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Research and analysis of the low-temperature potential of heat networks

A G Batukhtin[1], M V Kobylkin[1] Yu O Rikker[2] and S G Batukhtin[1]

[1]Department of Energy, Transbaikal State University, Aleksandro-Zavodskaya St., 30, Chita, 672039, Russia
[2]Scientific Department, Transbaikal State University, Aleksandro-Zavodskaya St., 30, Chita, 672039, Russia

E-mail: mkchita@gmail.com

Abstract. The article is devoted to the use of heat pump installations in heat supply systems with TPP. The technique of the primary assessment of the efficiency of heat pumps in district heating systems is considered, on the basis of which it was concluded that it is possible to get the maximum effect from the introduction of a heat pump in the inter-heating period to compensate for the HPU load when using a heat pump at a consumer and transferring the heat and power plant to the condensation mode from the condenser to the heating system. At the same time, for greater effect, the heating system must be cooled below 20 ° C in order to use the low-temperature potential of the heating network. Based on the findings, a comprehensive heat supply system has been developed that includes TPP and HPU installed at the consumer by the universal compensation system of hot water supply load (UCS-HWSL) scheme. Modernization of the basic heat supply system to the UCS-HWSL system with a lowered temperature schedule will allow improving the technical and economic indicators of the Chita TPP-1.

1. Introduction

Energy is the basis for the development of production processes in all sectors of the economy, ensuring the development of the material and technical base of society, improving the quality of life of the population.

The basis of the uninterrupted operation of the energy industry of any state is to provide energy enterprises with fuel. However, a rough estimate of global reserves of fossil hydrocarbons indicates that by the middle of the 21st century, these reserves may be depleted. Thus, humanity at the present stage of development is on the verge of a global energy crisis.

In view of the above-mentioned global problem, the direction of the development of the country's heat supply in the context of energy conservation takes on special relevance in the energy sector. The relevance of energy saving measures is supported by the legislative base (Federal Act 261-FA On Energy Saving and on Improving Energy Efficiency and Amending Certain Legislative Acts of the Russian Federation and Related Sub-Law Acts).

Given this legislative base in Russia in recent years, interest has increased in the use of energy from renewable and secondary sources, including heat-pump unit (HPU). The emergence of demand for existing alternative technologies has expanded the existing domestic market for energy conservation, allowing consumers to use projects with HPU without the involvement of foreign experts. Regardless of the question of a full-scale transition from existing centralized heat supply systems to foreign analogues of integrated systems with district heating supply system [6-15], the use of heat pumps in modern Russian power engineering has a certain potential. This direction includes the adaptation of heat pump systems for their use in the improvement of existing district heating systems.

2. The initial assessment of the heat pump efficiency in district heating supply system

Traditionally it is believed that HPU is effective in recalculating the coefficient (COP) > 2.5. This expression is easy to verify. Supposadly, efficiency factor of condensing power plant ≈ 40%, therefore, the production of 1 kW of electricity will be spent 1/η=1/0.4=2.5 kW fuel heats.

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Thus, the HPU seems to «return» the heat, initially spent on electricity production, and when the COP threshold is exceeded by 2.5, its work becomes energy efficient.

For TPP, the efficiency of a heat pump unit is not so obvious, since the heating, from a thermodynamic point of view, is much more efficient than separate generation [2], besides cogeneration does not allow directly estimating the efficiency of a heat pump unit through the efficiency factor of electricity generation at a heat plant.

This feature causes a lot of controversy among Russian engineers and scientists, the result of which was a lot of contradictory data about the economic feasibility or inexpediency of the use of HPU in conjunction with TPP. Most tend to the fact that the heat pump unit is notoriously inefficient in heating plants.

To obtain a specific answer to the question about the efficiency of heat supply systems in district heating systems, it is proposed to introduce the concept of extremely inefficient COP for the system in question.

This term should be understood as such COP, in which the introduction of heat pump unit into the district heating supply system of a TPP will not lead to a change in fuel consumption.

The condition for the extreme inefficiency of the HP, for isolated TPP, can be expressed as follows:

$$B_{TPP} = B_{TPP+HPU}$$

provided: BTPP,BTPP+HPU– fuel costs for TPP, respectively, in the absence and in the presence of HPU in the heating system.

Since the CHP under consideration is similar for both options, the equality of fuel consumption will be determined by the equality of steam consumption (D) for turbines:

$$D_{TPP} = D_{TPP+HPU}$$

In general, with certain assumptions, the equality of steam costs can be described as a balance:

$$\frac{N}{H_i \cdot \eta_{em}} + \frac{i_s - i_c}{H_i} \cdot \frac{Q_{rel.}}{(i_s - i_d) \cdot \eta_{h.e.}} = \frac{N + \Delta N_{HPU}}{H_i \cdot \eta_{em}}$$

provided: N – power, which must be maintained for the supply of electricity to the consumer, Hi – disposable turbine heat drop, is – steam enthalpy taken for heating, ic – steam enthalpy in condenser, id – enthalpy of drainage network water heater (NWH), Qrel. – the amount of heat released from the station to the needs of heating, ΔNHPU – necessary increase in electrical power to cover the needs of the HPU, ηem, ηh.e. – electromechanical efficiency factor of the turbine and the efficiency factor of the heat exchanger, respectively.

Assumptions:

- turbines of type T, PT;
- all the heat required by the consumer is compensated by the HP from the autonomous low-potential source of heat;

- single-stage heat line water;
- neglecting the release of power auxiliary equipment of heat networks;
- TPP has a power reserve to cover the needs of the HP.

Simplifying equality we get:

$$\frac{\Delta N_{HPU}}{Q_{rel.}} = \frac{(i_s - i_c)\cdot\eta_{em}}{(i_s - i_d)\cdot\eta_{h.e.}}.$$

Since on the left side of the equality is the value inverse COP the extremely ineffective COP for the system:

$$\mu_{ext.} = \frac{Q_{rel.}}{\Delta N_{HPU}} = \frac{(i_s - i_d)\cdot\eta_{h.e.}}{(i_s - i_c)\cdot\eta_{em}}.$$

From the obtained equation it can be seen that the efficiency of the heat pump when working together with the TPP in an isolated system depends only on the parameters of the steam selected at the NWH.

In the general case, if the released power, when closing the heat extraction samples, is sufficient only to cover the needs of a HPU, then in such a case the HPU can be considered extremely inefficient.

In particular, for the conditions of the Chita TPP-1 is extremely inefficient COP = 4,6.

Thus, the installation of HPU in the power system of the Chita TPP-1 with a COP value of up to 4.6 for the purpose of heat supply to consumers will certainly lead to excessive consumption of fuel in the system.

It is possible to reduce extremely inefficient COP and to ensure full compensation of the heat load of the TPP by using the secondary thermal resources of the TPP for heating supply to consumers equipped with heat pumps. This approach assumes the elimination of heat losses in the heat network [3, 4].

Considering the above, the maximum effect from the introduction of heat pump systems can be obtained in the inter-heating period to compensate for the load of hot water supply when using a heat pump unit at the consumer and transferring the TPP plant to the condensation mode, with the organization of heat removal from the condenser to the heating system. At the same time it is possible to cool the heating network below 20 ° C excluding the deterioration of the turbine vacuum.

At the same time, the cooling of the heat network below the ambient temperature will provide additional renewable heat, which will also reduce the extremely inefficient COP.

3. Development of complex heat supply system from TPP with HPU

A promising direction for the introduction of heat pumps at the initial stage with observance of the set conditions may be load compensation of hot water supply (HWS) in a non-heating period using a non-classical source of low-grade thermal energy [5]. In this case, the developed method of compensating for the load of HWS is accepted as a «baseline».

The hot water supply system of the building (Figure 1), modernized using the «basic» method, uses a heat carrier circulating in the closed loop of the heating system as a heat source for the heat pump. A closed loop is organized by closing the shut-off valves 8 and the three-way valve 12 along the supply line 1, and also the automation of the valves 7 is performed to reduce or completely stop the circulation of the coolant through the heat exchanger 6. The system effectively covers the load of hot water due to the heat accumulated in the building, and provides significant savings for the consumer. The method is characterized by high values of the conversion coefficient, which are characteristic of water heat pump units (HPU), with compactness and minimal implementation costs. The method also allows to utilize the excess heat of the premises during the summer period, reducing the energy consumption for air conditioning, which is characteristic only of expensive complex heat and cold supply systems [5].

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If there is a «base» method on all consumers, it becomes possible to convert a source of thermal energy to work as a low-potential source of heat for the consumer according to the following method.

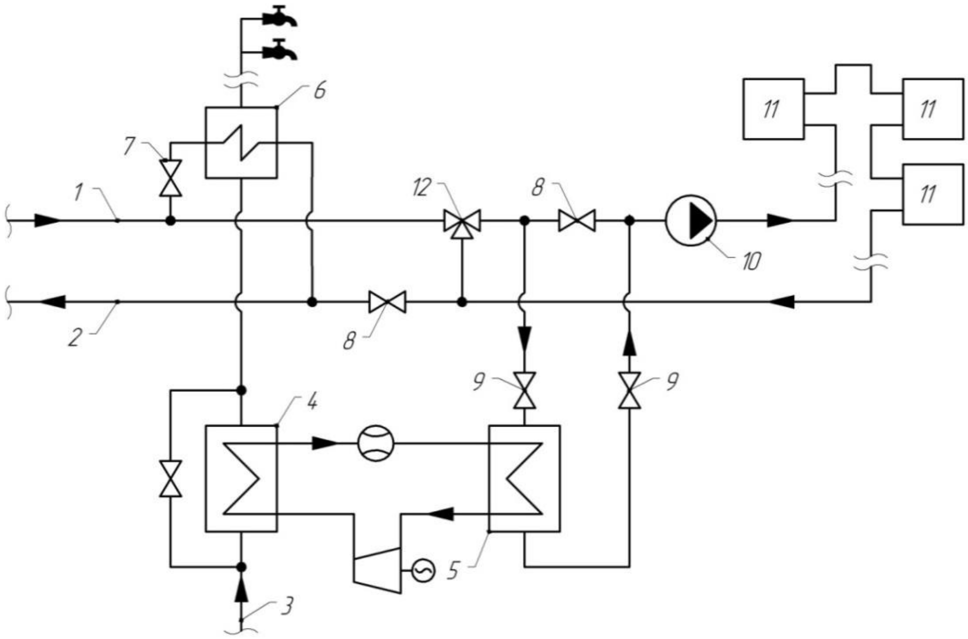

Figure 1. Hot water supply system of the building: 1 - supply pipe, 2 - return pipe, 3 - water pipe for hot water supply, 4 - heat pump condenser installation, 5 - heat pump evaporator installation, 6 - hot water heat exchanger, 7, 8, 9 - stop valves, 10 – circulation pump, 11 - heating device, 12 - three-way valve.

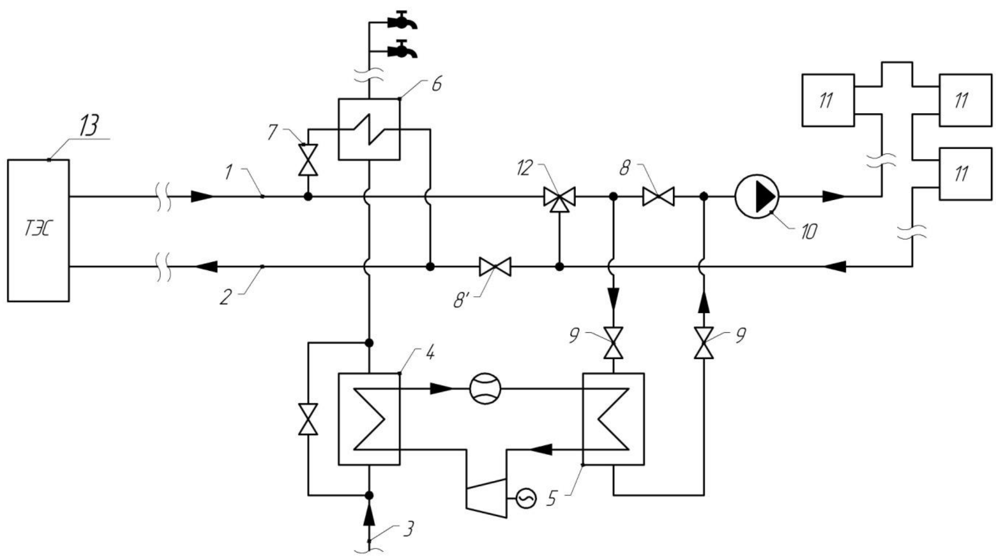

Figure 2. Integrated hot water supply system of the building (UCS-HWSL): 1 - supply pipe, 2 - return pipe, 3 - water pipe for hot water supply, 4 - heat pump installation condenser, 5 - heat pump installation evaporator, 6 - hot water heat exchanger , 7, 8, 8', 9 - stop valves, 10 - circulation pump, 11 - heating device, 12 - three-way valve, 13 - heat source.

In the transition from the «base» method to an integrated hot water system of the building, which was called universal compensation system of hot water supply load (UCS-HWSL), (Figure 2) opens valve 8' and also the three-way valve controlled by the adjusted automation of the heating system comes into operation in order to organize the supply of low potential heat. In the circuit of the heating system coolant, using a circulating pump, served in the heating system. Passing heating devices, the coolant collects the excess heat of the premises, after which it is divided into two streams, one of the streams returns to the TPP, the second stream passes the three-way valve, mixes in the required proportions with the low potential coolant from the supply pipeline and enters the HPU.

Simultaneously with the closure of the valve 8, the valve 7 is closed to shut off hot water heat exchanger.

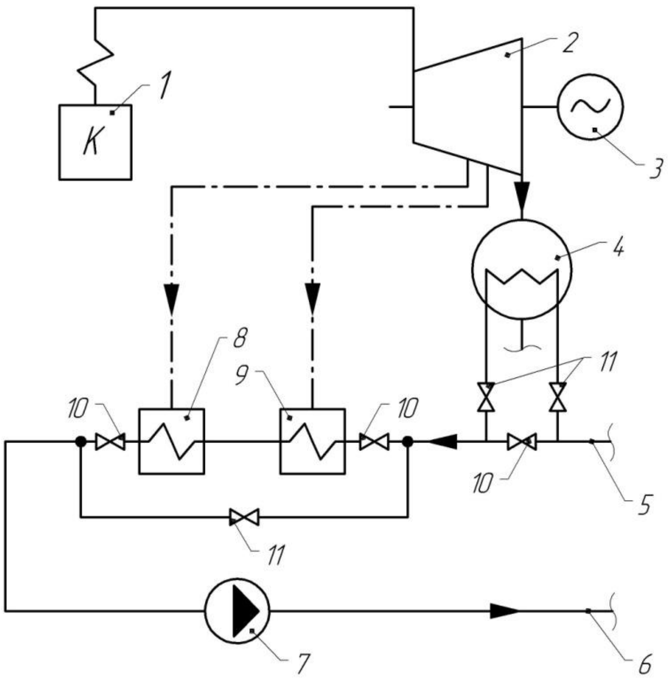

Figure 3. Schematic diagram of heating medium heating at TPP: 1 - boiler installation, 2 - turbine, 3 - generator, 4 - condenser, 5 - return pipe, 6 - supply pipe, 7 - mains pump, 8 - upper mains heater, 9 - lower mains heater, 10, 11 - stop valves.

When the coolant flow returns to TPP (Figure 3), its temperature becomes close to the ambient temperature due to heat gains in the buildings of consumers and through the insulation of heat networks. The relatively low temperature makes it possible to use it as cooling water directly in the condenser of the turbine unit when closing the shut-off valve 10 and opening the valve 11. Also, to reduce the supply high potential heat from turbine extraction, the upper and lower network heaters are disconnected.

The redistribution of steam flows from the network heaters to the condenser will provide consumers with coolant with low potential and eliminate the underproduction of power by turbines.

Transfer of consumers, heating networks and TPP to work with low potential coolant is a global expansion of the «basic» method and can significantly increase the efficiency of district heating by reducing heat losses in the condenser and increasing electricity generation based on heat consumption by reducing the pressure needed for heating. At the same time, this transition for the majority of TPP equipped with cogeneration beams is regime and does not provide for capital expenditures. In the case of CPP, there are relatively small costs for organizing the supply of coolant to the condenser.

The possibility of operating the station without shutting down the network heaters in the event of the likelihood of condensate overcooling is also considered. In this case, the mode of operation of the heating system will be similar to the standard one, but under the condition of low mains water temperature.

Thus, the gradual and controlled implementation of this technological solution will allow you to create energy-efficient systems at minimum cost and without the drawbacks of most foreign and Russian projects. In addition, the unification of plans for the development of heating systems will give impetus to the development of engineering, in particular the industry for the production of heat pump equipment, which in turn will also reduce the total cost of equipment and the entire project as a whole.

4. Assessment of the efficiency of the heat network as a source of low potential heat energy

In order to verify the presented provisions, it is necessary to simulate the heat supply system, which will make it possible to assess the degree of influence of the heat supply system on the efficiency of heat supply. As a prototype for the model, the equipment and heat supply systems of the Chita TPP-1 are adopted.

To determine heat gains in the heating system in a non-heating period based on the general model in ZuluThermo™ An experimental model of a conventional heat network with material characteristics has been created that correspond to the material characteristics of the heat networks of the Chita city, taking into account climatic features (Figure 4).

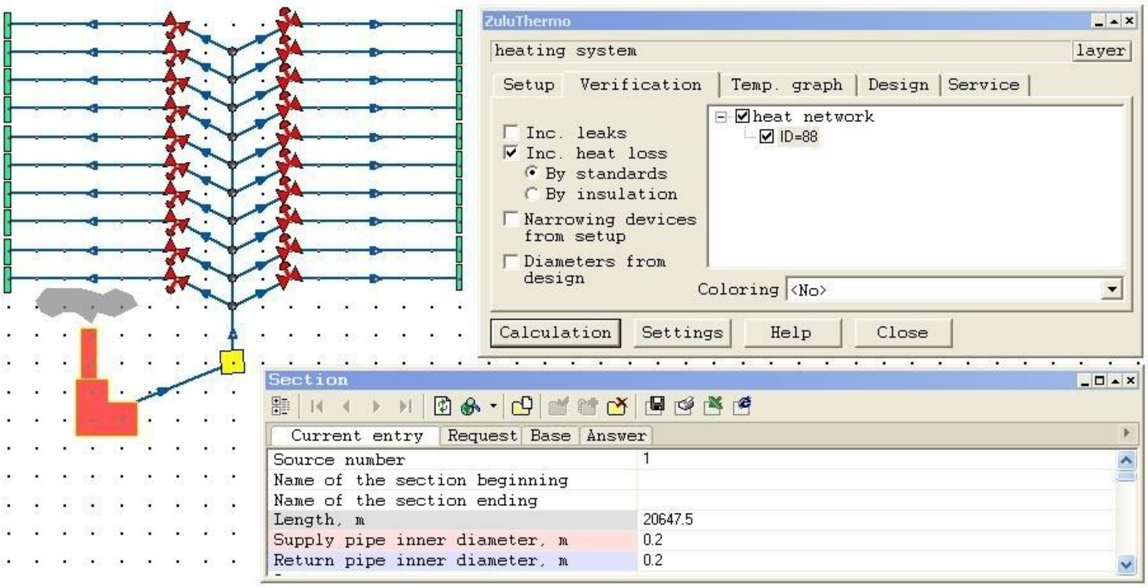

Figure 4. Thermal network topology of the experimental model

In the course of the experiment, the heat network was calculated at the average summer temperature of the soil, and the average summer air temperature for the conditions of the underground and above-ground laying. The following assumptions were made:

- the flow rate for each considered section of the heat network was taken from the condition of maintaining the flow velocity of 1 m/s.
- heat losses from the supply pipe of the heat network were excluded due to the absence of temperature pressure between the coolant and air temperature.
- leaks in the experimental system are not counted.
- thermal insulation for pipelines was calculated according to the norms of heat losses for networks not older than 2003.

According to the calculations, the highest efficiency of heat absorption can be obtained at the lowest possible coolant temperature. Since the heat pump unit is able to provide an inlet temperature of 10 ° C to the heating system, then for further calculations we will accept the heat perception, provided that the coolant temperature is minimal.

Overhead gasket, heat gain 2.27 Gcal/h.

Underground gasket, heat gain 1.8 Gcal/h.

The overall average heat absorption, taking into account the energy efficiency coefficient of the heat network and the heterogeneity of the gasket, was 2.64 Gcal/h.

This value is 2.6% of the total HWS load of the Chita TPP-1.

According to the conducted research, the UCS-HWSL is able to compensate up to 68.8% [18, 20] of the heat load of the TPP in the inter-heating period, taking into account the heat network, this value will be 71.4%.

5. Evaluation of efficiency of TPP after modernization

To obtain technical and economic indicators that determine the efficiency of the TPP-Consumer Complex with a UCS-HWSL and a lowered temperature schedule, you can use the calculation of indicators using the example of the Chita TPP-1 equipment according to the procedure outlined in [5].

In the mode without HPU, the Chita TPP-1 has the following indicators:

The specific consumption of reference fuel for the generation of thermal energy is 161.6 KgCE/Gcal, the specific consumption of reference fuel for the generation of electricity is 314.60 g / (kW•h).

Without modernization, the extremely inefficient COP for most classic projects for the implementation of heat pump units in heating systems will be 4.6.

When transferring the load of selection to the condenser and in the presence of heat gain through the heat network and taking into account the redistribution of power, the extremely inefficient COP of the system being developed was 1.71.

When introduced using the proposed HPU scheme with COP 3.2, we obtain a reduction in the specific consumption of coal equivalent for the generation of thermal energy to 138.4 KgCE /Gcal and a specific consumption of coal equivalent for generation of electric power is 303 g /(kW•h). In absolute terms, the introduction of a combined system with a heat pump system will save up to 28,670 tons of coal equivalent per inter-heating period.

6. Conclusion

1. The maximum effect of the introduction of a HPU may be obtained in the inter-heating period to compensate for the load of the HWS using the HP at the consumer and the transfer of the TPP to the condensation mode. At the same time, the heating system may be cooled below 20 ° C.

2. The most rational use of the development of TbSU with the utilization of excess heat of the premises, thereby providing trigeneration based on a standard heating system using commercially available steam-compression heat pumps.

3. It is possible to obtain the highest efficiency of heat absorption at the lowest possible coolant temperature in the heat network.

4. The overall average thermal perception of heat supply systems at low temperature, taking into account the energy efficiency coefficient of the heat network and the heterogeneity of the gasket, is 2.38 Gcal /h for the TPP under consideration.

5. The proposed system allows to reduce the extremely inefficient COP from 4.6 to 1.7.

6. Modernization of the base heat supply system to the UCS-HWSL with a lowered temperature schedule will improve technical and economic indicators, when using HPU with COP 3.2, the specific consumption of coal equivalent for the generation of thermal energy decreases from 161.6 KgCE /Gcal to 138.4 KgCE/Gcal, and the specific consumption of equivalent fuel for electricity generation from 314.60 g / (kW• h) to 303 g / (kW•h). In absolute terms, the introduction of a combined system will save up to 28,670 tons of coal equivalent per inter-heating period.

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