Evaluation of heat transporting losses due to changes of insulation properties during operation

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Abstract. The need for measuring the thermal conductivity of various materials exists in different fields of science and industry. First of all, it relates to constructing and power engineering. Thermal control allows evaluating the thermal insulation properties of the structure, identifying problem areas and assessing the energy efficiency of the pipeline. The paper assesses the transporting heat losses taking into account the actual operating conditions of the pipelines and the heterogeneity of the thermal insulation properties. A number of experiments were carried out. Experiments have shown that the destruction of insulation properties depends on such factors as the surface temperature of the pipe, the humidity of the environment, the service life.

1. Introduction

Currently, Russia produces about 1/2 billion tons - this is about 10% of the world's total production. The explored reserves of "light oils" in the world are decreasing, and the reserves of high-viscosity oils and natural bitumen are increasing [1]. Some experts consider that in the next 20-25 years the technology of extraction of high-viscosity oils will be the main ones in the development of new fields.

In the Russian Federation, the Republic of Tatarstan is in the first place in the extraction of highly viscous oils (Figure 1).
Development of energy-saving technologies for the production of high-viscosity oil (HVO), ultra-high viscosity oil (UHVO) and bitumen (B) is one of the most important tasks of oil production.

To extract HVO, UHVO, B the methods of thermal impact on the stratum are promising. Due to the effect of heat, the viscosity of the oil decreases, the mobility of oil and water in the formation increases. The methods are characterized by high energy costs for steam production [2].

To reduce heat losses during the transportation of the heat carrier, the next types of thermal insulation can be used:

1) stitched mineral wool plates in galvanized cover;
2) half-cylinders of basalt fiber in galvanized cover;
3) two-layer insulation (basalt + polyurethane foam) in galvanized and polyethylene cover;

During the operation of steam pipelines and bitumen pipelines, the temperature on the inner surface of the thermal insulation may exceed 120°C, that leads to a change in the thermal insulation properties of the materials (Figure 2).

Manufacturers often guarantee that the polyurethane foam operates at a temperature of 150°C. However, in fact, even at a temperature of 120°C, its destruction occurs.

From the experience of operating steam pipelines transporting a heat carrier with a temperature of 190-200 °C, it can be concluded that a two-layer thermal insulation in which the first layer consists of basalt materials, the second layer consists of polyurethane foam, does not meet the technical requirements. [3, 4].

It is established that the specific thermal losses with increasing thermal conductivity coefficient can increase to 35-40% [5].

In works of A G Dementiev it’s found that the durability of PPU insulation depends on the temperature environment in which it operates. The graphs of the dependence of the thermal conductivity on prolonged thermal aging are given [6].

According to the fact that to determine the actual heat losses taking into account the technical condition of thermal insulation, there are no specialized instruments and measurement methods, we need a research, which will have as the result the method for diagnosing thermal insulation with the help of a device-complex, developed on the basis of the meter of a heat flux density and temperature.
2. Methods

The heat flux meter is an important element in controlling the heat consumption. Thermal control makes it possible to evaluate thermal insulation properties, identify problem areas and assess the overall energy efficiency of the pipeline. The meter of density of heat flows and temperature allows conducting thermal control of constructions in the maintenance process, which contributes to the timely detection and elimination of energy losses.

The density of heat flow, as an indicator of resistance to heat transfer, characterizes the quality of thermal insulation of external enclosing structures. The heat flux density can be determined by measuring the temperature outside and on the inner surface of the testing construction. To make the measurement results more reliable, it is necessary to take measurements for a long time. Electronic meter of heat flux density allows to simplify and automate this process considerably. It is a measuring device that incorporates heat flux density sensors that convert the heat load into an electrical signal and an electronic unit that performs the necessary calculations, displays the results and forms a report.

In addition to the energy-saving aspect, heat flow meters allow to influence the flow of technological processes, providing the necessary data package on the state of the objects of the heat and power complex.

Inspecting the condition of insulation of pipelines under operating conditions is proposed to be carried out using a device that based on the method of an additional wall [7]. It consists in the fact that an additional wall with a known thermal resistance is densely pressed against the surface of the pipeline $\lambda_0/\delta_0$ (Figure 3).

![Figure 3. The illustration of the «additional» wall method.](image)

By measuring the temperature difference $\Delta t_0$ in the additional wall, we can find the heat flux (W/m²) passing through it, using the equation

$$q = \frac{\lambda_0}{\delta_0} \Delta t_0$$

(1)

If the thermal resistance of the additional wall is small compared to the thermal resistance of the main insulation, then in the case of a steady-state thermal state, the same heat flow will pass through the main wall. This flow is the heat loss of the pipeline.

The system for controlling the thermal insulation properties is implemented in the LabVIEW environment. The scheme of the developed data acquisition system in LabVIEW is shown in Figure 4.
A block-diagram of the developed program for registration and analyzing data is presented in Figure 5.

The program is a control system that automatically reads the signal from the sensors and converts it from analog to digital, using the SCXI-1000 and displays the measurement results in the diagram, that shows the dependence of the amplitude from time. The measurement result is automatically saved.

To conduct the research, an installation was assembled including a data acquisition device (PC, multichannel ADC); laboratory adjusting autotransformer type RNO-250-2 (220V, 9A); a fragment of a steel pipe with PPU insulation, a heater; heat flow sensors.

Prior to conducting the tests, the measuring system was calibrated. As a model device, a mass-produced heat flow meter ITP-MG4.03 / X (Y) «Potok» was used.

When assessing heat losses with aging of insulation the measurements were carried out with samples of insulation of different degrees of destruction.

The change in the heat flux density $q$, depending on the aging of the insulation, can be observed in the diagram (Figure 6).
3. Conclusion
According to the methods given in SNaR 41-03-2003 «Thermal insulation of equipment and pipelines» (updated version of SR 61.13330.2012), calculation of specific heat losses of steam pipelines of the above-ground gasket d-76 mm Φ and d-159 mm was carried out, through which steam with a temperature of 194 °C was transported. The results of the calculation are shown in the diagram (Figure 7). Thus, it can be stated that the difference in thermal losses, taking into account thermal destruction and without taking it into account, is significant. In the case of thermal destruction of heat insulation, losses during the transportation of steam are increased by 39%. This circumstance acquires a special urgency in connection with the increase in prices for energy carriers.

![Figure 6. Dependence of the heat flux density on the aging intensity of insulation.](image)

![Figure 7. Results of calculation of specific thermal losses of a steam pipeline](image)

a) Figure 7. Results of calculation of specific thermal losses of a steam pipeline a) d-76 mm, b) d-159 mm. Row 1 – specific heat losses without taking into account the thermal degradation of the foam polyurethane insulation. Row 2 – specific heat losses with increasing coefficient of thermal conductivity due to thermal degradation by 20%.
It can be seen from Figure 7 that operation of the heat network in conditions different from projected leads to a significant increase in heat losses. The received results testify to the need to take into account the actual operating conditions when estimating heat losses. Timely detection of «problematic» places with the help of the developed system will allow ensuring the implementation of energy saving programs.

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