Analysis of the issue of the selection, operation and improvement of thermal insulation materials for pipelines of heating networks

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Abstract. Improving the energy efficiency of thermal energy generation, transportation and consumption systems is one of the priority tasks of the modern development of the fuel and energy complex of Russia. The climatic conditions of Russia determine the heat supply systems as an energy-intensive industry that consumes up to 40% of the primary energy resources of country. Russia is characterized by a high level of centralized heat supply, mainly from sources of combined generation of heat and electric energy, which led to the creation of an extensive pipeline system with a length of more than 250 thousand km with a diameter of 57 to 1400 mm. In practice, the following methods of laying pipelines are used: canal, canal-free, aboveground. The heat losses of pipelines of thermal networks amount to 324 million gcal/year, which is approximately 16% of the heat released to consumers, this indicates significant reserves of saving thermal energy. The successful solution of the problem of reducing heat losses during the transportation of the heat transfer agent can be achieved by using modern materials and developing highly efficient porous thermal insulation structures, as well as improving the methods of calculating heat networks and the optimal choice of thermal insulation materials for the required operating conditions.

1. Introduction

A number of requirements set out in legislative acts are imposed on thermal insulation materials for pipelines of heating networks [1-11]. In accordance with [11], when choosing thermal insulation products, it is necessary to take into account the factors affecting the performance of the thermal insulation structure and its applicability for the pipeline of the heat network.

Depending on the method of laying, there are requirements for the density of thermal insulation materials, so in accordance with [1] for pipelines of heating networks, with the exception of canal-free laying, it is necessary to use materials with a density of no more than 200 kg/m³.
In recent years, a huge variety of modern thermal insulation materials has appeared on the domestic market, and therefore there has been a sharp breakthrough in the field of energy saving. With the development of new technologies, existing thermal insulation products have become more efficient, environmentally friendly, diverse and meet the technical requirements of a specific industry [1,2].

The authors [3, 4, 5] considered the calculations of the thickness of the thermal insulation material, the materials used for thermal insulation of industrial pipelines, their advantages and disadvantages are given.

2. Materials and methods

One of the most common materials for pipelines of thermal networks is wired mats based on basalt and stone rocks. To give the mats strength, one side of a mat is reinforced with a mesh of galvanized or stainless wire. The mats are fixed using welded pins, bandages or knitting wire [12-13]. Stone wool is a chemically neutral material and it can be used in combination with many types of products that are used for thermal insulation of pipelines of heating networks.

In order to reduce the time of installation work, thermal insulation cylinders have been developed, which can be conditionally divided into two types: cut-out and wound. Each of the cylinders has its own disadvantages and advantages.

Thus, cut-out cylinders are less expensive in comparison with wound cylinders, but at the same time, pipes with a diameter of more than 89 mm are made of segments, which complicates installation work and leads to their rise in price. As it stated in the works [8-10] cut-out cylinders have an uneven thermal conductivity along the circumference associated with the technology of its manufacture.

Wound cylinders have a more uniform distribution of thermal conductivity, since the porous structure is homogeneous along the entire circumference of the cylinder.

The hydrophobized wound cylinders are made on a synthetic binder and they are hollow products that are made of stone wool based on the geologic material of basalt group. The products can be produced with an aluminum foil coating.

The cylinders have a continuous longitudinal section on one side and a corresponding incision from the inside on the opposite side for easy installation on the pipeline. The plane in which the cut and incision lines lie passes through the axis of the cylinder.

The cylinders have a high rigidity, which makes it possible to dispense with the installation of support and unloading elements, thereby to minimize the number of thermal bridges and to significantly increase the installation speed.

Recently, elastic products with a closed cellular structure made of foamed synthetic rubber, characterized by a long service life and resistance to high temperatures and ultraviolet rays, have appeared on the market of thermal insulation materials. The prospects for the use of this type of thermal insulation are described in [11-12].

Thermal insulation materials based on polyurethane foam shells are rigid porous cylinders, semicylinders or segments. They are produced with a diameter of 18 mm and an insulation thickness of 25 mm. They have longitudinal and transverse thermal locks that exclude direct heat leaks at the joints and improve the adhesion of the segments to each other.

Polyurethane foam shells have high thermal resistance, but at the same time they have a significant disadvantage – they are destroyed under the influence of ultraviolet radiation.

The universal thermal insulation product (STR) is a segmental structure based on fibrous thermal insulation materials (mineral wool) with high pre-installation readiness. Fiber insulators in each segment are installed with fibers that are perpendicular to the insulated surface, which allows to reduce the penetration of the thermal insulation structure, thus giving it rigidity.

The fiberglass, or aluminum foil coated on fiberglass are used as a cover layer. In the interval between the layers, mineral wool is segmented by fiberglass partitions, which allows the main thermal insulation material to be fragmented, ensuring its stability to dumping when placed on the pipeline. In this case, the segments take a trapezoidal shape with a decrease in the density of the thermal insulation material as they move away from the heat-insulated surface of the pipeline. The STR can be equipped with any
waterproofing material. Recently, this thermal insulation material has been widely used in heating networks due to the ease of installation in comparison with thermal insulation mats [13].

3. Results
Determining the actual heat losses is an actual task of the heat supply industry, since organizations engaged in the transportation of heat energy in Russia, without knowing the actual heat losses, apply certain regulatory characteristics [14]. So at present, to determine heat losses through the insulation of pipelines of thermal networks, normative and technical documents are used [15-16] according to which all calculations are reduced to determining the thickness of the thermal insulation structure through the norms of density of heat flux corresponding to the specific diameter of the pipeline of the thermal network and the type of its laying. The norms of density of heat flux for a cylindrical surface with a nominal diameter of 1400 mm or less, \( q_t^{reg} \), are determined by the formula (1):

\[
q_t^{reg} = q_t k
\]

where \( q_t \) is the specific normalized linear density of the heat flow, W/m, is taken from the tabular data [1];

\( k \) is a coefficient that takes into account the change in the cost of heat and thermal insulation construction depending on the construction area and the method of laying the pipeline.

The applied experimental estimates of heat losses in practice are carried out by [17] according to the formula (2):

\[
Q_i = \sum_{aboveground} (q_{a.s.i.} + q_{a.r.i.}) \cdot \beta \cdot l + \sum_{underground} q_{n.t.} \cdot \beta \cdot l
\]

where \( \beta \) is the coefficient of local losses, which takes into account heat losses in fittings, supports and compensators. It is accepted according to regulatory documents;

\( q_{n.t.} \) is the value of specific heat losses of this heat network for each diameter of underground laying pipes at the temperature test mode, kcal/(m·h);

\( q_{a.s.i.} \) and \( q_{a.r.i.} \) are the values of the specific heat losses of this heat network, respectively, along the supply and return pipelines for each diameter of the pipes of the aboveground laying at the temperature test mode, kcal/(m·h).

The values of specific heat losses for underground and aboveground laying are determined based on the norms of heat losses at the temperature regime in the circulation ring during tests according to the formulas (3-5), W/m or kcal/(m·h):

\[
q_{u.i.} = q_{n} \cdot \frac{\tau_{air,i}^{av} + \tau_{r,i}^{av} - 2 \tau_{boar,i}^{av}}{\tau_{air,i}^{av} + \tau_{r,i}^{av} - 2 \tau_{boar,i}^{av}}
\]

(3)

\[
q_{a.s.i.} = q_{a.s} \cdot \frac{\tau_{air,i}^{av} - \tau_{s,i}^{av}}{\tau_{air,i}^{av} - \tau_{s,i}^{av}}
\]

(4)

\[
q_{a.r.i.} = q_{a.r} \cdot \frac{\tau_{r,i}^{av} - \tau_{air,i}^{av}}{\tau_{r,i}^{av} - \tau_{air,i}^{av}}
\]

(5)

The values \( q_n \), \( q_{a.s} \) and \( q_{a.r} \) are accepted by the norms of heat flux density according to the requirements of [16].

The values of specific heat losses at temperatures that differ from the standard ones are determined by the method of linear interpolation.

The average water temperatures during the test mode, respectively, in the supply and return pipelines of the tested ring are determined by the formulas (6-7), °C:

\[
t_{s,i}^{av} = \frac{\Delta t_i}{4} + \frac{t_{s,i}^{env} + t_{r,i}^{env}}{2} + \frac{\Delta t_i}{4} + t_{s,i}^{env} - t_{s,i}^{av}
\]

(6)

\[
t_{r,i}^{av} = \frac{\Delta t_i}{4} + \frac{t_{s,i}^{env} + t_{r,i}^{env}}{2} - \frac{\Delta t_i}{4} + t_{r,i}^{env} - t_{r,i}^{av}
\]

(7)
The calculated water flow rate in the circulation ring, that is assigned for the test time, is determined by the formula (8), t / h:

$$G_i = \frac{Q_i}{c \Delta t_i} \cdot 10^{-3}$$  

(8)

where $c$ is the specific heat capacity of the mains water, it is assumed to be equal to 1.0 kcal/(kg · °C)

The value of the supply of the heat network during the tests is assumed to be equal to 0.5% of the total capacity of the pipelines within the tested circulation ring.

To obtain the required minimum temperature difference of 8°C, the length of the circulation ring should be approximately 13 kilometers. Testing on short sections of the heat network is possible with a sharp decrease in the flow rate of the heat transfer agent, which will lead to a violation of the hydraulic regime. In the above methodology, a lot of assumptions are made, which ultimately lead to distortion of the test results.

The existing system of rationing of heat energy losses does not allow taking into account many factors that affect the efficiency of the heat supply system. In the work [15], the authors propose to make a transition to the practice of flexible rationing, which would take into account the conjuncture of prices for thermal energy and thermal insulation materials in a particular region, as well as the operating conditions of thermal insulation structures. Structural, climatic, economic and operational factors have a great influence on the heat losses of pipelines [16]. To optimize the operation of heat networks, the authors of the scientific study [17] propose the use of a single generalized indicator of total costs, which would take into account the main factors affecting the heat losses of pipelines (figure 1).

![Figure 1. The dependence of total costs on specific linear heat losses.](image)

This model, like many others, is more aimed at determining heat losses during the design of new heating networks, but for most enterprises of thermal networks, the problem of choosing thermal insulation during current and major repairs of pipelines is relevant. To choose the optimal type of thermal insulation coating, it is essential to take into account the remaining service life of the pipeline, since the use of expensive thermal insulation coatings with high characteristics can ultimately lead to the fact that the cost of thermal insulation will be many times higher than the cost of saved thermal energy. Thus, when assessing the thickness of thermal insulation, it is important to apply modern principles and criteria for assessing the economic feasibility and optimality of investment projects, which include net discounted income, profitability index, internal rate of return, payback period.

In European countries, heat energy losses are determined by the difference in the total indications of devices of heat producers and consumers [2-6, 8-12]. Taking into account the fact that the availability of heat meters in Russia is 15-20%, this approach is not possible to implement in practice. In addition, this method allows to determine the average loss of thermal energy in the main line, but does not provide...
the information about losses on a specific section of the network. It was also proposed to determine heat losses based on the indications of measuring devices in the works [1,5,6,8,10,18]. In [17], it was proposed to determine the heat losses during the transportation of the heat transfer agent by the expression (9):

\[ Q_{n.t} = kF_i \cdot (T_{aver} - T_{air}) \]  

(9)

where \( kF_i \) is the complex of pipeline determined by the meter indications for each end user, W/K;

\( T_{air} \) is the average outdoor air temperature, K;

\( T_{aver} = (T_0 \cdot T_p)/2 \) – the average temperature of the heat transfer agent on the pipeline section from the source to the consumer, K;

\( T_0, T_p \) are the temperatures of the heat transfer agent at the output and at the input of a particular consumer, respectively, K.

In accordance with [19], for consumers who are not equipped with measuring devices, it is very difficult to carry out measurements using portable pyrometers or thermal imagers, which is not easy with a huge number of subscribers.

In the modern scientific and technical literature devoted to the issues of heat supply, the main attention is paid to methods for determining heat losses, taking into account the features of the heat main. A significant number of studies are devoted to the development of mathematical modeling tools [3,7,9], however, most of them mainly consider the issues of humidification of thermal insulation.

The paper [16] considered numerical modeling of heat exchange processes in the zone of laying underground heat pipelines, but this model makes a number of assumptions that reduce its value and application in practice.

The issues of determining heat losses in case of mechanical damage to thermal insulation are not sufficiently covered, this is especially important when laying pipelines above ground in the area of schools, crossings and other crowded places [20-24].

Due to the constant increase in the cost of energy carriers, the issue of accurate determination and reduction of heat losses is relevant. Also, according to some sources, [25-29] 40-50% of thermal energy simply does not reach the final consumer.

4. Conclusion
Due to the constant increase in the cost of energy carriers, the issue of accurate determination and reduction of heat losses is relevant. Also, according to some sources, [30-36] 40-50% of thermal energy simply does not reach the final consumer.

It can be concluded that today there is no method for determining the actual heat losses in heat networks, which would take into account all the factors affecting the losses, despite the fact that this task is one of the most important and determines the efficiency of heat energy transfer.

Acknowledgements
The study was carried out within the framework of a scientific project of the Russian Science Foundation (RSF) No 21-29-10406 (https://www.rscf.ru/project/21-79-10406/).

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