THE USAGE OF LOW POTENTIAL SOURCES OF HEAT FOR PRODUCTION OF ELECTRICITY AND HOT WATER

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KEY WORDS

Low potential sources of heat, heat pumps, binary energy systems

ABSTRACT

By low potential heat (LPT) is meant different sources of temperature from 0° up to 160°C. This could be fresh or seawater, the drains of purifying systems, geothermal sources, the steam and exhausted gases of heat engines, and waste heat from cooling systems etc. This report considers the possibility of utilizing LPT for electrical energy production (binary energy system BES) and hot water for heating (heat pumps HP) by making use of industrial cooling equipment. This will allow the design and supply of new engines to a customer over a period of 12-24 months. BES uses low boiling liquids as a working agent, thereby enabling the creation of systems using temperatures from 80° to 160°C. The change of the apportioned effectiveness of systems according to the different external conditions of an individually designed BES are analyzed in this report. The effectiveness of a heat pump for the utilization of hot water depends on many factors that should be taken into consideration while the pump is being designed. Apart from construction considerations, these include the area taken up by its installation, the heating equipment, the quality of LPT, and also regional prices for fuel and electrical energy. In order to receive more efficiency, the approach as regards the design of a heat pump should be strictly individual as regards the conditions of each case in hand. Some examples of the efficient usage of heat pumps in different industries are considered in this report. In choosing BES and HP, the analysis of the choice of working agent was done according to the temperature and power of the heating source as well as the conditions of the cooling condensers.

1. INTRODUCTION

By low potential heat is meant different sources with temperatures from 0°C to 160°C. This can be pure and seawater, the waste of purifying systems and geothermal sources, steam and the exhaust gas of heat engines, spent heat from cooling systems etc.
The possibility of utilizing the above mentioned parameters for the production of electricity by means of industrial cooling equipment are considered in this report.

2. THERMAL PUMPS

Thermal pumps (TP) are refrigerating machines, in which the condensing heat of the refrigerant is used. The condensing heat is the sum of the heat from low potential heat (LPH) and the electric motor capacity of the compressor.
The efficiency of a thermal pump depends on the load of different parameters, which ought to be taken into consideration while developing the construction of a pump. These parameters are, apart from those concerning the engineering ones, as follows:

The location, the heating equipment, the existence of hot water, the quality of LPH etc., and the local fuel and electricity costs for central heating in a particular area.
For these reasons, considerations concerning the development of a TP should be based on the particular circumstances of particular situations.
In figure 1 is shown the use of a TP for a hot water supply using the heat from the wastewater of an electrical power station. In such a case, the return water flows as a source of low potential heat into a TP evaporator. Another part of this water is pumped through a condenser, where it is heated up to a temperature of 70° to 90°C and is used for central heating systems. Having been used in this way, this water is pumped into the return system by the TP evaporator. In summer, hot water is supplied by pipes from a boiler, but is heated by the TP when it is working.

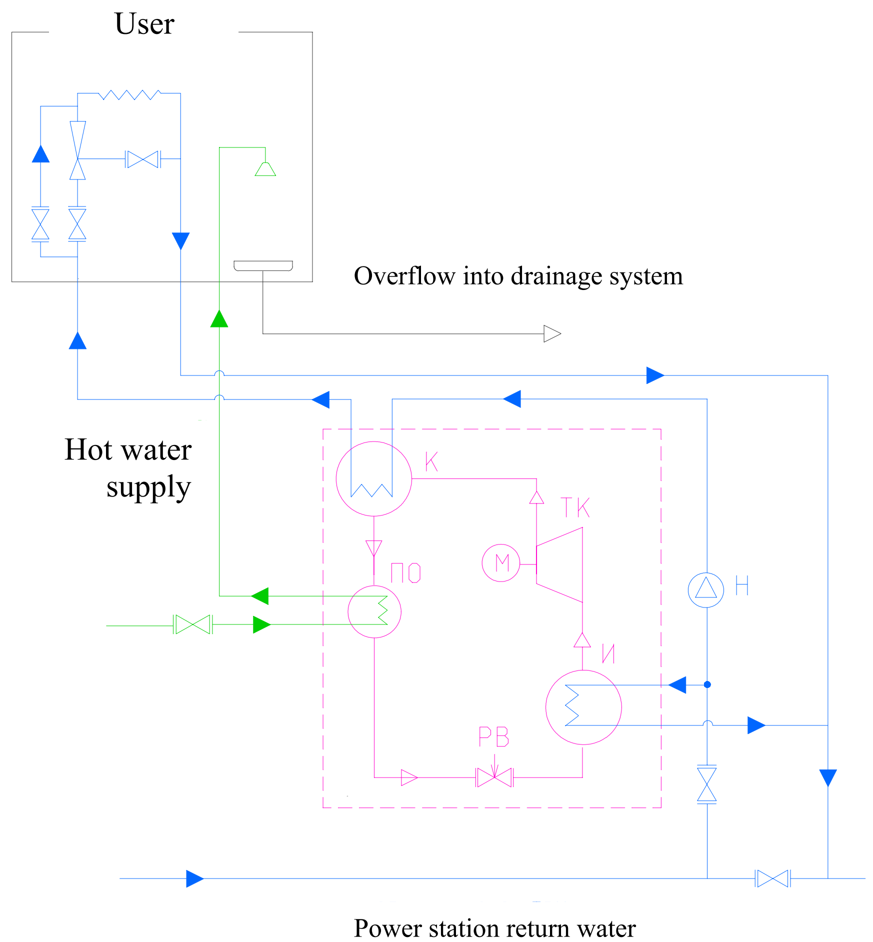

Figure 1. Diagram for a heating pump using the heat from a return water system

ТК - turbo compressor; К - condenser; И - evaporator ; Н - pump;
ПО - super cooler; РВ - regulator valve

In Figure 2 is shown a graph representing the transformation coefficient φ, where $\varphi = Q_T/N$, the quantity of heat generated divided by a unit of electrical power for different temperatures of out flowing water at different LPT temperatures. As it is seen on the graph, the coefficient φ increases with an increase of LPT temperature and with a decrease in the hot water temperature.
In this way the HP efficiency is determined by the difference in the temperatures of LPT and that of the heat transfer agent (tw2) supplied to the user from the system condenser.

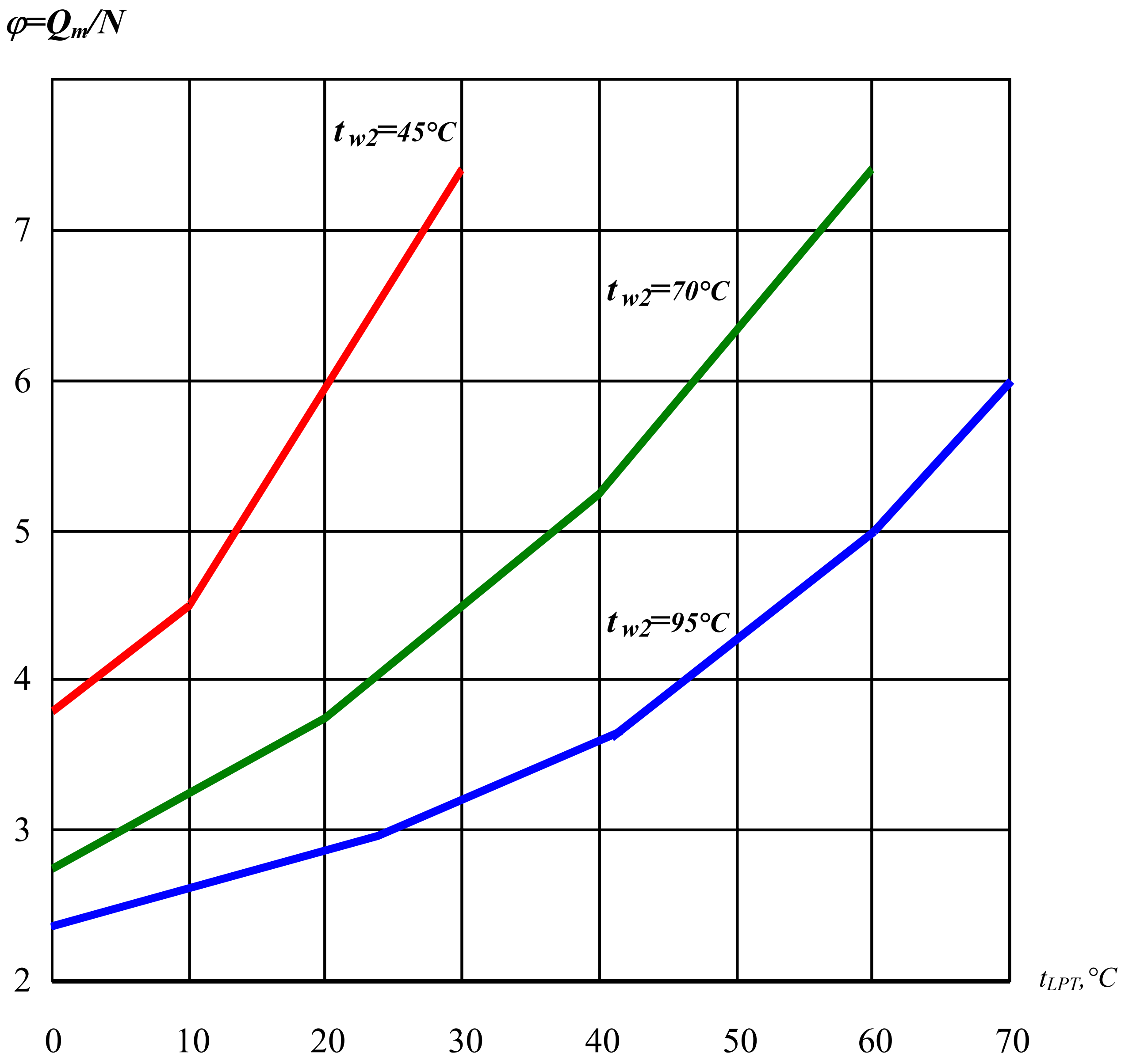

Figure 2. The dependence of the transformation coefficient φ on LPT temperature t_{LPT}

Q_m - , quantity of generated heat, KWt
N - power supply, KWt
t_{w2} - temperature of water supplied to the user

In Figure 3 is shown a field of temperature ranges for heat pumps, calculated for water temperatures of up to tw2 = 95°C, that can be created using refrigerating machinery having centrifugal compressors.

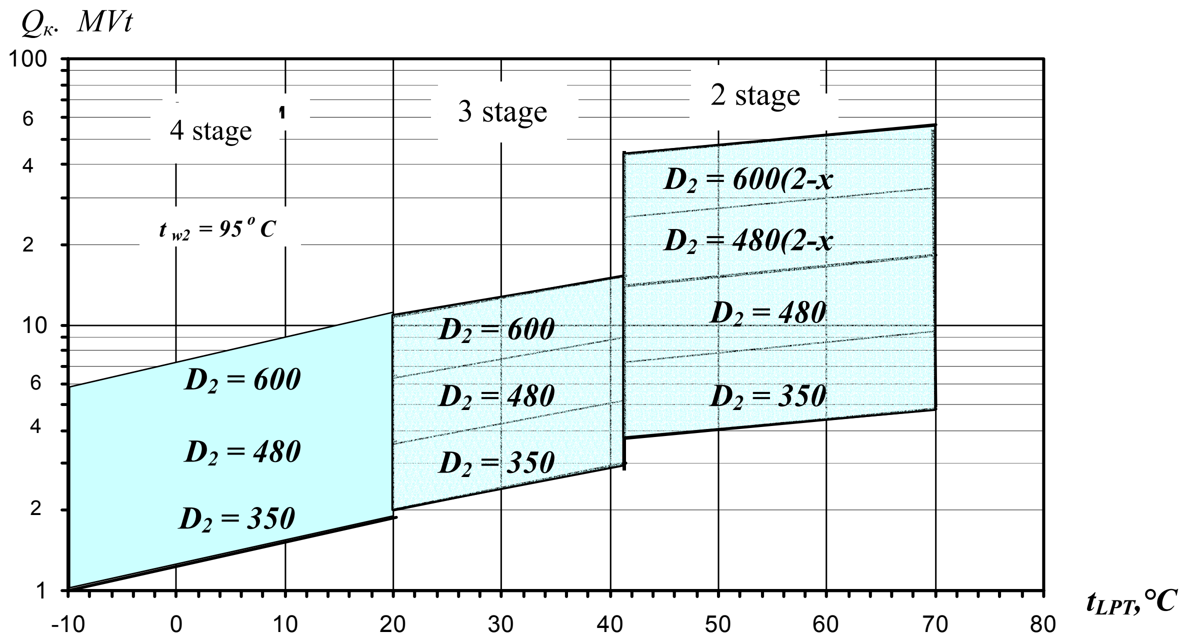

Figure 3. Field of temperature ranges for heat pumps using refrigerating machinery having centrifugal compressors.

In Figure 4 is shown a 2-stage refrigeration compressor having an impellor diameter of 480 mm. It is suggested that in northern regions where fuel oil is piped, such a pump be powered by a heat engine (HE) using an internal combustion engine or a gas turbine, in which, after passing through the condenser, water is reheated by means of a waste heat boiler that uses the exhaust gases of the HE or heat from the engine cooling system.

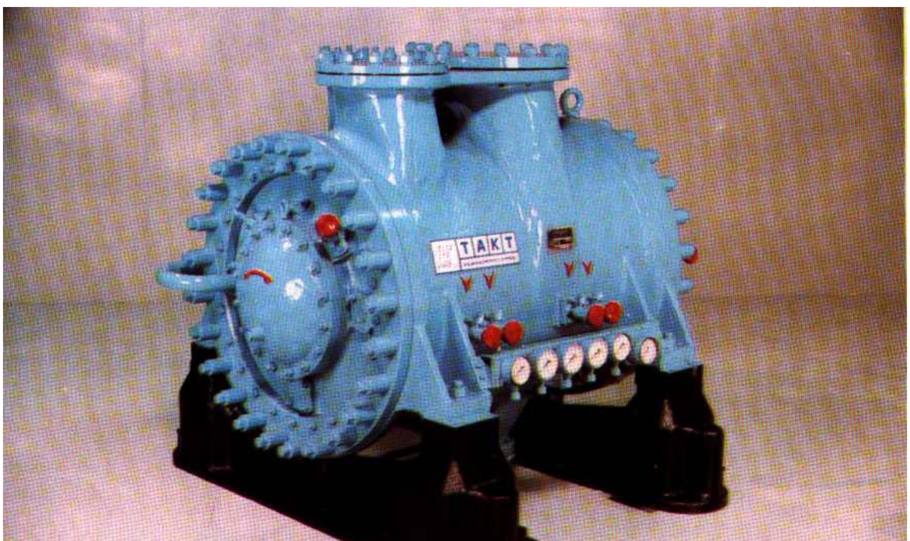

Figure 4. A 2-stage refrigeration compressor usinga 480 mm diameter impello

Figure 5 shows a graph that compares the heat of a TP at different engine efficiencies and having a boiler efficiency of 80% and depending on the transformation coefficient (φ) of the TP. As can be seen in the graph, even at φ = 2 such a pump gives an increase in heat quantity by a factor of 1,5, as compared to a boiler and at a normal value where φ = 4 this increase is greater than twofold.

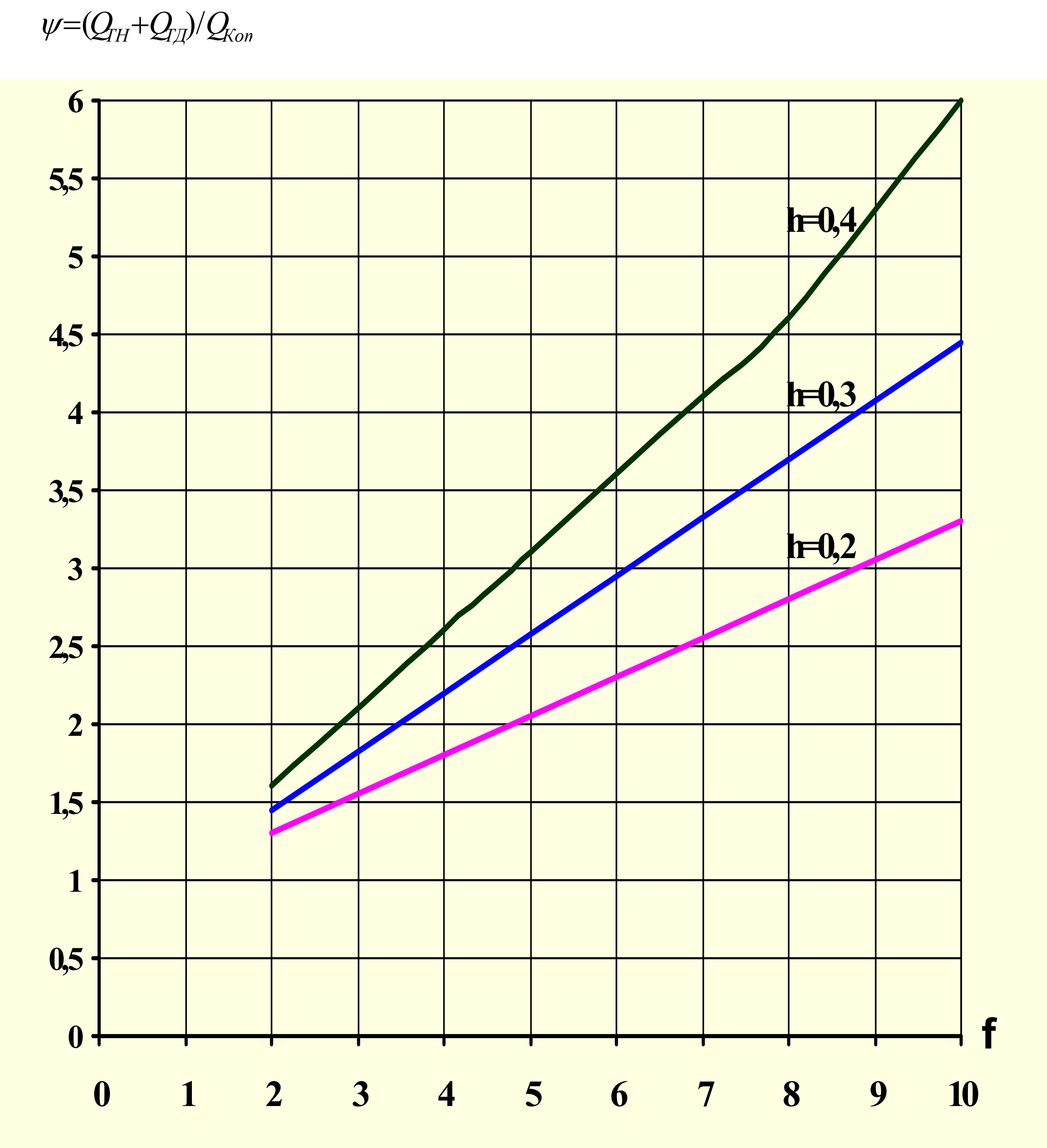

Figure 5. Increase in the heat generated by a HP driven by a heat engine as compared with the heat generated by a boiler

In Figure 6 a graph is shown displaying the relationship between the average costs for 1 KWt of calorific capacity generated by a TP system and the transformation co-efficient.

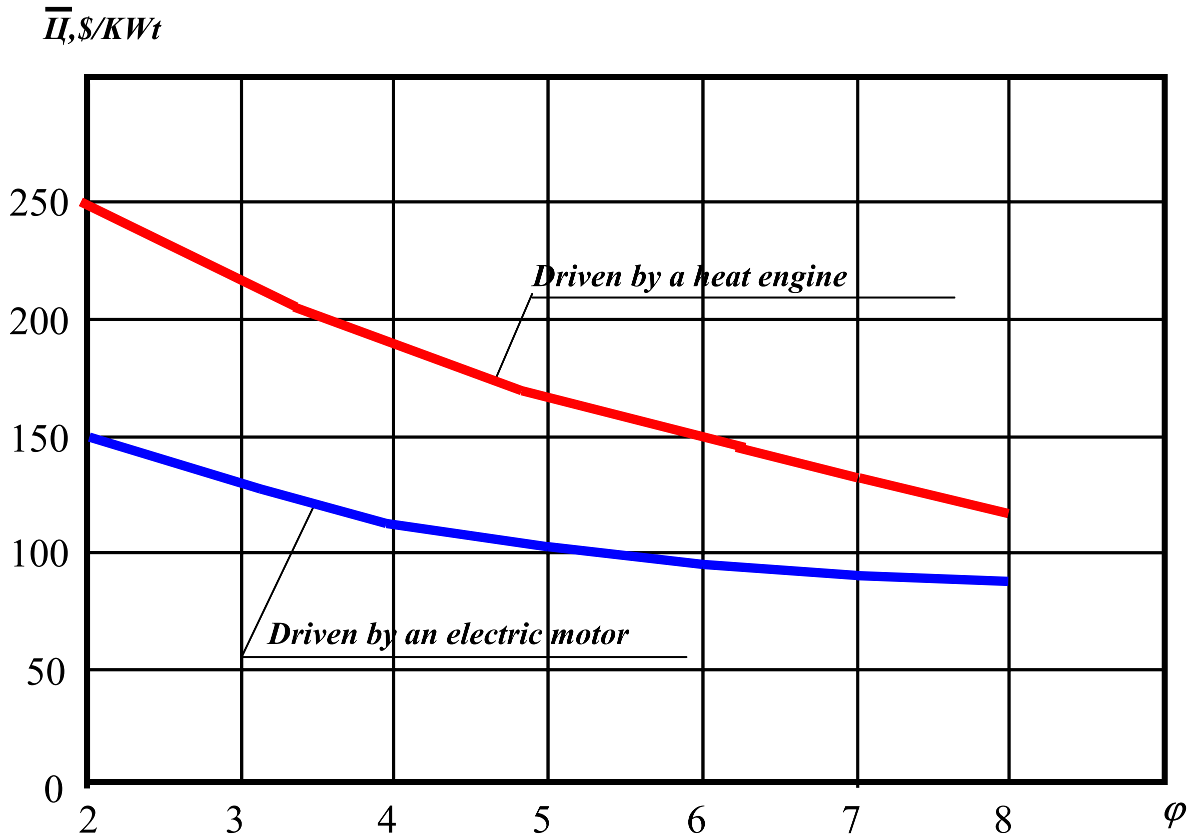

Figure 6. The dependence of average costs of 1 KWt of heat generated by a HP and the transformation co-efficient

3. BINARY ENERGETIC SYSTEMS

Binary Energy Systems (BES) are steam turbine generators operating according to the Renkin cycle. Their working agents have low boiling temperatures (different refrigerants, light carbohydrates etc.). The use of such agents allows a cooling cycle having approved pressure values and temperature differences when using an LPT with temperatures from 80° to 160°C. These may be hot spring waters and waste heat from power plant (including nuclear) industrial enterprises. Using agents that have low boiling temperatures also allows one to increase the energy capacity by lowering the condensation temperature when the incumbent temperatures are below zero degrees.

In Figure 7 is shown a 750 KWt Freon turbine at the Paratynskaya geothermal station and which uses water at a temperature of 80°C. This system was set up in 1966 by VNIIkholodmash by the head of the Defence Committee of the Science Academy of the Soviet Union.

The power efficiency of one tonne of steam and heating water and its dependence on temperature is shown in figure 8. As can be seen, when water is being used the power efficiency is strongly dependant on the water temperature. When the heat of the condensed steam is being used, this dependence is somewhat lower.

A geothermal energy system working in a combined cycle and having a power of 6.5 MWt 92.5 MWt of steam power and 4 MWt of binary) has been tried out at the Mytnovsku geothermal field.

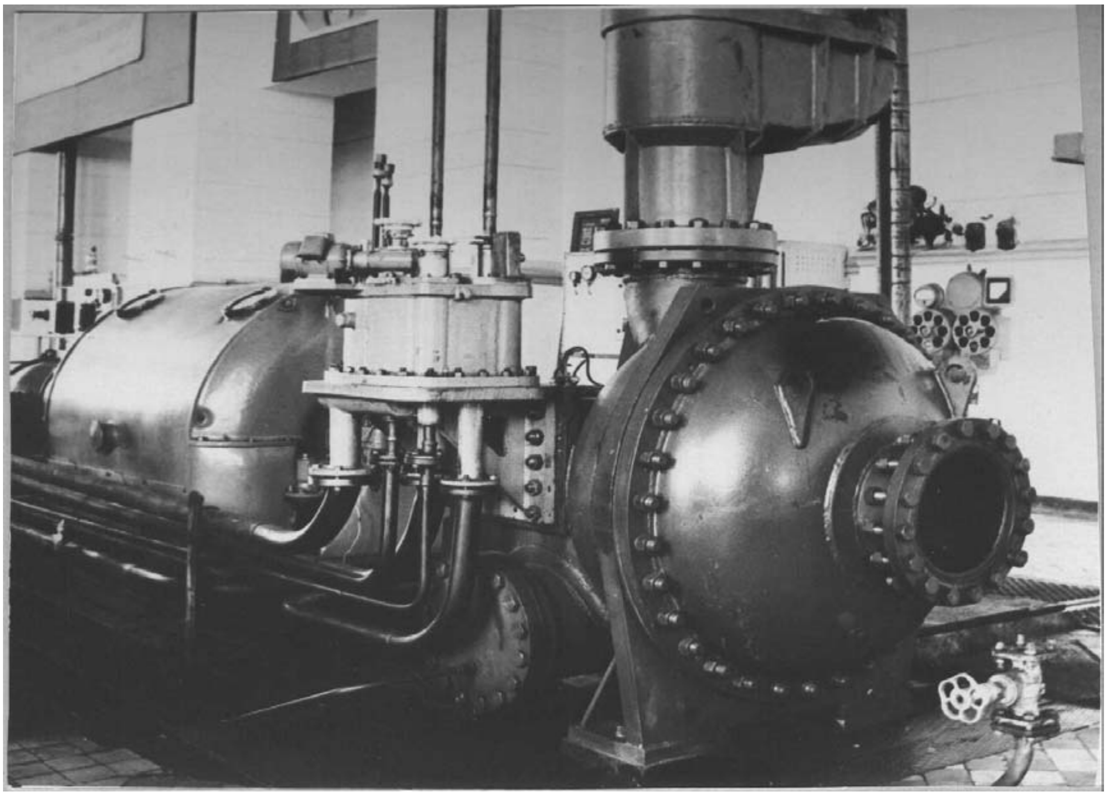

Figure 7. A binary system having a power of 750 KWt

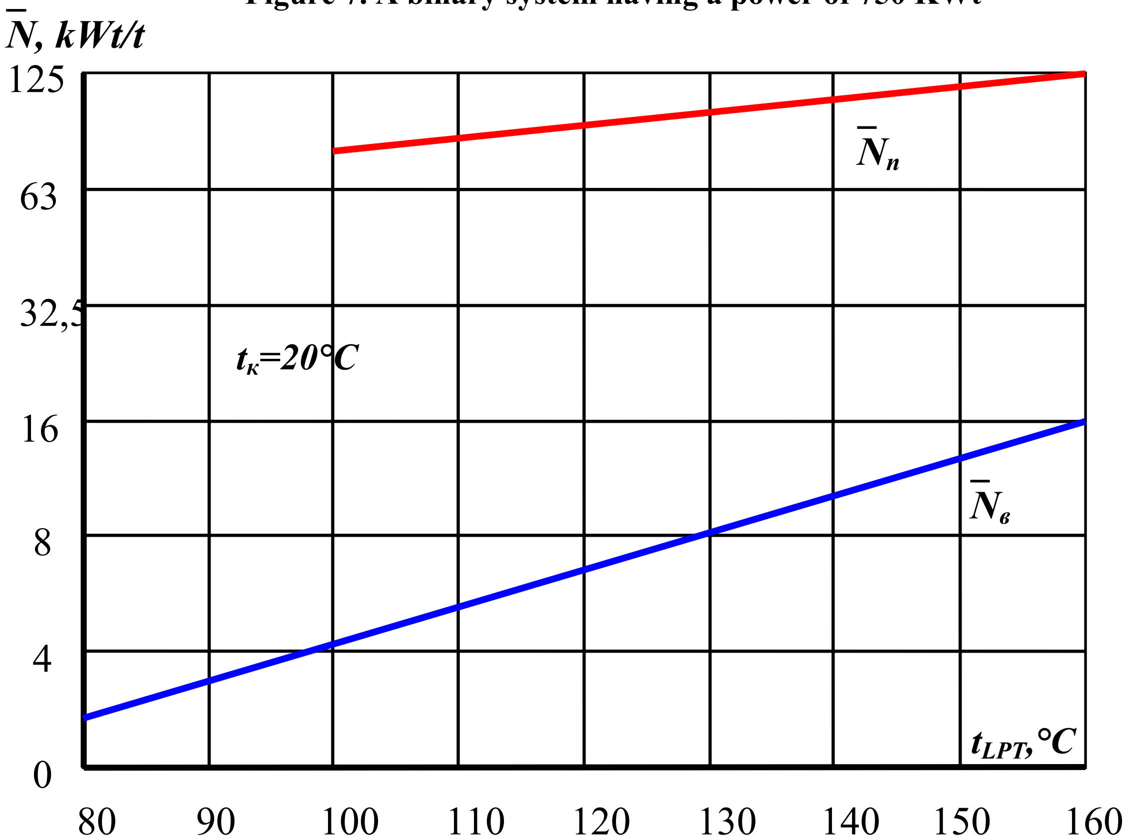

Figure 8. The dependence of the power efficiency of the energy exploited from a tonne of water N_b or steam N_n (not taking into account energy used for internal purposes) with temperature of a hot spring with a condensation temperature t_k=20°C

The majority of present day gas turbine systems is equipped with exhaust boilers. On order of Gazprom a system for a BES compressor station having a power of 2,5-4,0 MWt was undertaken by our firm. As a heat source steam from waste heat boilers of a gas turbine was utilized (temp. 115°C, press. 0,17).
A diagram of the system is shown in Figure 10 and the dimensions and emplacement of the equipment is shown in Figure 9.

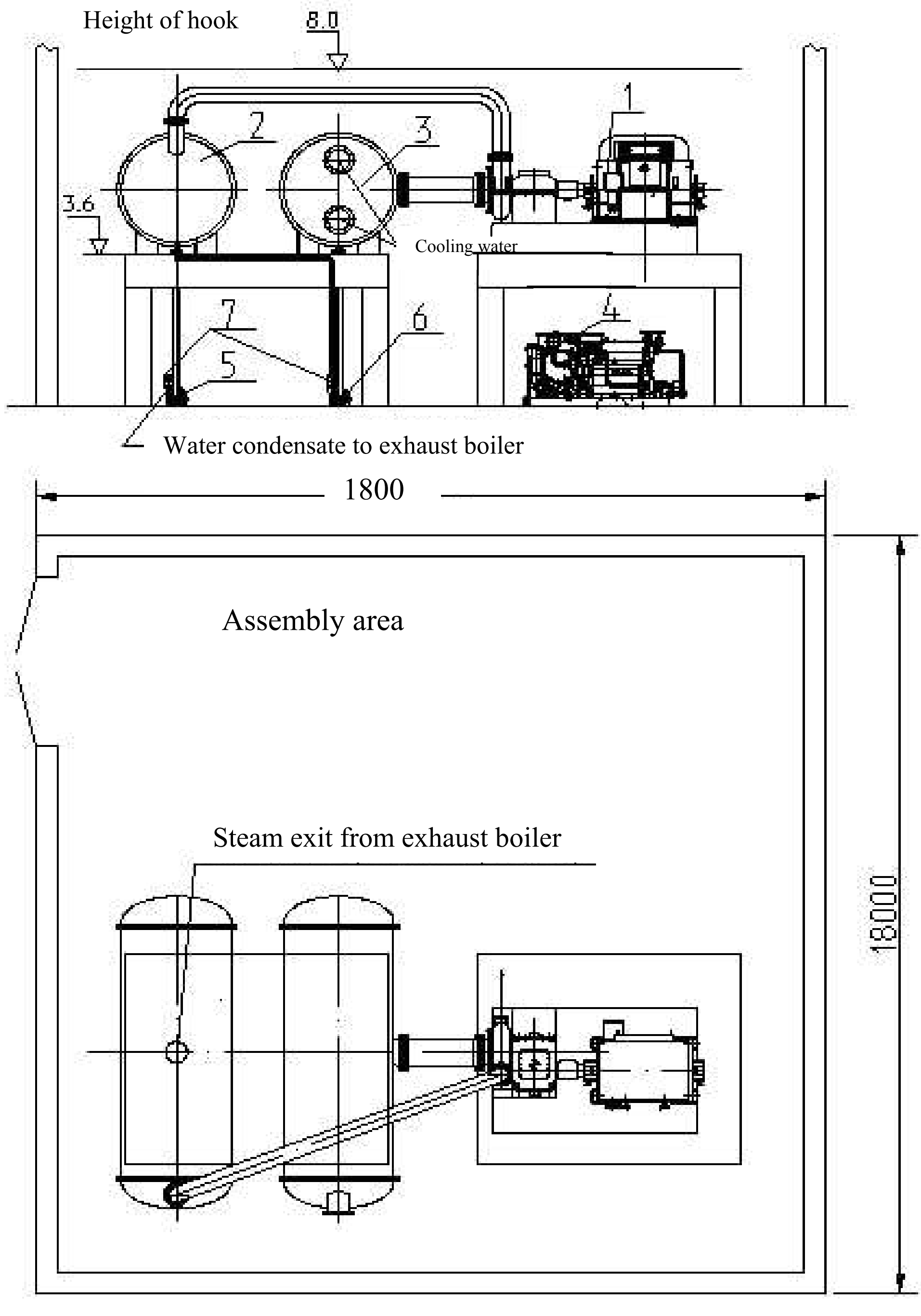

Figure 9. A binary system having a power of 4,0 MWt

1 - binary generator
2 - binary cycle steam generator
3 - binary cycle condenser
4 - oil sump
5 - steam cycle feed pump
6 - binary cycle feed pump
7 - regulator valve

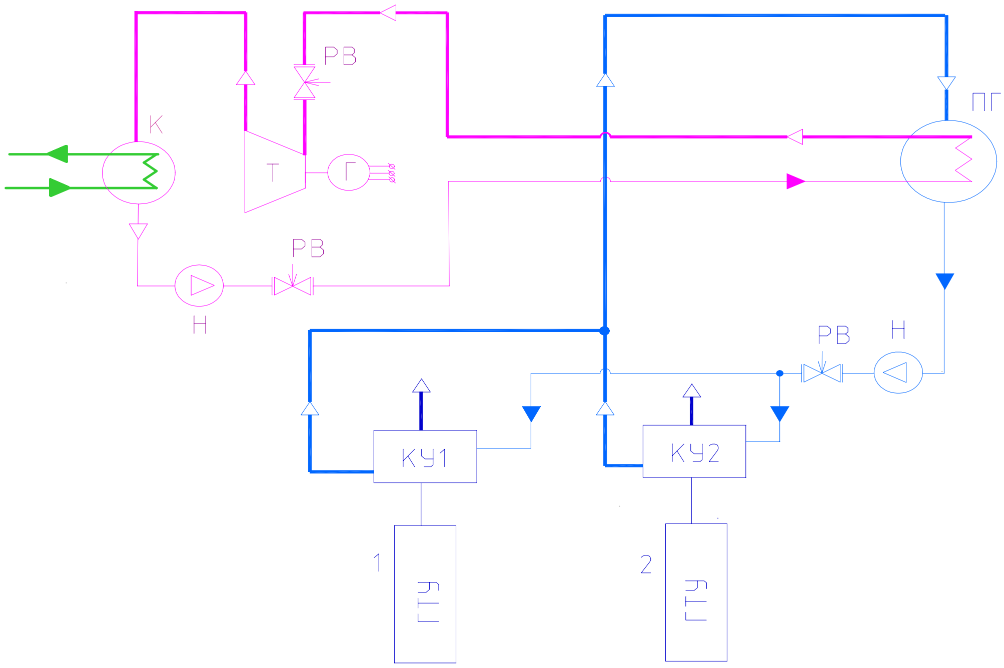

Figure 10. Diagram of a binary energy system
Т – binary turbine; К — condenser; Г – generator; ПГ — steam generator;
РВ— regulator valve; Н – feed pump; КУ – exhaust boiler.

Based on an analysis of waste water from the Astrakhan hydroelectric power station undertaken by VNIIgas there was outlined the possibility of essentially changing the structure of the energy consumption of the enterprise by means of producing additional electrical energy.

In the technological processes of refining natural gas with the help of AVO a large quantity of heat with a temperature of 90-150°C was dispersed into the atmosphere and irreversibly lost.

Only a simple analysis undertaken by us of the waste heat showed that there probably could be obtained about 10 KWt of electrical energy in power units of 0.6 to 6 MWt, as shown in operation in the diagram above (Figure 10).

For the realization of a binary cycle there must be obtained a working agent having thermodynamic physical properties that satisfy specific demands, which demands depend on the function of the system, its layout, the calorific value of its heat source, the maximum and minimum levels of temperature of the heat source and the required standards of durability and safety.

The properties of an agent are determined by the parameters and dimensions of the running parts of turbines and a correct choice of such parts guarantees optimal conditions of construction.

At a saturated steam temperature of 160°C and higher it is expedient to use a combined BES scheme where the steam at first disperses its energy in a steam turbine with condensation at a temperature of 105°C (the absence of a vacuum and level of steam dryness not dropping lower than 0.8) and the steam condensation temperature is used in the waste steam boiler of the binary cycle turbine.

A geothermal energy system working by means of a combined cycle and having a power of 6.5 MWt (2,5 MWt from steam, and 4 MWt from binary) has been developed for the Mytnovsku geothermal field.

In Figure 11 and Figure 12 shows a plan for a combined BES. After the 1st stage separators, steam enters a steam turbine at a pressure of 6,5 atmospheres. After leaving the turbine and with a pressure of approximately 1 atmosphere, the steam is condensed in the steam generator of the binary turbine and the condensate is injected back into a port. Hot water from the 1st stage separator having a temperature of approximately 160°C enters into the working agent superheater of the binary turbine. After this, it enters the 2nd stage separator, where it expands to a pressure of 1 atmosphere. The steam obtained also enters the binary system steam generator. Water is injected into a port after passing through a second throttle control. From the BES receiver the working agent is injected into the steam generator and after superheating passes to the working turbine. The used working agent enters an air-cooled condenser and is then discharged into a receiver. The steam turbine and the turbine working with the low-boiling working agent operate the same shaft. Load adjustment is only made by feeding steam into the steam turbine. A change in its heat load automatically alters the power of the second turbine.

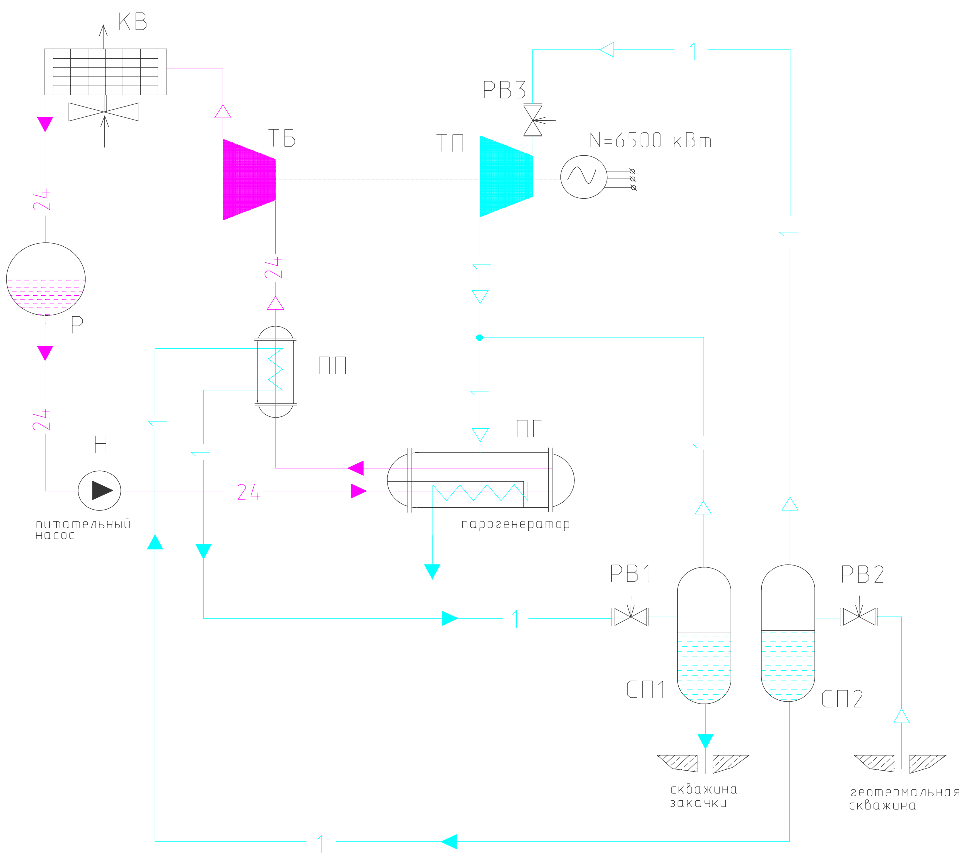

Figure 11. Layout of a combined binary energy system

ТБ – binary turbine; ТП - steam turbine; ПП – steam superheater;
ПГ– steam generator; КВ– air-cooled condenser; СП1 – 1st stage separator;
СП2 - 2nd stage separator; Р – receiver; РВ1…РВ3 –regulator valve; Н – feed pump.

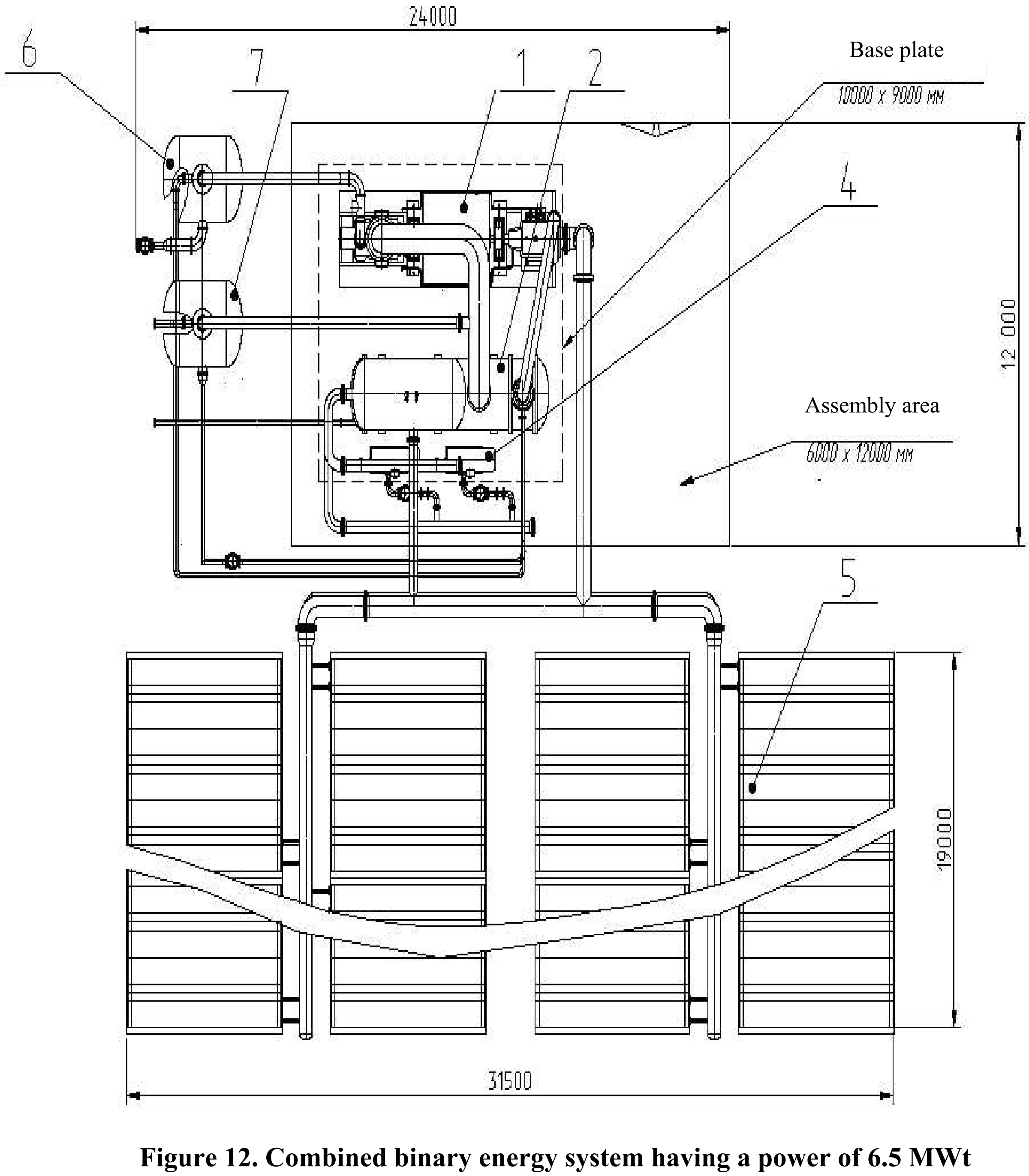

Figure 12. Combined binary energy system having a power of 6.5 MWt

1 - turbine mounting; 2 - generator; 3 - steam superheater; 4 - pump mounting; 5 - air-cooled condenser, 12 units.; 6 - 1st stage separator; 7 - 2nd stage separator

The main question concerning the use of BES is the price of electrical energy. Clearly, the cost of the system I inversely proportional to the temperature and power of the heat supply. An evaluation undertaken by us of the specific cost of a basic system installation according to a price orientated towards that of a refrigeration and chemical machinery plant is shown in Figure 13.

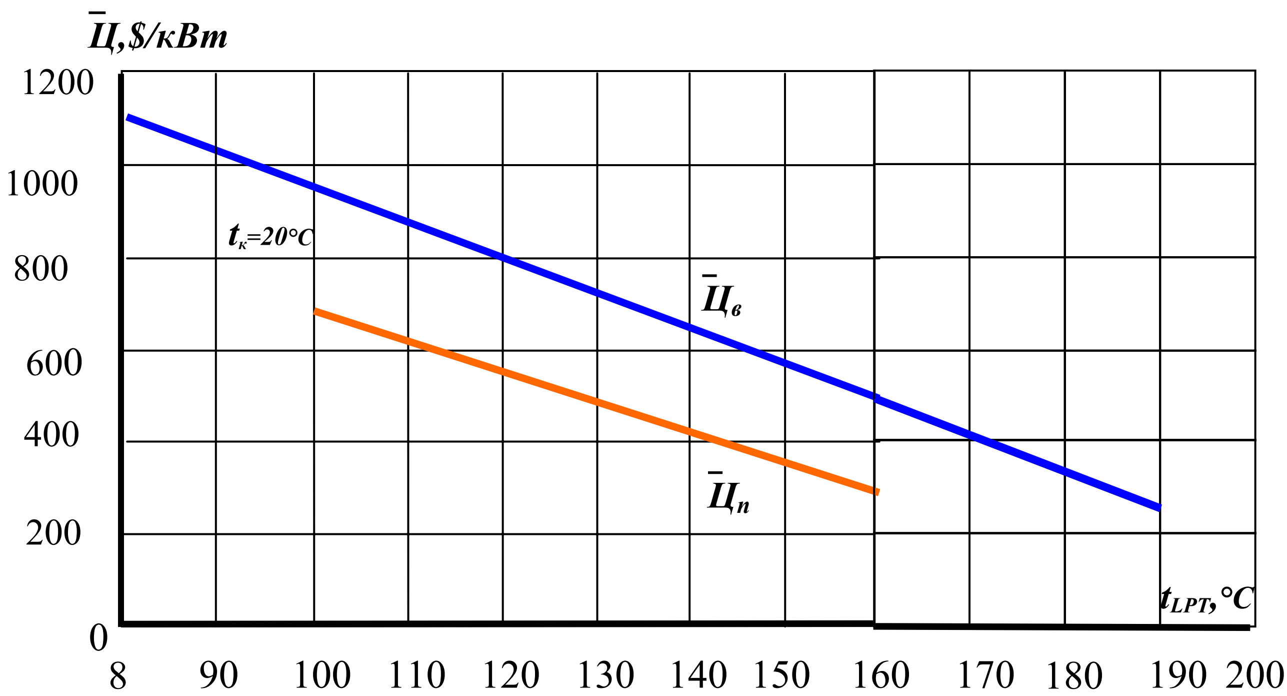

Figure 13. The dependence of the average specific price of 1 KWt of proven power of a BES installation in which the temperature of the heat source is tnpt and that of condensation is t_k=20°C

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4. CONCLUSION

A fundamental fault of both heavy-duty heat pumps and of energy installations is their uniqueness. Each system must be planned and constructed only according to concrete conditions that are dependent on the heating power of the source and its temperatures and the changes in these parameters during the course of a year.
At present refrigeration machinery plants can design and install over a period of 18 – 24 months a binary energy system and heat pumps at a price that is twice as low as those of foreign suppliers.