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Refined Evaluation of the Heat-Transfer Agent Loss When Moving in District Heating Line

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Abstract:
An analysis of the known methodology for determining heat losses by the maximum linear density of a heat flux during movement of a high-temperature heat agent in a pipeline has been carried out. Based on heat transfer equations, the refinement dependence for calculating heat losses in a heat pipe has been obtained and the criterion whose value determines the degree of reliability of the method for calculating heat losses from the maximum linear heat flux density was introduced. The calculation of heat losses during hot water flow in an insulated and non-insulated pipeline of the heat supply system according to the dependences discussed above has been made, the results obtained have been analysed.

Keywords: *heat loss, heat agent temperature, linear density of a heat flux.*

Introduction

When designing heating networks, an important task is to determine the heat loss to the environment during the heat-transfer agent movement from the source to the consumer. SNiP (Construction Standards and Regulations) [1] gives a simplified methodology for calculating heat losses by the value of the maximum linear heat flux density, which one can found in the tables. This methodology application allows obtaining accurate results for insulated heat pipes, but can give significant errors for non-insulated or slightly insulated long pipelines. Modern pipelines with overhead installation should be insulated to reduce heat losses [2], however, when operating heating networks, a situation may arise when some pipeline sections are devoid of thermal insulation [3]. The aim of this work is to refine heat losses during a high-temperature agent movement in heat pipelines.

Calculation of heat losses in pipelines

Let us consider the heat transfer between the heat-transfer agent moving in the pipeline and the environment.

Heat losses during movement of the heat agent through the heat pipe is determined by the formula:

$$Q = G_{\text{coolant}} \cdot c_{\text{coolant}} \cdot (t_{\text{in}} - t_{\text{fin}}) \quad (1)$$

Where G_{coolant} – the heat-transfer agent flow rate, kg/s; c_{coolant} – mass heat capacity of the heat agent, J/(kg·K); $t_{\text{in}}, t_{\text{fin}}$ initial and final heat agent temperatures, respectively, °C.

Heat is transferred to the environment through heat transfer.

In this case, the heat loss is determined from the expression [1]:

$$Q = k_l \cdot l \cdot \frac{(t_{\text{in}} - t_{\text{amb}}) - (t_{\text{fin}} - t_{\text{amb}})}{\ln\left(\frac{t_{\text{in}} - t_{\text{amb}}}{t_{\text{fin}} - t_{\text{amb}}}\right)} \quad (2)$$

Where k_l – the linear heat transfer factor, W/(m K); t_{amb} – ambient temperature, °C; l – pipeline section length, m

Equating expressions (1) and (2), we obtain:

$$\ln\left(\frac{t_{\text{in}} - t_{\text{amb}}}{t_{\text{fin}} - t_{\text{amb}}}\right) = \frac{k_l \cdot l}{\text{G}_{\text{coolant}} \cdot c_{\text{coolant}}} \quad (3)$$

Then the final temperature of the heat agent will be according to the formula:

$$t_{\text{fin}} = t_{\text{amb}} + (t_{\text{in}} - t_{\text{amb}}) \cdot e^{-\frac{k_l \cdot l}{\text{G}_{\text{coolant}} \cdot c_{\text{coolant}}}} \quad (4)$$

Let us introduce the dimensionless criterion:

$$\chi = \frac{k_l \cdot l}{\text{G}_{\text{coolant}} \cdot c_{\text{coolant}}} \quad (5)$$

Then the formula for calculating heat losses taking into account (5) will take the form:

$$Q = k_{l.} \cdot l \cdot (t_{\text{in}} - t_{\text{amb}}) \cdot \frac{1 - e^{-\chi}}{\chi} \quad (6)$$

The maximum density of the linear heat flux is equal to:

$$q_{\text{l.max}} = k_{l.} \cdot (t_{\text{in}} - t_{\text{amb}}) \quad (7)$$

The maximum heat losses in this case is found by the formula:

$$Q_{\max} = k_{l.} \cdot (t_{\text{in}} - t_{\text{amb}}) \cdot l \quad (8)$$

Then the actual heat losses can be expressed:

$$Q = Q_{\max} \cdot \frac{1 - e^{-\chi}}{\chi} \quad (9)$$

With $\chi \approx 0{,}2$ it is possible with an accuracy of about 10% to consider that:

$$e^{-\chi} \approx 1 - \chi \quad (10)$$

In this case, expression (6) can be transformed:

$$Q = Q_{\max} = k_{l.} \cdot (t_{\text{in}} - t_{\text{amb}}) \cdot l \quad (11)$$

From (11) it follows that for small values of the criterion χ the heat loss linearly depends on the pipeline section length and does not depend on the criterion χ.

Thus, the heat loss calculation by the maximum value of the linear heat flux density can be carried out at relatively small values of the complex χ, which is typical for short pipelines or at high thermal resistance of the insulating layer.

For extended, slightly insulated or non-insulated pipelines with low values of heat capacity and heat agent flow rate, the value of the complex χ exceeds 0.2, and heat loss should be calculated using formula (6). In this case, the heat loss dependence on the pipeline length is not a linear function.

Let us consider heat losses during hot water flow in the supply pipeline of the heat supply

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system. The heat load is regulated by heat quality. The water flow rate is 0.7 m/s. The outer pipeline diameter is taken equal to 150 mm. We take the temperature of 150°C as the initial water temperature, the ambient temperature is taken equal to the temperature of five coldest days in Lipetsk (-27°C) [4]. As a heat loss parameter when calculating the maximum heat flux and according to formula (6), we take the difference between the initial and final temperatures of the heat-transfer agent in the pipeline.

When determining the linear factor of heat transfer, heat transfer resistance inside the pipeline and thermal resistance of steel wall are neglected.

For a non-insulated pipeline, the linear heat transfer factor is determined by heat transfer from the pipeline surface to the environment [5]:

$$k_{l.\mathrm{uninsul}} = \pi \cdot d_{\mathrm{out}} \cdot \alpha \qquad (12)$$

where $\alpha -$ is heat transfer factor outside, W/(m^2 K); d_{out} – outer diameter of the pipeline, m

The external heat transfer factor is taken equal to 15 W/(m^2 K).

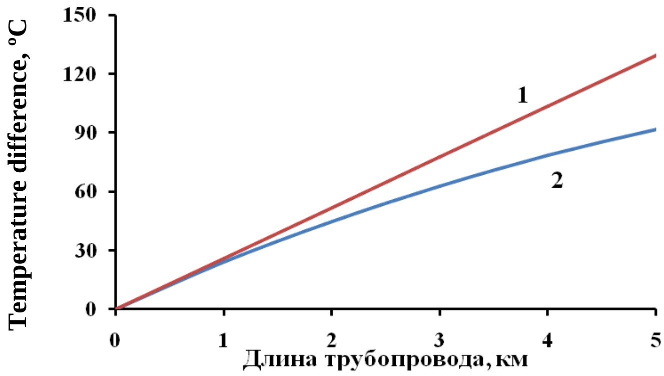
To determine heat losses of an insulated pipeline, let us take the insulation efficiency factor (ratio of difference in heat losses for a non-insulated and insulated pipeline to the heat flux through the pipeline in absence of insulation) equal to 0.15.

Then the linear heat transfer factor with an insulating layer available will be equal to:

$$k_l = k_{l.\mathrm{uninsul}} \cdot \eta_{\mathrm{insul}} \qquad (13)$$

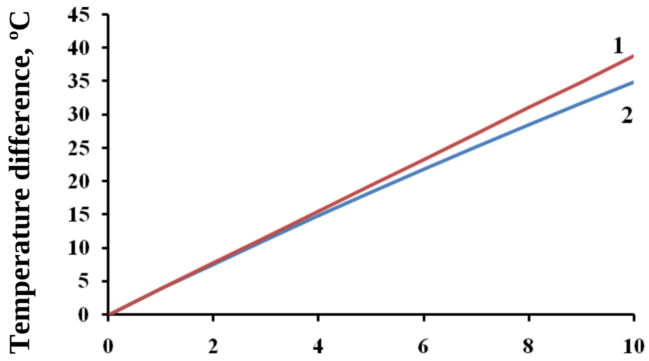
where $\eta_{\mathrm{insul}} -$ is the insulation efficiency factor.

Figures 1-2 show dependence of the difference between the initial and final heat agent temperatures on the pipeline length in presence and absence of insulation.



Pipeline length, km

Fig. 1. Dependence of the difference between the initial and final heat agent temperatures on the length of a non-insulated pipeline: 1 – when calculating the maximum linear heat flux density; 2 – when calculated by the formula (6).



Pipeline length, km

Fig. 2. Dependence of the difference between the initial and final heat agent temperatures on the length of an insulated pipeline: 1 – when calculating the maximum linear heat flux density; 2 – when calculated by the formula (6).

Analysing the calculation results, we can conclude that the calculation method by the maximum heat flux for an insulated pipeline length of up to 6 km is applicable. For longer pipelines, it is necessary to use the refined formula (6) to determine the heat loss.

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For non-insulated piping, it is necessary to apply the refined formula (6) even with a pipeline longer than 2 km.

Conclusions: A dimensionless criterion has been introduced that allows one to choose a dependence for calculating heat losses: when the criterion value is less than 0.2, heat losses are calculated by the maximum linear density of the heat flux and do not depend on the criterion value; when the criterion values are greater than 0.2, there is a refined formula obtained for determining heat losses, taking into account the value of this criterion. The results show that regardless of insulation availability for short pipelines (less than 2 km), heat losses can be calculated from the maximum linear density of the heat flux, and for long pipelines (over 2-6 km), the calculation should be carried out according to the refined formula.

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