperatures, wind, snow load, etc.);
- High temperature heat sources (120-140^{o}C);
- Use of steam and separate as the heat source in BGeoPPs;
- Low temperatures in condensers.

BGeoPPs in Southern variant (Northern Caucasus) are characterized by:
- Lower temperature heat sources (95-120^{o}C);
- Lightweight design of buildings (possibility of equipment assemblage on operating platform);
- Use of thermal water as the heat source in BGeoPPs.

3. WORKING FLUID SELECTION

One of the most important tasks undertaken during the creation of a binary power facility is the choice of its working fluid (Boyarskiy et al. 2005). During the design of binary units, various factors should be taken into account: the WF's thermalphysical and thermochemical properties, toxicity, explosive properties and flammability, environmental indices, cost, availability in the market, extent of knowledge about its properties, etc.

The history of the use of low-boiling fluids can be divided into four evolutionary stages of decision criteria. The first generation of coolants (1830-1930) adopted the philosophy of the "use of everything that is operating." The second (1931-1990) was concerned with "safety and durability." During the third generation (1990-2010), "ozone layer protection" was considered, and the fourth generation (2010 and later) will be focused on "global warming" (Calm 2008). The structural scheme of the coolant market is presented in Figure 2.

At present the following tendencies dominate binary power plant design due to the danger of climate change:
- predominant use of working fluids with low global warming potential, including hydrocarbons, ammonia, nitrogen and carbon dioxide;
- improvement of systems maintenance process procedures;
- increase of manufacturing quality requirements of instruments and creation of more perfect seals for reduction of working fluid leaks from closed circuits in binary plants;
- reduction of amount of working fluid introduced to the system;
- improvement of equipment in operating BPPs with to increase their energy efficiency.

It should be noted that it is impossible to choose a working fluid for a binary power plant that has optimal characteristics for all the indices. Thus, the choice of R-134a as the working fluid for the Pauzhetsky BGeoPP was determined by the following considerations:
- incombustibility and explosion safety;
- non-toxicity;
- good examination extent: R-134a is broadly used all around the world in motor vehicle air conditioners, domestic refrigerators, industrial plants, and residential and industrial air conditioning systems;
- R-134a has good thermophysical and thermodynamic features (high heat capacity, thermal conductivity, etc.);
- R-134a does not have considerable corrosive effects upon the applied structural materials;
- R-134a has zero ozone-destruction potential ODP;
- R-134a is widely available in the market.

The coolant R-134a chosen for use at Pauzhetsky BGeoPP has a GWP parameter of about 1300, (Maximov et al. 1996). A maximum value of 1500 units is widely considered the reasonable limit for coolants today, but a maximum GWP value of 150 is recommended for coolant use in industries in some countries (Calm 2008). The world's leading producers plan to produce alternative working fluids of this type: Honeywell company's Mixture H, DuPont's DP-1, and Ineos Fluor's AC-1.

These companies recently developed a considerable number of alternative refrigerants for medium- and long-term prospects. However, the introduction of any new coolant into technical systems causes certain problems. The new chemical product should satisfy established safety and environmental standards, correspond to regulating requirements and protocols, etc. Most importantly, examinations of human health and safety are necessary (as well as for toxicity, flammability etc.).

For example, Mixture H (Fluid H, 70 % $CF_3CF=CH_2$, 30 % CF_3I) from Honeywell company is one of alternatives announced by the sector. As can be seen in Figure 3 and Table 1, the properties of mixture H and R-134a are relatively similar. This creates the possibility of using alternative coolants with low GWP levels in binary cycle GeoPP's in the future.

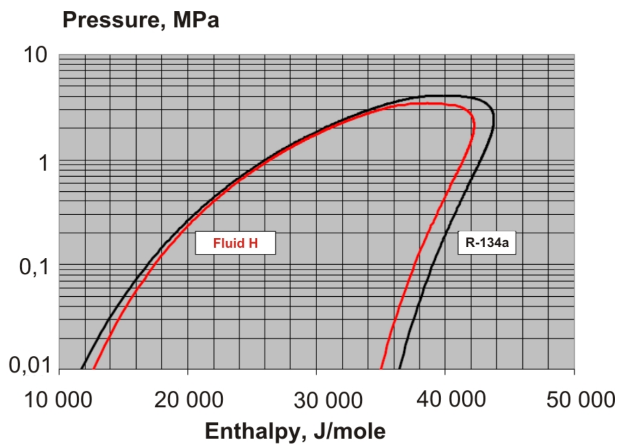

Fig. 3. Comparison of saturation lines of R-134a and Fluid H (Honeywell) in P-H diagram

Table 1. Comparison of thermophysical properties of R-134a and Honeywell company's new working fluid (Fluid H)

Properties	Fluid H	R-134a
Normal boiling temperature, ^{o}C	-30	-26
Critical point temperature, ^{o}C	97	102
Pressure (MPa) at boiling temperature of 0 ^{o}C	0.324	0.293
Pressure (MPa) at boiling temperature of 25 ^{o}C	0.685	0.665
Pressure (MPa) at boiling temperature of 80 ^{o}C	2.45	2.63

5. PILOT BINARY GEOTHEMAL POWER PLANT ON PAUZHETSKY (KAMCHATKA) SITE CONSTRUCTION

The construction of binary power units in the Northern variant is planned at the Mutnovsky (Kamchatka), Mendeleyevsky, and Okeansky (Kurils) geothermal fields.

At present, SC is in the process of designing and constructing its “New binary power unit” with scientific-technical support from SC “GEOENCOM.” The 2.5 MW pilot binary power unit will be located on the site of the operating Pauzhetsky GeoPP where the GeoPP (stages I and II) and office buildings are already located, which are shown in Figure 4 as 2, 3, and 4, respectively. It is planned to construct the proposed building (1) on currently vacant ground near the existing stage II building. Such a location allows for the minimization of changes to the existing transport scheme and of the re-laying of engineering systems within the site.

A simplified thermal circuit diagram of the Pauzhetsky binary geothermal power plant including the feed pump (I), evaporator-superheater (II), turbine (III) and condenser (IV) is presented in Figure 4. The geothermal fluid (e), water at about 120 ^{o}C which is separated from steam-water mixture, is the heat source. The heating, evaporation and superheating of working fluid vapor takes place in the evaporator-superheater, and the working fluid is then introduced into the turbine and rotates the electric generator. After the turbine, the steam is cooled and condensed by the water (f) in the condenser.

The circuit flow diagram of the power unit is presented in Figure 5. The steam parameters of R-134a at the turbine inlet (after evaporator-superheater) and outlet are as follows:

Inlet:

- pressure	2.19 MPa;
- temperature	75.8°C;

Outlet:

- flow rate	144.8 kg/s;
- pressure	0.76 MPa;
- temperature	33°C.

A unit of three pressurized centrifugal feed pumps with drives from AC electric motors will be used to transport the organic working fluid from condenser to the evaporator-superheater.

A single-stage Francis condensation type turbine will be used, in which the rotor wheel will be oriented on the free end of generator shaft, as shown in Figure 6. An axial turbine outlet allows for structural simplicity of the connection with the condenser and minimizes power loss. The second end of the generator shaft is connected with main oil pump, and the turbine and generator are mounted upon a common frame. The working fluid steam travels through a pipeline from the evaporator-superheater to the turbine via a check valve and a control valve. Waste steam comes into condenser from the axial exhaust manifold of the turbine. The throttling device allows steam to bypass the turbine and enter the condenser in cases of abrupt dump of electric load.

The evaporator-superheater and condenser of binary plant (Pauzhetsky BGeoPP) were developed by SC “Geoencom”.

All heat exchange surfaces in the evaporator “economizer-evaporator-superheater” were arranged into a single multi-pass mechanism, which is shown in Figure 7. The evaporator-superheater has a shell-and-tube design where the separate heating fluid flows inside the tubes and the working fluid flows in the shell cavity around the tubes.

The turbine condenser (shown in Figure 8) also has a shell-and-tube design and uses cooling water from the Pauzhetka River at +8°C. The condenser is installed at an angle to the horizon to prevent flooding of the lower tubes with condensate from the upper rows.

The BPP building has a rectangular design, as shown in Figure 9. The placement of equipment and pipelines in the BPP building was designed with the following considerations:

- free access to equipment and necessary space for seizure of internal instrument devices during revision and repair;
- free drainage of equipment;
- necessary head at inhaust of all the pumps;
- reduction of length of large diameter pipelines;
- passages for personnel and access to equipment and pipeline fittings;
- necessary lifting of machinery including overhead beam crane with ability to carry 10 t load.

The turbo-unit and its auxiliaries, condenser, heat exchanger devices (heater, evaporator and superheater united in a common housing), feed pumps, auxiliaries of the power unit (including storage tank for waste working fluid), corrosion-protection and salt-sedimentation-protection devices, and cooling water pumps will be installed within BPP building. Sufficient space is designed for equipment maintenance, lifting and allocation of equipment parts, stairs and platforms for maintenance, and seizure of the generator.

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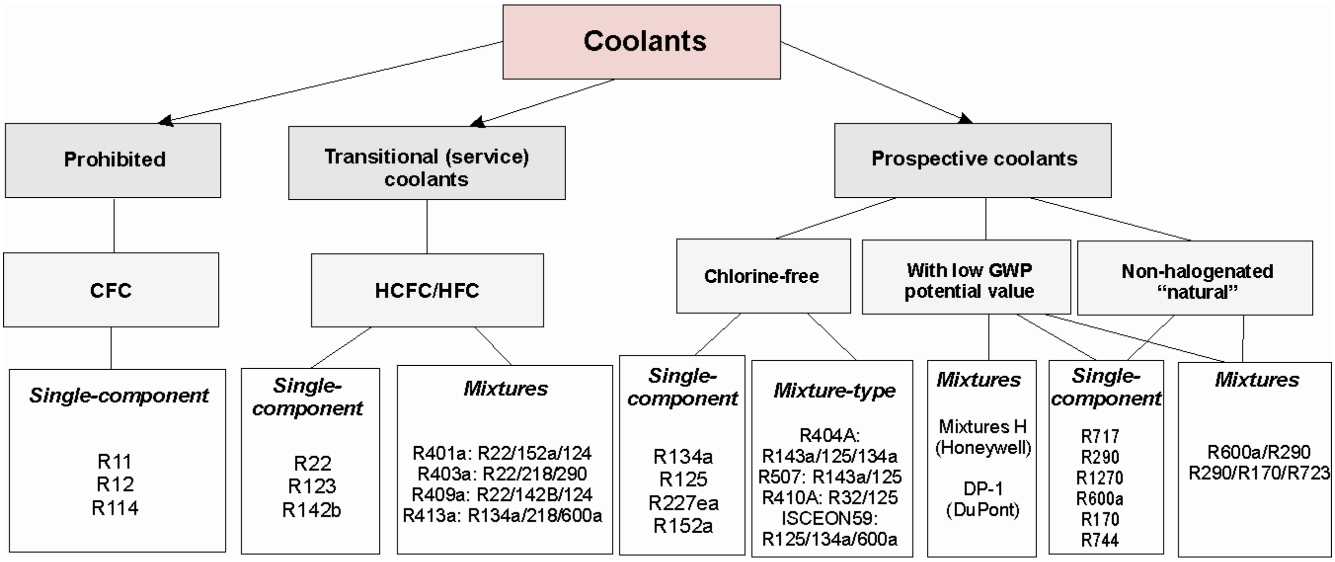

Fig. 2. Classification of alternative coolants for use as working fluids in power plants

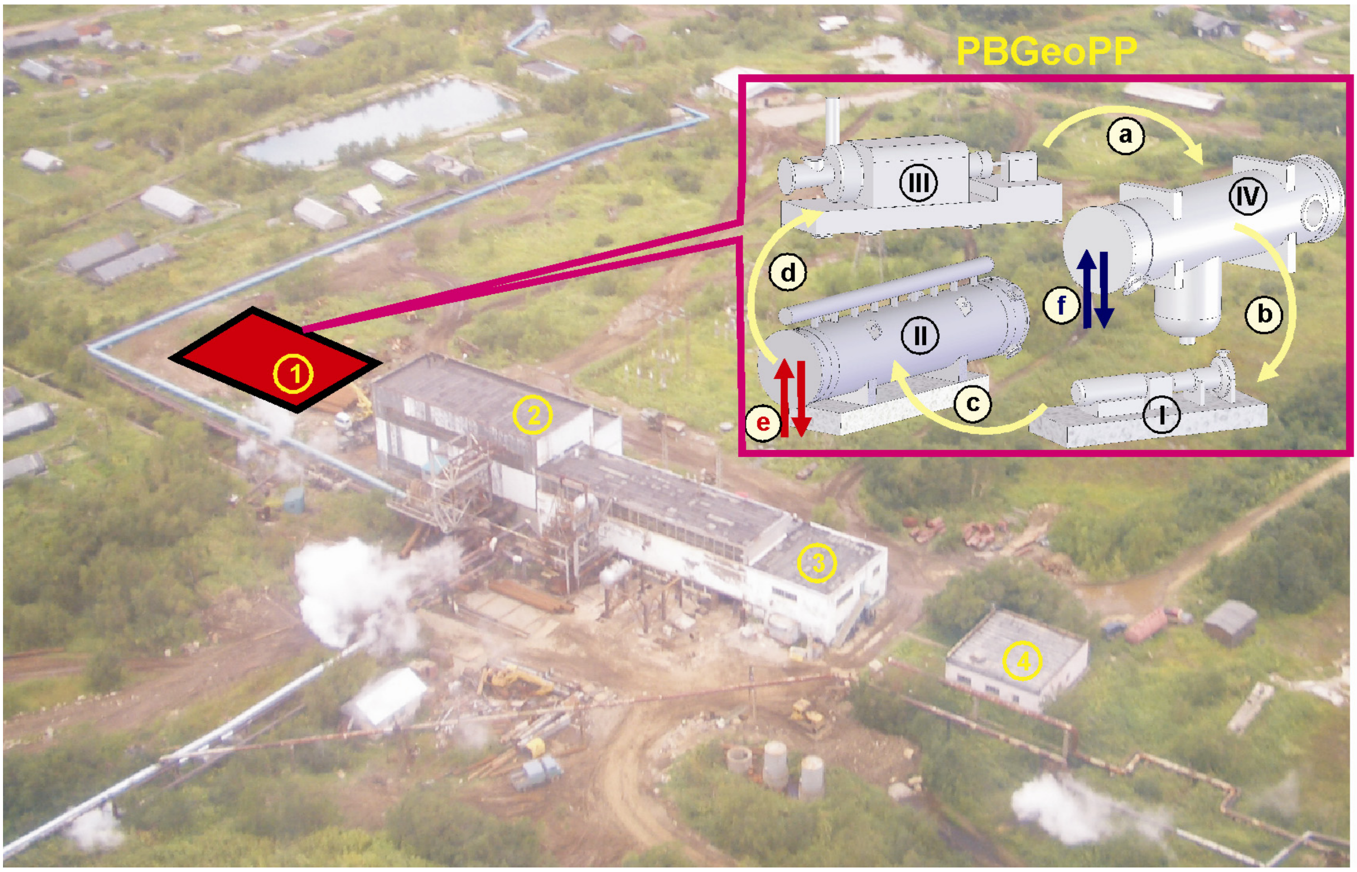

Fig. 4. Location of constructed pilot unit of Pauzhetsky BGeoPP and simplified thermal circuit diagram of power plant

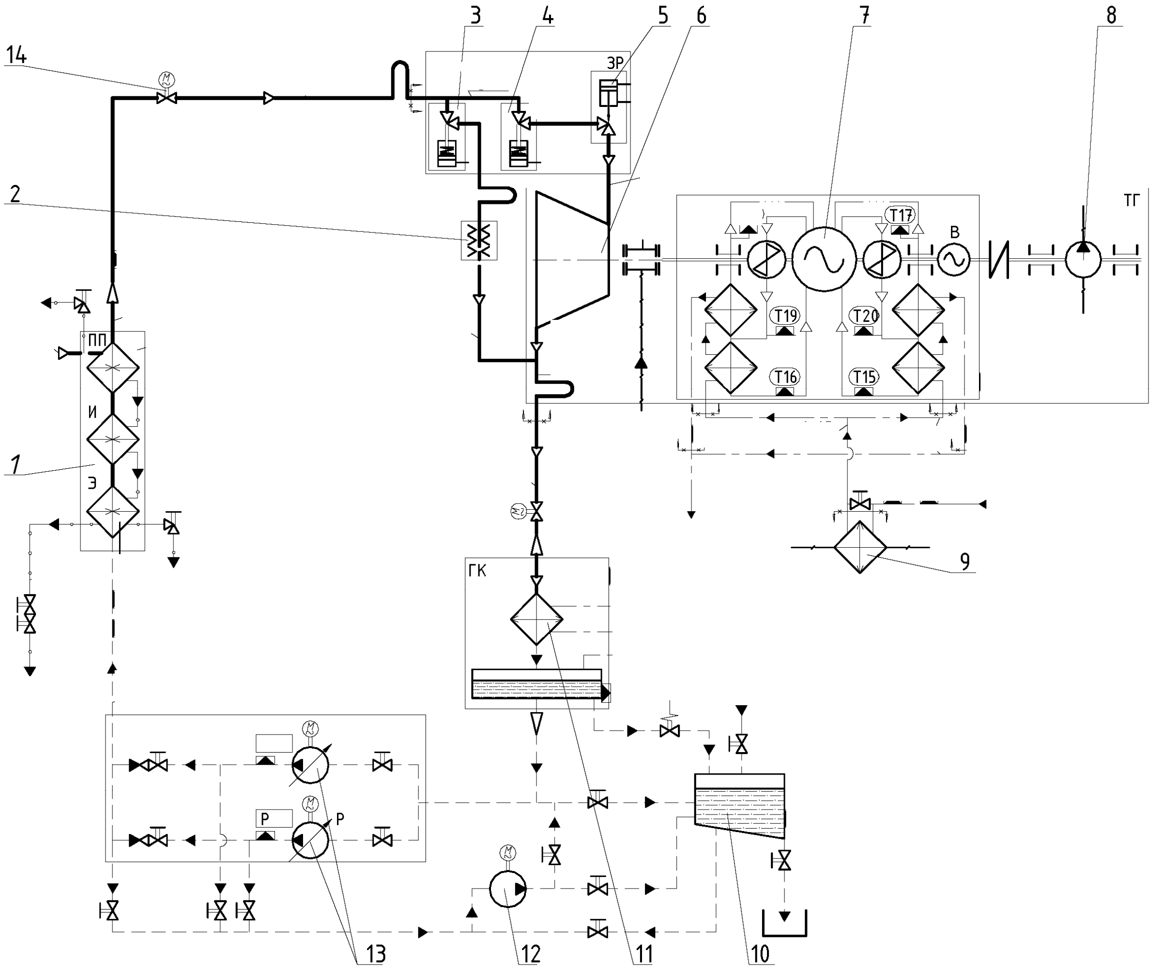

Fig. 5. Circuit flow diagram of Pauzhetsky BGeoPP power unit (1 – evaporator-superheater, 2 – throttling device, 3, 5 – gate valves, 4 – check valve, 6 – turbine, 7 – generator, 8 – oil system pump, 9 – oil cooler, 10 – tank, 11 – condenser, 12 – pumping and make-up pump, 13 – condensate-feed pump, 14 – main steam valve)

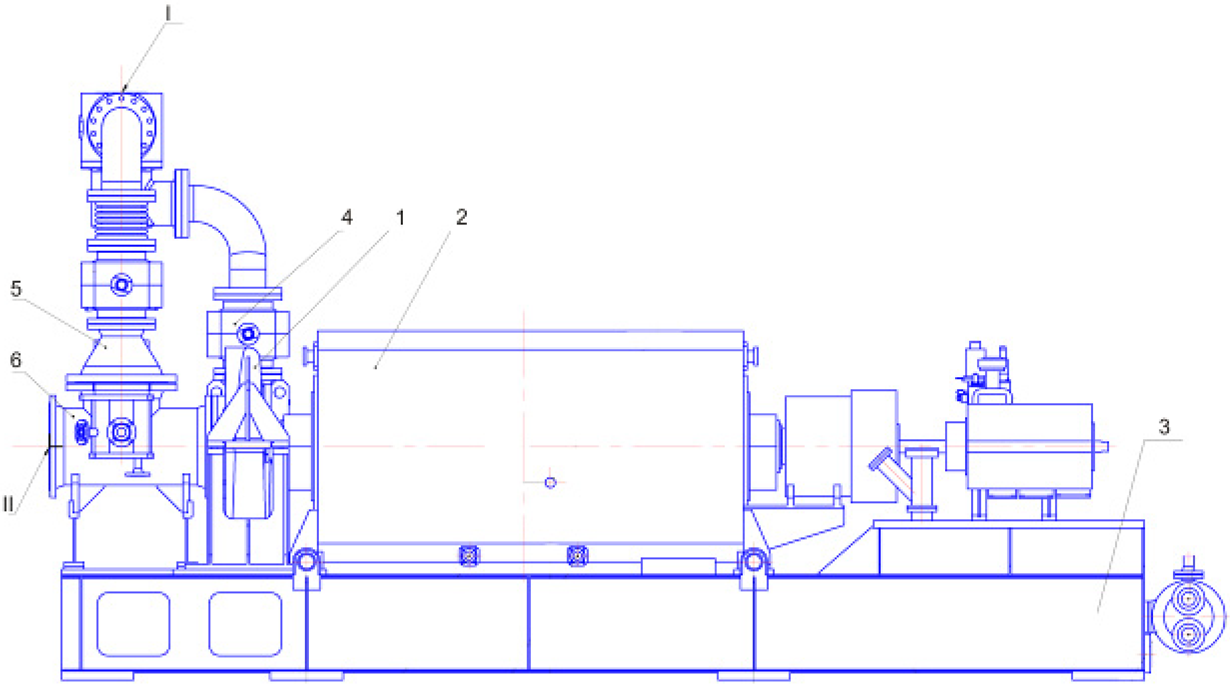

Fig. 6. Turbo-generator of Pauzhetsky Binary GeoPP (I – steam supply to turbine, II – steam takeoff into condenser, 1 – turbine, 2 – generator, 3 – frame-oil tank, 4 – control valve, 5 – throttling device, 6 – exhaust arrangement)

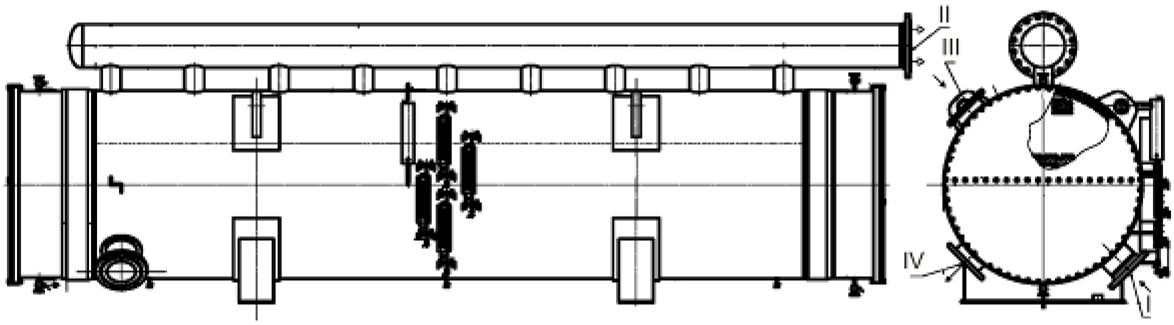

Fig. 7. Evaporator of Pauzhetsky Binary GeoPP (I – supply of liquid R-134a, II – withdrawal of R-134a steam, III – supply of separate, IV – withdrawal of separate)

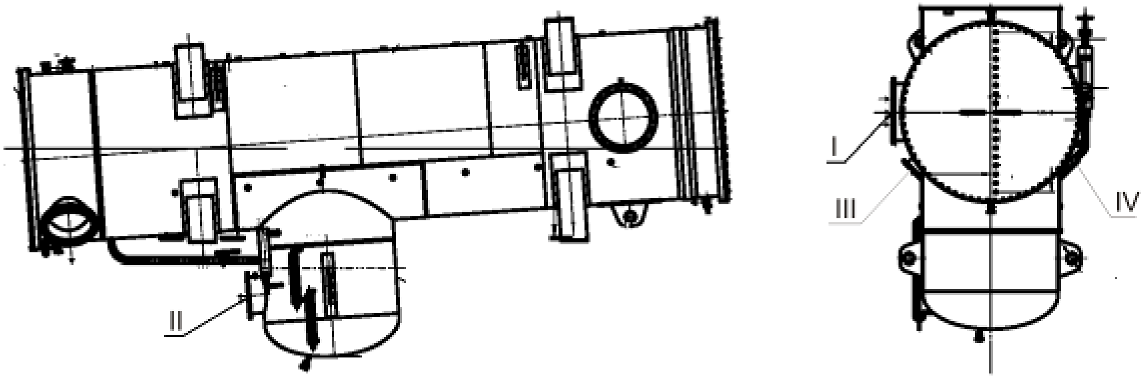

Fig. 8. Condenser of Pauzhetsky Binary GeoPP (I – supply of R-134a steam, II – withdrawal of R-134a condensate, III – supply of cooling water, IV – withdrawal of cooling water)

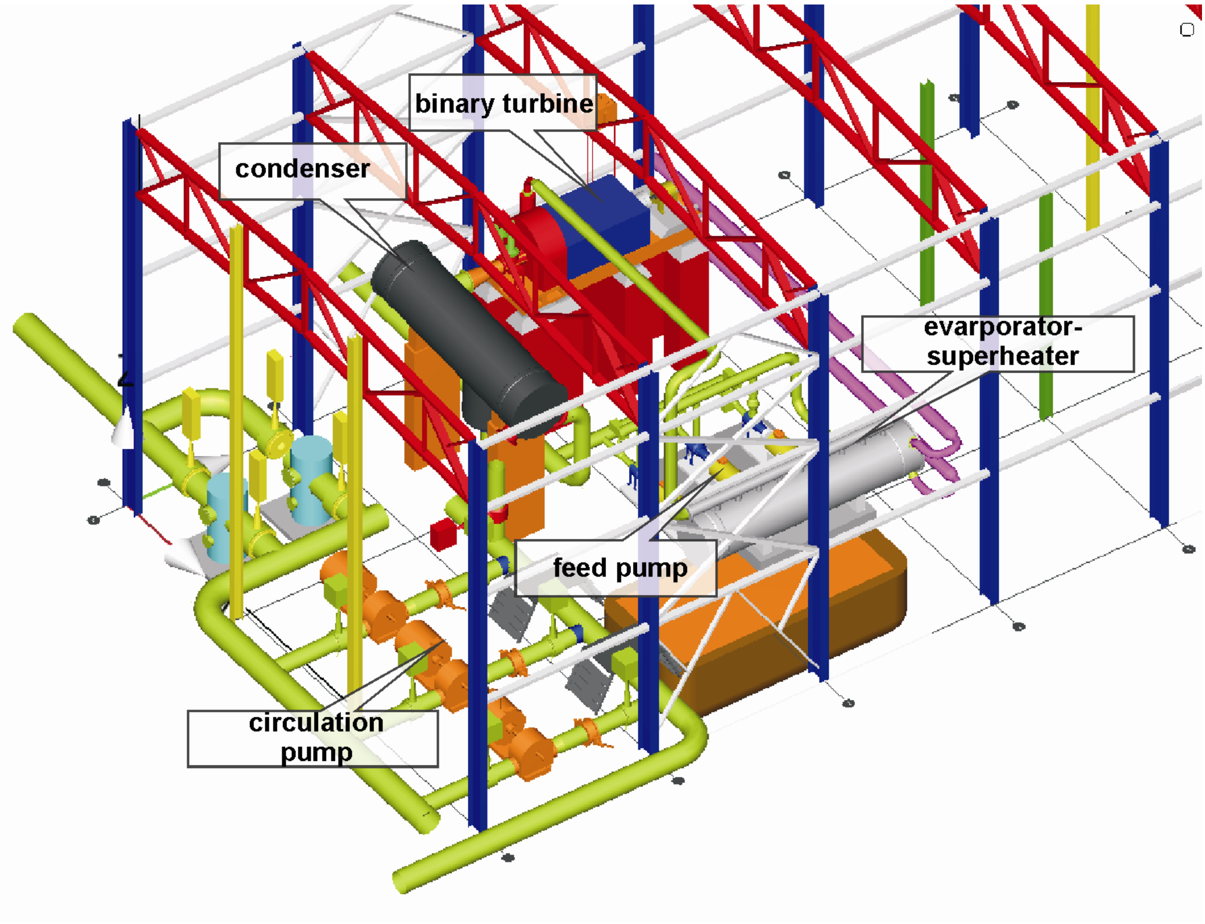

Fig. 9. Layout solutions for placement of equipment within Pauzhetsky BGeoPP building