Improving a heat supply system by increasing the efficiency of the heat pump unit

P V Rotov and R A Gafurov

Ulyanovsk State Technical University, ul. Severnyi Venets 32, Ulyanovsk, 432027
Russia

gafurus@mail.ru

Abstract. The reliability and efficiency of the operation of district heating systems is largely determined by the efficiency of preparation of heating network water. In open heat supply systems, make-up water, among other things, compensates for the water intake in hot water supply systems. A number of technologies have been developed that increase the efficiency of an open heat supply system by reducing the water consumption in the supply pipeline of the heating network, increasing the operating time of the heat pump, and increasing the specific generation of electricity for heat consumption at the CHP plant due to additional cooling of the network water in the return pipe of the heating network.

District heating systems are a set of interconnected devices and equipment that cover most of the heat load of cities and towns. Most domestic heat supply systems operate according to a high-quality heat schedule. Coolant is prepared at a CHP plant, regulated depending on the outside air temperature, and supplied through a pipeline system to the heating and hot water supply systems of to consumers.

Due to the intensive regulation of heat consumption by end users, the efficiency of the heat source can be significantly reduced. The use of heat pumps at intermediate points of the heat supply system makes it possible to compensate for the influence of the operating modes of the heat consumption systems of end users on the efficiency of the thermal power plant.

Scientific and technical studies have shown that low-grade heat sources can be an effective complement to the traditional heat supply system. The heat of return network water can be used as one of such sources of heat [1, 2]. The use of a heat pump installation allows independent heating of water for hot water supply, which makes it possible, first, to provide backup heat supply, if necessary, and second, to increase the radius of effective operation of the heat supply system in cases of insufficient capacity of pipelines of heating networks to remote consumers.

A significant contribution to the development and justification of the use of heat pumps in centralized heat supply systems has been made by the staff of the laboratory of Heat Power Systems and Installations (headed by Prof. V I Sharapov) at the Ulyanovsk State Technical University (USTU [3-6].

A special feature of the developed technologies is the heating of heat network water to the required temperature using a heat pump.

Major advantages of these technologies are reduced cost of heat transport, reduced heat loss in the heat supply system, reduced fuel consumption, and increased electricity generation based on heat consumption.
At the same time, some operating restrictions reduce the energy-saving potential of the technologies. One of these restrictions is the use of return network water only in the transition range of the temperature schedule of the central quality control without a lower break.

A method for improving the operation efficiency of an open heat supply system is proposed. The improved heat supply system is shown schematically in Fig. 1.

**Figure 1.** Open heat supply system: 1 is a heat source; 2 is a supply pipeline; 3 is a return pipeline; 4 is a heat point; 5 are pipelines of the heating system; 6 is a hot water system; 7 is a temperature sensor; 8 is a heat pump; 9 is a condenser; 10 is a vaporizer; 11 is a temperature controller.

A distinctive feature of the new solution is that analysis of water for hot water supply is carried out only for the return pipeline of the heating network.

To determine the effectiveness of this solution, we analyzed the operating modes of the steam compression heat pump installation in the heat supply system for different initial data. Figure 2 schematically shows the heat pump design for which the parameters of the operating points of the heat pump cycle were determined using the Solkane 6.0 software. Ozone-safe R-134a refrigerant is used as the working fluid for the heat pump. The low-grade source of heat is return network water with a temperature of 35–50 °C. In the heat pump, the water for hot water supply is heated to a temperature of 65–70 °C. In the calculation of the heat pump cycle, the electromechanical efficiency of the pump was set equal to 0.95 and the adiabatic efficiency equal to 0.8.

**Figure 2.** Schematic design of the heat pump: C is a condenser; V is a vaporizer; CM is a compressor; TH is a throttle; 1, 2, 3, and 4 are characteristic points of the cycle.
Figure 3. Operating cycle of the heat pump

The analysis and calculation of the heat pump cycles under the specified conditions confirmed the possibility of a stable temperature regime of the refrigerant at points 2 and 3 with a variable refrigerant temperature at point 1.

Figure 3 shows a diagram of the heat pump operation cycle for the following initial data: temperature of the low-grade heat source $t_{gs}=45^\circ C$; temperature of the refrigerant at the outlet of the evaporator $t_1=40^\circ C$.

The efficiency of the developed technology is calculated by the method of specific electricity generation based on thermal consumption [7, 8]. The efficiency of the new technology is estimated by the amount of annual savings of conventional fuel due to an increase in electricity generation based on thermal consumption with an additional decrease in the temperature of the return network water in the heat pump installation.

The initial data for the calculation are: steam capacity of the boiler $500$ t/h; temperature of the network water supplied to the consumer after the network heaters $t_1=77^\circ C$; return water temperature in normal mode $t_2=45^\circ C$; return water temperature taking into account the operation of the heat pump installation $t_{2\text{new}}=40^\circ C$; cost of a ton of conventional fuel 4400 rubles. The calculation used the operating parameters of the turbo stop given in [7].

The thermal power developed by the turbine based on heat consumption due to the upper and lower network selections in the traditional mode $N_{tf}^{\text{trad}}$, MW, is:

$$N_{tf}^{\text{trad}} = (D_{unh}^{\text{trad}} \cdot (i_s - i_{unh}) \cdot \eta_{em}) + (D_{inh}^{\text{trad}} \cdot (i_s - i_{inh}) \cdot \eta_{em})$$

where $i_{unh}$ and $i_{inh}$ are the enthalpies of the hot steam, the pair of upper and lower heaters for heating the network, and make-up water flows; $D_{unh}^{\text{trad}}$ and $D_{inh}^{\text{trad}}$ are the consumptions of steam released from the selections for heating the network water in the upper and lower heaters; $\eta_{em}$ is the electromechanical efficiency.

The thermal power developed by the turbine based on heat consumption due to the upper and lower network selections in the new mode $N_{tf}^{\text{new}}$, MW, is

$$N_{tf}^{\text{new}} = (D_{unh}^{\text{new}} \cdot (i_s - i_{unh}) \cdot \eta_{em}) + (D_{inh}^{\text{new}} \cdot (i_s - i_{inh}) \cdot \eta_{em})$$

The difference in the thermal power developed by the turbine based on heat consumption between the traditional and new methods $\Delta N_{tf}$, MW, is

$$\Delta N_{tf} = N_{tf}^{\text{trad}} - N_{tf}^{\text{new}}$$
The annual savings of conventional fuel from the use of the new solution are

\[ \Delta B = (\Delta N_{tf} \cdot n - N_{comp}) \cdot \Delta b_e \]  

(4)

where \( \Delta b_e \) is the difference in the specific fuel consumption for electricity generation for the condensation and heating cycles; \( N_{comp} \) is the the power developed by the compressor of the heat pump installation; \( n \) is number of days of the heating period.

The savings in monetary terms \( E \), rub, are

\[ E = \Delta B \cdot P \]  

(5)

where \( P \) is the cost of conditional fuel.

Calculation The annual saving of conventional fuel calculated using equations (1–5) is 3425 tons (14.7 million rubles per year), which allows reducing the payback period of the heat pump by at least 2 years compared to previously developed technologies [5, 6].

Technical and economic calculations confirm the sufficient efficiency of the proposed technology.

Conclusions

1. One of the ways to increase the efficiency of centralized heat supply systems is to include in them heat pump installations that use low-grade heat sources and, in particular, the potential of return network water.
2. Technology of hot water preparation using a heat pump that allows the use of a wider temperature range of return network water has been proposed and technically and economically justified.
3. The developed technical solution allows an increase in the life of the heat pump installation, a reduction in water consumption in the supply pipeline of the heat network, an increase in the specific generation of electric energy based on heat consumption at a CHP due to additional cooling of network water in the return pipeline of the heating network, and, hence, a reduction in the payback period of the proposed technology.
4. The annual savings from the use of the proposed technology are more than 14.7 million rubles.

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