Study of the Effectiveness of the Transition from an Open Heat Supply Systems to a Closed One

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Abstract. A promising direction in terms of improving heating networks is the transition from an open heating system to a closed one, which meets modern requirements fixed at the legislative level. However, the effectiveness of such measures is ambiguous. Despite the fact that closed systems maintain high quality water for hot water supply, stable hydraulic mode, automatic regulation of heat supply, their advantages are questioned. At the same time, open systems have significant advantages that, in some cases, give preference to: low corrosion rate of metal in pipelines and equipment due to the use of boiler-quality heat transfer agent that has been processed at a heat source, low cost of ITP, due to the lack of heat exchange devices that increase the cost of thermomechanical equipment, the use of exhaust steam from turbines of thermal power plants and thermal power plants, which increases the efficiency of heat supply. The disadvantage is the low quality of water for hot water supply systems and the need to replenish open heating networks with large volumes of prepared and treated water. A comparative analysis of costs in the transition from an open heating system to a closed one is devoted.

1. Introduction

For a comfortable life activity of the annually growing number of consumers of thermal energy, it is necessary to maintain its quality at a given level by improving heating networks. According to the Federal Law No. 190-ФЗ «On Heat Supply» from 01.01.2020 «... it is not allowed to use open heat supply systems for the needs of hot water supply» [1, 2, 3]. Therefore, consideration of the effectiveness of the transition from an open heating system to a closed one is relevant and necessary.

When considering switching to a closed heat supply system, the following cost reduction options are suggested:

- reduction of the amount of source water for replenishment of the system, which is required only in the presence of leaks, in connection with which a decrease in the required power of the recharge pumps, a decrease in the amount of electricity consumed and, as a result, a reduction in energy costs;
• reduction in the volume of tap water, which must be treated in chemical water treatment devices using heat sources and, as a result, reduced costs for reagents and purification devices, as well as for pumping prepared water.

At the same time, the closed system needs additional costs for the equipment of the hot water supply system connection nodes in individual heating units of consumers, aimed at the use of hot water heating system equipment and additional chemical water treatment plants in the ITP of the consumers due to the fact that they will use unprepared cold water from domestic drinking water supply, which contains a large amount of dissolved oxygen and salts, which, when heated, are released and interact with the inner surface of pipelines and equipment, causing intense internal corrosion.

In open heat supply systems, such make-up water treatment is carried out at heat sources, and consumers receive boiler-quality water, which is not corrosively active.

Comparison is also made according to the magnitude of the coolant flow rates, according to heat supply schemes and other indicators.

2. Analytical methods for determining the costs of preparing make-up water in an open and closed heat supply system

A comparative analysis is carried out on the example of the existing heat network of a district village, supplying thermal energy to a group of buildings for various purposes.

When determining the coolant flow rate in open and closed systems, various dependencies are used, in accordance with [4, 5], formulas (1–4).

– average hourly water consumption for domestic hot water (closed system, parallel circuit), kg/h:

\[
G_{hm} = \frac{3.6 \cdot Q_{hm}}{c(t_1 - t_3)}
\]  

(1)

– maximum water consumption for domestic hot water in a closed system, kg/h:

\[
G_{h\text{max}} = \frac{3.6 \cdot Q_{h\text{max}}}{c(t_1 - t_3)}
\]  

(2)

– hourly average domestic hot water flow, kg/h:

\[
G_{hm} = \frac{3.6 \cdot Q_{hm}}{c(t_h - t_c)}
\]  

(3)

– maximum DHW flow in an open system, kg/h:

\[
G_{h\text{max}} = \frac{3.6 \cdot Q_{h\text{max}}}{c(t_h - t_c)}
\]  

(4)

where \(Q_{hm}\), \(Q_{h\text{max}}\) – average hourly and maximum thermal load on the DHW system, W; \(c\) – specific heat of water, kJ/(kg °C); \(t_1\) – coolant temperature in the supply pipe of the heating network at the break point of the graph, °C; \(t_3\) – coolant temperature after a parallel heating water heater at the break point of the graph, °C; \(t_h\) – hot water temperature in the DHW system, °C; \(t_c\) – cold tap water temperature, °C.

The difference in the obtained values of the coolant flow between an open and a closed system is not more than 10%, therefore there will be no differences in the magnitude of the diameters, wiring diagram, and installed thermomechanical equipment.

It follows that the biggest difference is only the cost of makeup water [4, 5].

According to the recommendations of the normative and reference literature [4–7], the consumption of feed pumps for a closed system is assumed to be equal to the conditional value of leaks, \(G_{\text{leaks}}\), from it, which is defined as 0.25% from the volume of water in the system, m³/h:
\[ G_{\text{ppn}}^{\text{closed}} = G_{\text{leaks}} = 0,00025 \cdot V_s + G_m, \quad (5) \]

where \( V_s \) – volume of water in the heat supply system, \( m^3 \); \( G_m \) – water consumption for filling the largest sectioned section of the system in diameter, is determined depending on the diameter according to table 3 [4].

The volume of water in the system, \( m^3 \), determined by the formula:

\[ V_s = 65 \cdot Q_{\text{heat source}} \]

\[ V_s = 65 \cdot 3,537 = 229,905 \quad m^3 \]

The volume of water is taken equal to 65 \( m^3/MW \) of the calculated heat flow, the flow rate of water to fill with a diameter of 200 mm is 20 \( m^3/h \).

Productivity of feed pumps at a heat source for a closed system, \( m^3/h \):

\[ G_{\text{ppn}}^{\text{closed}} = G_{\text{leaks}} = 0,00025 \cdot 229,905 + 20 = 20,575 \quad m^3/h \]

For an open system, the performance of the feed pumps at the heat source is assumed., \( m^3/h \):

\[ G_{\text{ppn}}^{\text{open}} = G_{\text{leaks}} + G_{h_{\text{max}}} = 0,00025 \cdot V_s + G_{h_{\text{max}}} \quad (7) \]

where \( G_{h_{\text{max}}} \) – maximum heat carrier consumption for hot water supply, \( m^3/h \).

The volume of water in an open system, \( m^3 \), is determined by the formula:

\[ V_s = 70 \cdot Q_{\text{heat source}} \]

\[ V_s = 70 \cdot 3,537 = 247,59 \quad m^3 \]

The volume of water is taken equal to 70 \( m^3/MW \) of the calculated heat flow, according to [4]:

\[ G_{\text{ppn}}^{\text{open}} = G_{\text{leaks}} + G_{h_{\text{max}}} = 0,00025 \cdot 247,59 + 29,484 = 30,103 \quad m^3/h \]

The consumption of PPN pumps for an open system exceeds the consumption of PPN pumps for a closed system by 1.5 times, which has a significant impact on the costs of chemical water treatment of make-up water.

Chemical water purification is necessary to ensure the reliability of the heat supply system, pipelines and equipment [6–11]. The cost of chemical water treatment is 15 rubles/m\(^3\) of deaerated water and depends on the amount of recharge.

The value of the annual cost of chemical water treatment will be, rubles/year:

\[ \text{Cost} = G_{\text{ppn}} \cdot n \cdot 24 \cdot C_{\text{chemical water treatment}} \quad (9) \]

For a closed system:

\[ \text{Cost} = 20,575 \cdot 365 \cdot 24 \cdot 15 = 2,703,555 \quad \text{rubles/year} \]

For an open system:

\[ \text{Cost} = 30,103 \cdot 365 \cdot 24 \cdot 15 = 3,955,534 \quad \text{rubles/year} \]
Table 1. Economic comparison of heat source recharge costs.

| Indicators                          | Units                  | Heating system |
|------------------------------------|------------------------|----------------|
|                                    |                        | open | closed   |
| Annual operating costs for         | million rubles/year    | 3,96 | 2,70     |
| chemical water treatment           |                        |      |          |
| Economic effect                    | million rubles/year    | –    | 1,26     |

Next, you need to consider the installation of equipment in ITP consumers.

3. Analytical methods for determining the costs of ITP equipment

For a closed system, an ITP designed on the basis of Danfoss block heat point (BTP), fully factory-made, is accepted. [5, 12–16]

A local estimate for an open and closed heat supply system was developed. [5, 17–21]

According to local estimates, including the installation of heaters for domestic hot water, thermometers, manometers, water meter assemblies, mud collectors, safety valves, regulators, the costs amounted to about 1,719 thousand rubles. The cost of a similar kit for an open system does not exceed 1,150 thousand rubles.

Table 2. Technical and economic indicators for the equipment of one ITP.

| Indicators      | Units       | Heating system |
|-----------------|-------------|----------------|
|                 |             | open           | closed          |
| Estimated cost  | rubles      | 1 149 733      | 1 718 733       |
| Economic effect | rubles      | 56900          | –               |

Given the equipment of chemical water treatment plants (table 3).

Table 3. Comparison of indicators for open and closed heat supply systems taking into account chemical water treatment equipment.

| Indicators                          | Units                  | Heating system |
|------------------------------------|------------------------|----------------|
|                                    |                        | open | closed   |
| Estimated cost                     | million rubles         | 1,15 | 1,72     |
| Annual chemical water treatment    | million rubles         | 3,96 | 2,70     |
| costs                              | MW                     | 3,537| 3,537    |

4. Conclusion

Comparing the main indicators of open and closed heat supply systems, it was found that:
– the costs of thermal energy and heat carrier, as well as the diameters of pipelines with closed and open circuits are almost the same;
– the main difference is the volume of make-up water and the cost of electricity for pumping it. At the same time, in closed circuits of heat supply systems, the load on chemical water treatment systems located at consumers in the ITP is increasing.

The studies show the need for an individual and comprehensive analysis of each consumer and each heat supply system, taking into account the territorial and economic characteristics and development plans of the heat supply system and heat power industry as a whole.

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