Mathematical modeling of the process of determining the standards for process losses in the transfer of thermal energy of the coolant

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Abstract. Currently the actual problem is a precise definition of the normative and actual heat loss. Existing methods - experimental, on metering devices, on the basis of mathematical modeling methods are not without drawbacks. Heat losses establishing during the heat carrier transport has an impact on the tariff structure of heat supply organizations. This quantity determination also promotes proper choice of main and auxiliary equipment power, temperature chart of heat supply networks, as well as the heating system structure choice with the decentralization. Calculation of actual heat loss and their comparison with standard values justifies the performance of works on improvement of the heat networks with the replacement of piping or its insulation. To determine the cause of discrepancies between normative and actual heat losses thermal tests on the magnitude of the actual heat losses in the 124 sections of heat networks in Kazan. As were carried out the result mathematical model of the regulatory definition of heat losses is developed and tested. This model differ from differs the existing according the piping insulation type. The application of this factor will bring the value of calculative normative losses heat energy to their actual value. It is of great importance for enterprises operating distribution networks and because of the conditions of their configuration and extensions do not have the technical ability to produce thermal testing.

Introduction
Over a long period of time, heat supply in Russia developed on the basis of combined energy production (heat and electricity). The result is the district heating predominance. The main load for thermal energy in large and medium-sized cities is carried by the CHP [1]. According to the data of [2] almost 72% of the heat energy from the total volume produced in Russia is generated at the CHPP. Combined generation of electrical and thermal energy is an economically more profitable way. However, the mass cogeneration process led to large-scale construction of extended and ramified heating networks [3].

1. The problem of determining thermal losses
The Russian heat supply infrastructure needs a global improvement. The level of losses in the country's heating networks reaches 20-30% [4] (Figure 1), which is approximately four times higher than in Europe (4-8% [5]).
In Russia, there are a large number of governmental and industry acts regulating the country’s the heat supply, however, they are not without shortcomings.

There are three methods for heat losses evaluation.

The first method [6-11] is the determination of losses based on experimental data. Undoubtedly, this method is the most reliable, but in practice it is not always possible to perform tests because of the difficulty of the necessary experimental requirements fulfilling [9]: consumers detachment from the tested ring, temperature provision with a drop of at least 8 °C, constant maintenance of the flow regime during the test. Therefore, this method of heat losses determining is used extremely rarely and, mainly, on trunk heat pipes, while heat losses occurring in distribution networks have a greater specific weight [14].

The second method of heat losses determination is to remove the indicators for metering devices from the consumer. Several methods have been developed for this method [12-16]. However, according to the difference between the released thermal energy and fixed at the consumer, it is possible to estimate only the average losses along the heating main. This method does not allow to establish losses on a particular section of the heat network. This method does not represent practical interest, since it does not allow to identify the section of the heat pipe with the greatest losses.

The third method of thermal losses determination is based on the method of mathematical modeling of specific losses of thermal energy, when a its properties change occurs during the thermal insulation using [17-25]. However, the results of studies [26] showed that the increase in thermal losses is not affected by the problem of moisture insulation, as described in [17-25], but insulation faults associated with its physical degradation and integrity damage of the insulation layer.

Thus, today there is no universal method of heat losses establishment. But this task is one of the most important, since the establishment of heat loss during the coolant transportation affects the structure of the tariff for heat supply organizations. This value understanding also contributes to the correct selection of the main and auxiliary equipment power, the thermal schedule of the heating networks, and the choice of the heat supply system structure, with its possible decentralization. Determination of actual heat losses and their comparison with normative values justifies the effectiveness of carrying out works to improve heat networks with the replacement of pipelines or their insulation.

However, the greatest interest from our point of view is the definition of normative losses, since this value affects the size of the heat supply organization tariff. Today, the methodology of normative losses determination is regulated by the Order of the Ministry of Energy No. 325 of 30.12.2008 «On...
approval of the procedure for technological losses standard determination in the heat energy transfer coolant».

Normative values of technological losses during the heat transfer must be determined for each heat supply organization in an individual order. The definition of standards is realized by calculation performance for the heat supply system.

An analysis of the methodology for indicator finding of losses in the thermal energy transfer, coolant showed that it does not take into account some important features, such as the type of insulation and its thickness.

2. Experimental research

Thermal tests were conducted using the example of heat networks in Kazan. As a result of the tests, thermal losses were determined for each of the test ring sections, and separately for the supply and return pipelines. Calculations of the thermal energy actual losses in the tested sections of the heat network were made.

For comparison with the normative values, the heat losses results for each tested section were recalculated into average annual operating conditions of the heat network.

In the standard heat losses calculation, a factor was introduced that takes into account the value of thermal losses for a thermal insulation specific type for new pipelines:

$$Q_u = \sum_{i=1}^{n} k_{i} \cdot (k_{i} \cdot q_{i} \cdot L_{i} \cdot \beta_{i}) \cdot 10^{-6},$$

where $k_{i}$ - a coefficient that takes into account the type of insulation (mineral wadding, basalt, polyurethane foam, tilith, etc.).

In Table. 1 there are shown the values of the actual heat losses and the normative values given to the average annual operating conditions of the heat network as a result of thermal tests.

The conducted experiments made it possible to establish that the actual heat losses differ from the standard values even for new, newly laid pipelines, and the magnitude and the deviation sign depend on the used of thermal insulation type (Figure 2).

![Figure 2. The ratio of actual and standard heat losses for different types of insulation for new heating networks](image)

Thus, a mathematical model for the standard heat losses determination has been developed and tested, which differs from existing ones taking into account the type of pipelines insulation. This coefficient using will make it possible to approximate the value of the calculated standard thermal energy losses to their actual value. This is of great importance for enterprises operating distribution
networks and because of their configuration conditions and lengths it has no technical capability to perform thermal tests.

3. Results of the experiment

A block diagram of the calculation program and a list of used the initial data are shown in Tab. 1 and Fig. 3.

**Table 1.** Actual and standard losses comparison

| №  | Network section                                                                 | Type of gasket                          | Year of laying | Qф ср.г | Qн ср.г | K1   |
|----|---------------------------------------------------------------------------------|----------------------------------------|----------------|---------|---------|------|
| 1  | Boiler room Zalesnaya,1B-Thermal chamber-5                                       | Overground (polyurethane foam)          | 2004           | 0,00470 | 0,00710 | 0,66 |
| 2  | Thermal chamber-5 - Thermal chamber-4                                            | Underground (polyurethane foam)         | 2004           | 0,00224 | 0,00340 | 0,66 |
| 3  | Thermal chamber-4 - Thermal chamber-8                                            | Underground (polyurethane foam)         | 2014           | 0,00221 | 0,00340 | 0,65 |
| 4  | Thermal chamber-8 - garage                                                       | Overground (mineral wadding)            | 1995           | 0,03170 | 0,02330 | 1,36 |
| 5  | Garage - Diameter transfer                                                        | Overground (basalt)                     | 1989           | 0,03510 | 0,03000 | 1,17 |
| 6  | Diameter transfer - Thermal chamber-12                                            | Overground (tilith)                     | 2015           | 0,00183 | 0,00250 | 0,73 |
| 7  | Central heating station - 3 (Boiler room Privokzalnaya) - Railway Privokzalnaya, 10 | Underground (mineral wadding)           | 2014           | 0,00354 | 0,00310 | 1,14 |
| 8  | Railway Privokzalnaya, 10 - Diameter transfer on 133 mm                           | Underground (mineral wadding)           | 2014           | 0,00307 | 0,00270 | 1,14 |
| 9  | Diameter transfer - Railway Privokzalnaya, 18                                    | Overground (basalt)                     | 2014           | 0,02370 | 0,02220 | 1,07 |
| 10 | Central heating station - Zur-Uram, 4A - Thermal chamber-22(sm)                   | Underground (polyurethane foam)         | 2014           | 0,00440 | 0,00673 | 0,65 |
| 11 | Thermal chamber-22(sm) - before the turn of the road                               | Overground (mineral wadding)            | 1989           | 0,01590 | 0,01167 | 1,36 |
| 12 | The turn of the road - Thermal chamber Railway Second Azinskaya str, 3a           | Underground (tilith)                    | 2014           | 0,00930 | 0,01280 | 0,73 |
| 13 | Boiler room – Thermal chamber-10                                                 | Underground (mineral wadding)           | 2004           | 0,01460 | 0,01111 | 1,31 |
| 14 | Thermal chamber-10 - Thermal chamber-19                                           | Underground (mineral wadding)           | 1989           | 0,11280 | 0,08060 | 1,40 |
| 15 | Thermal chamber-19 - ул.Красикова, 5/34                                         | Underground (mineral wadding)           | 2014           | 0,00950 | 0,00835 | 1,14 |
| 16 | Krasikova str, 5/34- Thermal chamber-24                                            | Underground (mineral wadding)           | 2011           | 0,00199 | 0,00170 | 1,17 |
| 17 | Thermal chamber-24 - Thermal chamber-30                                          | Underground (mineral wadding)           | 2011           | 0,02000 | 0,01712 | 1,17 |
| 18 | Thermal chamber-30 - Thermal chamber-36a                                         | Underground (polyurethane foam)         | 2014           | 0,00890 | 0,01370 | 0,65 |
Figure 3. The program block diagram for heat losses calculations.
As a test of the proposed model, the standard heat losses calculation for the boiler Vysotnaya, 30 was carried out. For this boiler, thermal tests were not performed. Calculation of the standard thermal losses is carried out taking into account the coefficients accounting for the types of thermal insulation. A comparative analysis of computational studies using the existing methodology of the Order of the Energy Ministry of the Russian Federation No. 325 of December 30, 2008 and developed by us, is presented in Table 2.

| Table 2. Heat losses (boiler room Vysotnaya, 30, Kazan) |
|--------------------------------------------------------|
| **Normative losses according to the existing methodology, Gcal** | **Normative losses according to the existing methodology, recalculated for actual conditions of the year, Gcal** | **Actual losses according to instruments, Gcal** | **Standard losses by the proposed method, Gcal** |
| 4 495,48 | 3 302 | 5 168 | 5 220,4 |

4. Conclusions
The obtained results show that the boiler house standard thermal losses differ from the actual values by 36%. This is due to the fact that polyurethane foam is mainly used as thermal insulation in these areas. In case of using mineral wadding, the discrepancy would not be so significant. Since the tariff for thermal energy depends on the amount of normative losses, in the example of a boiler-house Vysotnaya, 30 it can be seen that this boiler-house did not receive a significant part of the money resources.

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References
[1] Semenov B A and Khomyakova O P 2006 Technical and economic optimization of thermal protection of external pipelines of heating networks Problems of Energy 3-4 61 - 71
[2] Melnikova M P 2010 Heat supply of Russia: state and prospects of development ESCO 3 (URL: http://esco-ecosys.narod.ru/ (reference date: 20.03.2011))
[3] Bukhin V E 2002 Pre-insulated pipelines for district heating systems Heat Power Engineering 4 24 - 29
[4] Strategy for improving the energy efficiency of the municipal infrastructure of the Russian Federation 2010 Russian Heat Supply 308.
[5] Shishkin A N 2010 On the Draft Federal Law «On Heat Supply» Heat Supply News 6 20-24
[6] Safonov A P and Shubin E P 1954 Determination of heat losses in operating thermal networks Teploenergetika 5 8-14
[7] Dayan A, Merbaum A N and Segal I 2010 Temperature distributions around a buried network in the soil with a temperature dependent thermal conductivity International Journal of Heat and Mass Transfer 1 409-417
[8] Methodological guidelines for the compilation of energy characteristics for thermal energy transport systems in terms of the "heat loss" index, Part 3: RD 153-34.20.523-2003.M .: SPR ORGRES 2003 28
[9] Methodical guidelines for determining heat losses in water heating networks: RD 34.09.255-97.M .: SPO ORGRES 1988 18
[10] Chernysh C B Research and forecasting of thermal losses of underground heating mains: Dis .... kand. Candidate of Technical Sciences: 05.23.03 - Rostov-on-Don, 2000.- 165 pp. Bibliography: p. 125 - 139.
[11] Shavandrin A M, Solomatin V P and Gladinova G I 1989 To the problem of determining heat losses in operating thermal networks Izvestiya VUZov. Power Engineering 5 70-73.
[12] Semenov V G 2003 Determination of actual heat losses through thermal insulation in the networks of district heating Heat supply news 4 30-33
[13] Gudzyuk B P and Shomov E V 2010 Rapid assessment of actual heat losses during transport of steam and hot water Heat supply news 11 30-33
[14] Baibakov S A 2010 To the question of methods and problems of determining actual heat losses in heat networks Heat supply news News of heat supply 6 36-39
[15] Khomchenkov V G, Ivanov G V and Khromchenkova E V 2006 Determination of heat losses in heat networks Heat supply news 6 36-39
[16] Baibakov S A and Timoshkin A C 2009 Methods for determining and estimating actual losses through insulation in water networks of district heating systems without disconnecting consumers Heat supply news 5 38-44
[17] Ivanov V V, Bukarov N V and Vasilenko V V 2002 Influence of humidification of insulation and soil on heat losses of underground heating mains Heat supply news 7 (23) 32-33
[18] Ivanov V V and Vershinin L B 1998 Distribution of temperatures and heat fluxes in the area of heating mains laying The Second Russian National Conference on Thermal conductivity, thermal insulation Heat 7 103-105
[19] Ivanov V V and Shkrebko S V 1998 Modeling of thermal processes of underground non-channel heating mains The Second Russian National Conference on Thermal conductivity, thermal insulation Heat 7 106 108
[20] Kuznetsov G V and Polovnikov V Yu 2006 Estimation of the scale of heat losses in the main heat-pipe lines under flooding conditions Industrial Power Engineering 8 32-34
[21] Kuznetsov G V and Polovnikov V Yu 2009 Analysis of heat losses of heat pipes in conditions of interaction with moist air Energy saving and water treatment 2 37-40
[22] Polovnikov V Yu Mathematical modeling of thermal conditions of heat-pipe lines in the conditions of moisture moistening: Dis .... kand. Cand. those. Sciences: 05.14.04.-It is protected 25.12.2006.-Tomsk: B.I., 2006, - 122 pp. Bibliography: p. 112-122
[23] Kuznetsov G V and Polovnikov V Yu 2008 Numerical Analysis of Heat Losses by Main Heat Pipelines in Conditions of Full or Partial Flooding Engineering and Physics Journal 2 303-311
[24] Kuznetsov G V and Polovnikov V Yu 2006 Thermal losses of main pipelines under conditions of full or partial flooding Proceedings of higher educational institutions: Problems of energy 3-4 3-12
[25] Kuznetsov G V and Polovnikov V Yu 2008 Numerical simulation of the pipeline thermal state under flooding conditions, taking into account the nonstationarity of the process of saturation of insulation with moisture Teploenergetika 5 60-64
[26] Kuznetsov V G, Ozeraeva I P, Polovnikov V Yu and Tsyganova Yu S 2011 Evaluation of the change in thermal insulation properties of insulation in the process of operation of heat networks Increasing the efficiency of power equipment 1 284 - 289