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Analysis of energy-saving measures in industrial steam supply systems

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Abstract. The high level of heat losses in Russia is determined by both the excessive centralization of many heat supply systems and the poor state of heat networks and the low quality of their service. For this reason, the development and application of energy-saving measures to reduce heat loss is a priority and urgent area in the power industry. The article is devoted to the assessment and analysis of energy-saving measures of industrial steam supply systems using the example of an industrial steam pipeline from Smolensk CHPP-1. The study examined the main factors affecting the parameters of the heat transfer agent in the consumer. The main measures to reduce heat losses in steam networks are considered and their calculation is carried out. Of the considered methods of energy saving, it is preferable to increase the thickness of the thermal insulation of steam pipelines. Moreover, the calculations showed that the optimal value of the insulation thickness for the investigated steam pipeline was 0.17 m, which corresponds to the highest quality of the supplied steam and the shortest payback period.

1. Introduction

In most cases, the distribution of heat among consumers, regardless of the equipment used, is carried out with deviations from the standards. This is due to the fact that real heat supply systems differ significantly from the design in terms of the number and characteristics of consumers, characteristics of pumping equipment, pipeline diameters, length of sections, laying methods, routing, etc. All these deviations ultimately lead to a change in the thermal and hydraulic modes of operation of the heating network.

In industrial steam supply systems, the majority of losses are heat losses in steam networks for a number of reasons [1, 2]:

- poor technical condition and maintenance of heating networks;
- violation of thermal insulation;
- disconnecting old or connecting new consumers, as well as changing the heat load required by consumers;
- long service life of pipelines.

These factors lead to a decrease in the reliability of heat supply, a mismatch between the parameters of the heat transfer media and contractual ones, an increase in heat losses, and a decrease in the quality of heat supply as a whole [3]. In this regard, energy-saving measures aimed at reducing heat and coolant losses in steam networks were considered.

2. Materials and Methods

As an object of study, the steam heating system of the city of Smolensk was considered, providing the needs for a few of industrial enterprises [4]. All consumers have a steam technological load. At many enterprises, water vapor is used as a coolant, as well as for heating containers and heat pipes. Most often, water vapor is used as a heat transfer agent. This is due to the fact that during the reverse process of the phase transition of water into steam - condensation, a large amount of energy is released. The obtained energy can be used for heating various media and chemical reactors, for heating rooms, in the food industry, and for heating viscous fluid working in pipelines, which tend to thicken at lower temperatures (fuel oil, various chemicals, oils, etc.). For these reasons, it is especially important that steam is supplied to heat-consuming installations of subscribers with specified contractual values (pressure, temperature). In the winter mode of operation, consumers use steam for technological load, heating and ventilation system, as well as to cover the needs for hot water supply. In summer operation, the heating system does not function while the remaining loads are constant.

The scheme of the steam supply system of the city of Smolensk with the indication of the lengths and diameters of the sections and also the load of consumers is presented in Figure 1.

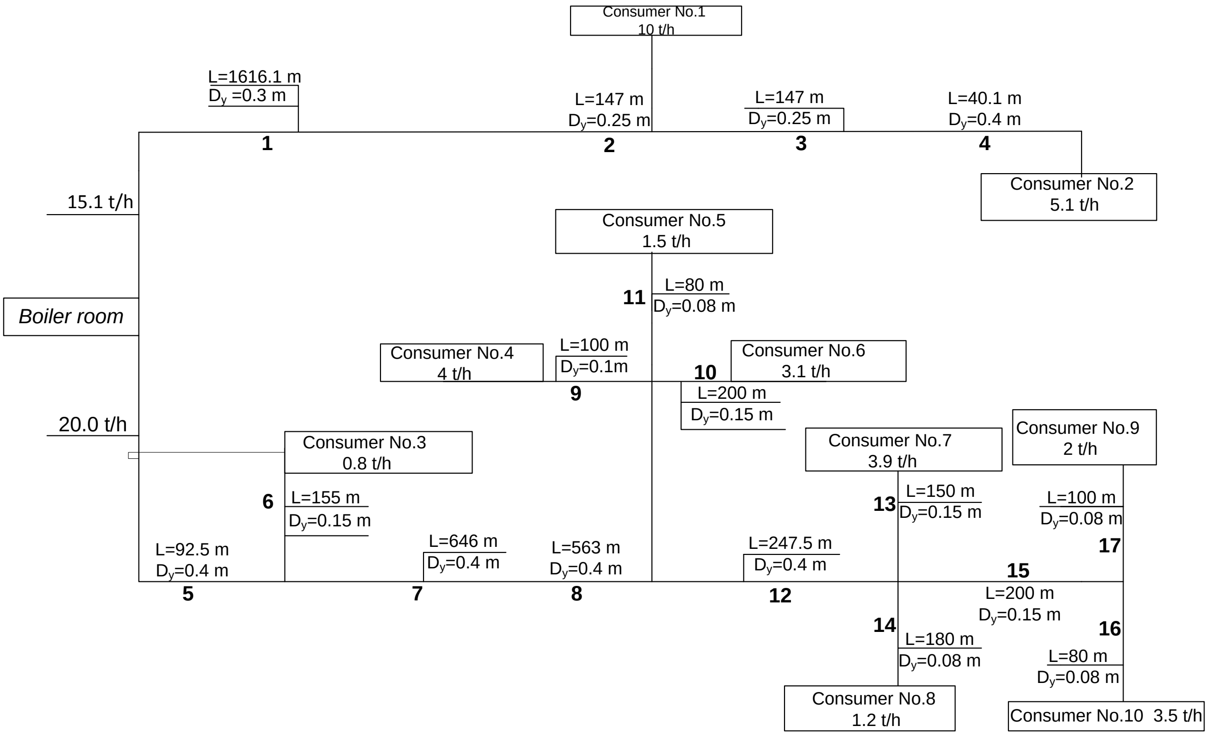

Figure 1. Scheme of connecting heat consumers to Smolensk CHPP-1.

The following were considered as energy-saving measures: changing the diameter of the pipeline and increasing the thickness of the insulation. All calculations in the work are based on thermodynamic dependencies.

The calculation results for the winter period are presented in table 1.

In the winter operating mode, the steam pipeline from the CHPP-1 fully copes with the technological load. Due to the economically feasible speed of the coolant and a large flow speed of steam, all consumers receive a pair of specified parameters, namely superheated. Therefore the implementation of energy-saving measures is possible only with the aim of reducing the total and consequently, specific losses [5]. We choose an arbitrary section of the steam pipeline and compare the efficiency of the applied energy-saving measures.

Table 1. The results of the calculation of heat losses when applying energy-saving measures in winter mode.

Section 9 L = 200 m	Technical design D_y=0.15 m, δ_{ins} =0.12 m .	Diameter change D_y: 0.15 m → 0.1m	The increase in insulation thickness δ_{ins}: 0.12 m → 0.17m	Joint increase in insulation thickness and pipe diameter
Q, W	15851.22	15847.41	13328.19	4161.52
q, W/m	79.26	79.24	66.64	20.81

Thus, the considered energy-saving measures, such as changing the diameter and increasing the thickness of the insulation separately, do not significantly affect the specific losses on the area. However when these parameters change (D_y, δ_{ins}) together, it can be seen that the value of specific losses decreases significantly and amounts to only 26.25% of the losses with the initially specified steam pipeline design. But carrying out these measures requires capital expenditures and may be economically disadvantageous, therefore, it is first necessary to assess whether these measures will be economically justified and appropriate for this project.

In the summer operating mode, despite the high steam parameters, some consumers do not receive the heater of the required parameters [6, 7]. Therefore, the implementation of energy-saving measures in this mode is a necessary.

Similarly, for the summer mode, a section of the steam pipeline was selected and the efficiency of energy-saving measures was calculated (Table 2)

Table 2. The results of the calculation of heat losses when applying energy-saving measures in summer mode.

Section 9 L = 200 m	Technical design D_y=0.15 m, δ_{ins} =0.12 m	Diameter change D_y: 0.15 m → 0.1m	The increase in insulation thickness δ_{ins}: 0.12 m → 0.17m	Joint increase in insulation thickness and pipe diameter
Q, W	15851.22	15847.41	13328.19	4161.52
q, W/m	79.26	79.24	66.64	20.81

Unlike the winter mode increasing the thickness of the insulation at a constant diameter is not the most effective measure to save thermal energy. An increase in the thickness of the thermal insulation layer by 42% gives a decrease in the specific heat loss by only 8%, which shows a low efficiency of the influence of the insulation thickness in the summer mode of operation, while some consumers receive wet steam instead of overheated [8]. In this mode of operation, only a change in the diameter of the pipeline can be performed constructively without changing the thickness of the heat-insulating layer, since the heat losses in these cases are practically equal, and an increase in thermal insulation requires the greatest capital outlay.

Based on the specifics of the object under consideration, of all energy-saving measures, it is only possible to strengthen the thermal insulation of the steam pipe, since the complete rearrangement of the steam network will lead to disruption of the technological process among consumers [9]. Since the network is already existing, it was decided not to change the material of thermal insulation.

For this, the payback period was calculated. The calculation was carried out based on the following conditions:

1) increase in insulation thickness from 0.12 to 0.17 m;

2) the calculation was carried out for the branches of the steam pipeline, in which the steam comes to consumers wet.

The following data were taken as initial data:

The insulation material is mineral wool.

The cost of 1 m^3 of insulation (C_{ins}) is 1470 rubles.

We will calculate for section No. 5, L = 92.5 m, D_y = 0.4 m, δ_w = 0.008 m.

The amount of insulation required is calculated by the following formula:

$$V_{ins} = L \cdot \pi \cdot (D_{o.ins} - D_{i.ins}), m^3 \quad (1)$$

where $D_{o.ins}$ – the outer diameter of the pipeline with a final insulation thickness, m;
δ_w – wall thickness, m;
$D_{i.ins}$ – the inner diameter of the pipeline with the initial insulation thickness, m.

Since there is an increase in the thickness of the pipe wall insulation by 0.05 m, it can be assumed that the value ($D_{o.ins} - D_{i.ins}$) = 0.1 m, and it remains constant in all sections of the steam pipeline.

The cost of this volume of insulating material is calculated as:

$$C = V_{ins} \cdot C_{ins}, \text{rubles} \quad (2)$$

The calculation results are presented in table. 3.

Table 3. Cost calculation increased thermal insulation.

No. section	Length section, m	Insulation volume, m^3	Cost, rubles
5	92.5	29.1	42696
6	155	48.7	71589
7	646	202.8	298181
8	563	176.8	259896
9	100	31.4	46158
10	200	62.8	92316
11	80	25.1	92316
12	274.5	86.2	126714
13	150	47.1	69237
15	200	62.8	92316
17	100	31.4	46158
TOTAL:		**804.2**	**1 182 158**

The final cost of this event will consist of the cost of material C_m and the costs of the work C_w (design, installation, commissioning, etc.). We accept that the cost of such work is about 150% of the cost of the material.

Then, the cost of increasing thermal insulation by 0.05 m will be equal to:

$$C = C_m + C_w, \text{rubles} \quad (3)$$

$$C = 1\,182\,158 + 1.5 \cdot 1\,182\,158 = 2\,955\,395 \text{ rubles.}$$

Determine the heat loss from the steam pipe with increased thermal insulation.

We accept that the duration of the heating period (winter mode) is 210 days and summer - 155: heat loss during insulation 0.12 m

$$Q = (558642.6 \cdot 24 \cdot 210 \cdot 3600 + 269273.8 \cdot 24 \cdot 155 \cdot 3600) / 10^6 = 13\,742\,126 \text{ MJ;}$$

heat loss during insulation 0.17 m

$$Q = (494351.8 \cdot 24 \cdot 210 + 243815 \cdot 24 \cdot 155) / 10^6 = 3398.5 \text{ MW}.$$

To calculate the heat savings, we translate these values in Gcal / h.

$$Q_{0.12} = 3282.1 \text{ Gcal / h}; Q_{0.17} = 2919.0 \text{ Gcal / h}.$$

With an average cost of 1 Gcal = 1485.5 rubles. It was found that heat saving with an increase in the thickness of the pipeline insulation is 363.1 Gcal / h or in the price equivalent of 539385.1 rubles per year. During the work of Smolensk CHPP-1, we get that the payback period for such an energy-saving event is about 2.2 years. Thus, this event can be recommended as energy-saving [10].

3. Results

Despite the fact that heat losses are actually reduced by 13%, final consumers (2 out of 8) still do not receive steam of specified parameters. Below are the calculations for heat saving with an increase in insulation thickness by 0.1 m (Table 4).

Table 4. Comparison of the effectiveness and economic feasibility of increasing the thickness of the insulation.

Insulation layer thickness δ_{ins}, m		Construction insulation 0.12	Insulation thickness 0.17	0.22
Heat loss Q, GJ	Summer mode	3 606.11	3 165.00	2 978.50
	Winter mode	10 136.01	8 087.45	7 444.97
TOTAL	**GJ:**	13 742.12	11 252.45	10 423.47
	Gcal:	3 279.74	2 685.55	2 487.71
Reduced heat loss compared to factory insulation, %			18.2	24.1
Heat saving while increasing insulation, Gcal/year			594.2	792.0
Annual savings by reducing heat loss, rubles			882 684.1	1 176 516
Cost of energy-saving measures, rubles			2 955 395	5 910 790
Payback on energy-saving measures, years			3.4	5.0
The number of consumers receiving pairs of specified parameters			6/8	7/8

The calculations presented in the table allow us to conclude that an increase in thermal insulation over 0.17 m is an economically and technically disadvantageous measure. Annual heat loss is reduced by only 5.9%, and the cost of increasing thermal insulation to 0.22 m compared to increasing thickness to 0.17 m is 200%.

Despite the fact that the payback period of each considered energy-saving measure does not exceed 5 years, an increase in the thickness of thermal insulation to 0.17 m should be recognized as optimal.

In order to determine the optimal value of the thermal insulation thickness, a graphical dependence of the heat loss on the increase in the insulation thickness was constructed, which is shown in Fig. 2 [11].

Each step of increasing the selected insulation is 0.05 m, since it is this value that corresponds to the standard value presented by manufacturers on the market.

The obtained dependence suggests that an increase in the thickness of the thermal insulation of the pipeline has its limits. For each pipeline diameter and steam parameters, there is an extremely effective insulation thickness exceeding which will entail only material costs with a constant value of losses. For the considered section, the calculations show that with an insulation thickness of 0.22

m or more, the magnitude of the heat loss will be constant. The research results show that only with a comprehensive solution is it possible to achieve the maximum energy-saving effect.

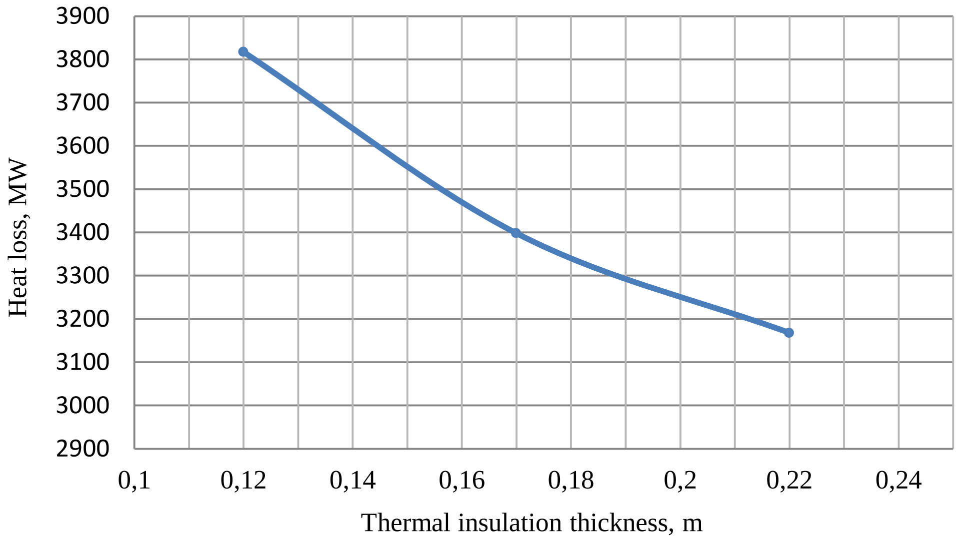

Figure 2. The dependence of heat loss on the thickness of the insulating material.

From the analysis of the calculations, it follows that the increase in the insulation thickness to 0.17 m should be recognized as optimal, since a further increase in the insulation thickness leads to an extension of the payback period of the event with a slight increase in the quality of the steam received by consumers [12].

4. Discussion

The steam parameters at the consumer are determined by the following factors:

1. Steam parameters at the source (pressure, temperature);
2. The operation mode of the steam pipe (design / non-design mode);
3. The state of thermal insulation of the steam pipe (material of thermal insulation, degree of deterioration).

In the course of the study, it was revealed that the final parameters of steam at the consumer in some modes of operation of the steam pipeline cannot correspond to the contractual values even when the steam parameters at the heat source increase [13, 14]. Given all these factors, it is necessary to increase the thermal resistance of thermal insulation relative to the standard value recommended by technical and regulatory bases.

5. Conclusion

Energy saving in the energy system is the application of a number of energy-saving solutions and measures at the levels of receipt, transportation and use of thermal energy. Heating networks are the most important and at the same time the most vulnerable part of the heat supply system. Industrial steam supply systems are an important part of the heat supply scheme of each of the cities of Russia. However, due to the economic and political situation, the load on thermal energy in the form of steam decreased, which led to the emergence of such a mode of operation of steam pipelines as non-project mode. Consumers ceased to receive pairs of specified parameters, which in turn leads to a violation of the process and entails a decrease in the quality of products. That is why industrial steam supply systems require careful study and research. The study examined energy-saving measures when transporting thermal energy in the form of steam

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For industrial steam networks 2 energy-saving measures aimed at increasing the parameters of steam at consumers were considered:

1) increase in insulation thickness;

2) ensuring the movement of steam at an economical speed.

Of the considered methods of energy saving, it is preferable to increase the thickness of the thermal insulation of steam pipelines [15]. Moreover, the calculations showed that the optimal value of the insulation thickness for the investigated steam pipeline was 0.17 m, which corresponds to the highest quality of the supplied steam and the shortest payback period.

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