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ANALYTICAL REASONS FOR THE HEAT LOSS ACCOMPANYING THE HEAT SUPPLY THROUGH HEAT NETWORKS

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ABSTRACT

At present, heat supply is characterised by high consumption of heat by consumers and high heat losses in distribution systems. The heat losses in heat networks represent the issue that is currently seriously discussed, especially by distributors of heat and hot water. Heat loss in a pipeline system depends on a number of factors, such as the medium temperature, external air temperature, heat network type and length, and the thickness and quality of the used insulation.

They may be identified applying two existing approaches: the experimental (using the balance method) or the analytical.

KEYWORDS: heat loss, heat networks, pipeline diameter.

INTRODUCTION

The heat loss calculation may be specified for three basic constructional types of heat distribution systems: Pre-insulated direct-buried heat networks, underground heat networks placed in heat distribution channels, and overhead heat networks (channel free).

The heat loss identification based on the balance method relates to the measurement of the temperature difference of the heat-transferring medium in the network and the volumetric flow rate. In order to obtain these parameters, it is necessary to use the state-of-the-art measuring technology which, however, cannot be permanently installed in every distribution network. Due to the above mentioned disadvantage of the balance method in the common technical practice, it cannot be applied in all heat networks directly and at any time.

The analytical expression of heat losses in individual pipeline systems is accompanied with a complication, especially when expressing the linear specific thermal resistance of the network. This depends on the nominal diameter of the pipeline, temperature of the conveyed water, ambient temperature, insulation quality and thickness, and the material used in the distribution system. The most complicated task is to express the coefficients of heat transfer on the side of the flowing water and on the side of the environment where the pipeline is located. These limitations of the currently applied methods of identifying specific or total heat losses of heat networks have become the reason why the novel method of heat loss identification has been developed.

HEAT LOSS IDENTIFICATION METHOD USING THE UNIT SPECIFIC HEAT LOSS

The application of this method facilitates the identification of heat loss in a heat network for particular temperatures of the medium (water) in the supply and return pipelines and the temperature of the external air, with the known method of pipeline construction, pipeline length, DN dimensions, and insulation thickness. In order to identify the heat loss, the heat network must be divided into individual sections, depending on individual dimensions and construction types.

Specific heat loss per 1 m of the pipeline for *overhead pipelines* (OP) is calculated using the following formula:

$$q_{l,\mathrm{OP}} = q_{l,\mathrm{OP},1} + q_{l,\mathrm{OP},2} = \frac{t_{\mathrm{i},1} - t_{\mathrm{a}}}{R_{l,1}} + \frac{t_{\mathrm{i},2} - t_{\mathrm{a}}}{R_{l,2}} \quad (\mathrm{W \cdot m^{-1}}) \qquad (1)$$

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where $q_{l,\mathrm{OP},1}$ is the specific heat loss for the supply pipeline (W·m^{-1}); $q_{l,\mathrm{OP},2}$ is the specific heat loss for the return pipeline (W·m^{-1}); $t_{i,1}$ is the temperature of water in the supply pipeline (°C); $t_{i,2}$ is the temperature of water in the return pipeline (°C); and t_a is the ambient temperature (°C).

R_l is the linear specific thermal resistance, and for an insulated pipeline it is calculated using the following formula:

$$R_l = R_{l,\alpha_{\mathrm{c},1}} + R_{l,\lambda} + R_{l,\lambda_\mathrm{in}} + R_{l,\alpha_{\mathrm{c},2}} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \qquad (2)$$

where $R_{l,\alpha_{\mathrm{c},1}}$ is the linear specific thermal resistance on the internal surface of the pipe (m·K·W^{-1}); $R_{l,\lambda}$ is the linear specific thermal resistance of the pipeline wall (m·K·W^{-1}); $R_{l,\lambda_\mathrm{in}}$ is the linear specific thermal resistance of the insulation (m·K·W^{-1}); and $R_{l,\alpha_{\mathrm{c},2}}$ is the linear specific thermal resistance on the external surface of the insulation (m·K·W^{-1}).

The linear specific thermal resistance during the heat transfer from the heat-transferring medium to the pipeline wall $R_{l,\alpha_{\mathrm{c},1}}$ and the linear specific thermal resistance during the heat transfer through the wall of the steel pipe $R_{l,\lambda}$ is very low; hence, it may be ignored in the calculation and the formula to be used is the following formula for the linear specific thermal resistance:

$$R_l = \frac{1}{2\pi \cdot \lambda_\mathrm{in}} \cdot \ln\frac{d_3}{d_2} + \frac{1}{\pi \cdot d_3 \cdot \alpha_{\mathrm{c},2}} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \qquad (3)$$

where d_2 is the external diameter of the heat-transfer pipe (m); $\square_\mathrm{in}$ is the thermal conductivity of the insulation (W·m^{-1}·K^{-1}); d_3 is the external diameter of the thermally insulated pipeline (m); and $\square_{\mathrm{c},2}$ is the coefficient of heat transfer from the surface of the insulated pipeline to the external environment (W·m^{-2}·K^{-1}).

The linear specific thermal resistances of the supply and the return pipelines may be regarded as identical because the thermal conductivity of the insulation and the coefficient of heat transfer from the surface of the insulated pipeline to the external environment for the supply and the return pipelines show only a small difference at the given temperature of the conveyed water. Therefore, formula (1) may be written as follows:

$$q_{l,\mathrm{OP}} = \frac{1}{R_{l,1,2}} \cdot (t_{\mathrm{i},1} + t_{\mathrm{i},2} - 2 \cdot t_\mathrm{a}) \quad (\mathrm{W \cdot m^{-1}}) \qquad (4)$$

or $q_{l,\mathrm{OP}} = q_{p,\mathrm{OP}} \cdot (t_{\mathrm{i},1} + t_{\mathrm{i},2} - 2 \cdot t_\mathrm{a}) \quad (\mathrm{W \cdot m^{-1}}) \qquad (5)$

where $q_{p,\mathrm{OP}}$ is the unit specific heat loss of the overhead heat distribution pipeline (W·m^{-1}·K^{-1}).

The specific heat loss per 1 m of the pipeline *for direct-buried pipeline* (DBP) is calculated using the following formula:

$$q_{l,\mathrm{DBP}} = q_{l,\mathrm{DBP},1} + q_{l,\mathrm{DBP},2} \quad (\mathrm{W \cdot m^{-1}}) \qquad (6)$$

or $$q_{l,\mathrm{DBP}} = \frac{R_{l,2} \cdot (t_{\mathrm{i},1} - t_\mathrm{a}) - R_\mathrm{s} \cdot (t_{\mathrm{i},2} - t_\mathrm{a})}{R_l} + \frac{R_{l,1} \cdot (t_{\mathrm{i},2} - t_\mathrm{a}) - R_\mathrm{s} \cdot (t_{\mathrm{i},1} - t_\mathrm{a})}{R_l} \quad (\mathrm{W \cdot m^{-1}}) \qquad (7)$$

where $q_{l,\mathrm{DBP},1}$ is the specific heat loss for the supply pipeline (W·m^{-1}) and $q_{l,\mathrm{DBP},2}$ is the specific heat loss for the return pipeline (W·m^{-1}).

Again, for this type of pipeline, the calculation of the total linear thermal resistance R_l may be made while ignoring the linear thermal resistance $R_{l,\alpha_{\mathrm{c},1}}$ and $R_{l,\lambda}$, and the formula to be used is the formula for the linear thermal resistance of the insulation $R_{l,\mathrm{in}}$ and of the soil $R_{l,\mathrm{s}}$.

The linear thermal resistance $R_{l,1}$ of the supply pipeline is calculated as the sum of the resistance of the insulation and of the soil, using the following formula:

$$R_{l,1} = \frac{1}{2 \cdot \pi \cdot \lambda_{\mathrm{in},1}} \cdot \ln\frac{d_3}{d_2} + \frac{1}{2 \cdot \pi \cdot \lambda_\mathrm{s}} \cdot \ln\frac{4 \cdot D_\mathrm{r}}{d_3} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \quad (8)$$

The linear thermal resistance $R_{l,2}$ of the return pipeline is calculated as the sum of the resistance of the insulation and of the soil using the following formula:

$$R_{l,2} = \frac{1}{2 \cdot \pi \cdot \lambda_{\text{in},2}} \cdot \ln \frac{d_3}{d_2} + \frac{1}{2 \cdot \pi \cdot \lambda_s} \cdot \ln \frac{4 \cdot D_r}{d_3} \quad (\text{m} \cdot \text{K} \cdot \text{W}^{-1}) \quad (9)$$

The recommended formula for the calculation of the resistance of the soil located between the two pipelines (degree of mutual effects) [1] is as follows:

$$R_s = \frac{1}{2.\pi.\lambda_s} \cdot \ln \sqrt{\left(\frac{2.D_r}{C}\right)^2 + 1} \quad (\text{m} \cdot \text{K} \cdot \text{W}^{-1}) \qquad (10)$$

and the calculation of the reduced depth of the pipeline D_r is made using the following formula:

$$D_r = D_1 + \frac{\lambda_s}{\alpha_0} \quad (\text{m}) \qquad (11)$$

where D_1 (D_2) is the depth of the pipeline (supply, return) (m); λ_s is the coefficient of thermal conductivity of the soil (W·m^{-1}·K^{-1}); □$_0$ is the coefficient of heat transfer from the surface of the ground to the external environment (W·m^{-2}·K^{-1}); and C is the distance between the axes of the pipelines (m).

The total thermal resistance is calculated using the following formula:

$$R_l = R_{l,1} \cdot R_{l,2} - R_s^2 \quad (\text{m} \cdot \text{K} \cdot \text{W}^{-1}) \qquad (12)$$

In this case again, it applies that the linear specific thermal resistances of the supply and the return pipelines are identical, or only with a minimum difference. Therefore, formula (7) may be written as follows:

$$q_{l,\text{DBP}} = \frac{R_{l,2} - R_s}{R_l} \cdot (t_{\text{i},1} + t_{\text{i},2} - 2 \cdot t_a) \quad (\text{W} \cdot \text{m}^{-1}) \qquad (13)$$

or $q_{l,\text{DBP}} = q_{p,\text{DBP}} \cdot (t_{\text{i},1} + t_{\text{i},2} - 2 \cdot t_a)$ (W·m^{-1}) (14)

where $q_{p,\text{DBP}}$ is the unit specific heat loss of the direct-buried heat distribution system (W·m^{-1}·K^{-1}).

On the basis of the above mentioned facts, the calculation of the *unit specific heat loss* per 1 m of the pipeline is made using the following general formula:

$$q_{l,x} = q_{p,x} \cdot (t_{\text{i},1} + t_{\text{i},2} - 2 \cdot t_a) \quad (\text{W} \cdot \text{m}^{-1}) \qquad (15)$$

where x is the constructional type of the given pipeline section (OH - overhead, DBP - direct-buried pipeline).

Fig. 1 and Fig. 2 show the relationships between the unit specific heat loss of the pipeline section $q_{p,x}$ (W·m^{-1}·K^{-1}) for individual pipeline types, depending on the pipeline DN and the insulation thickness.

In order to identify the value of the specific heat loss in equation (15), relevant $q_{p,x.}$ value must be read from the graphs, depending the pipeline type and insulation thickness, and such value is then substituted to formula (15).

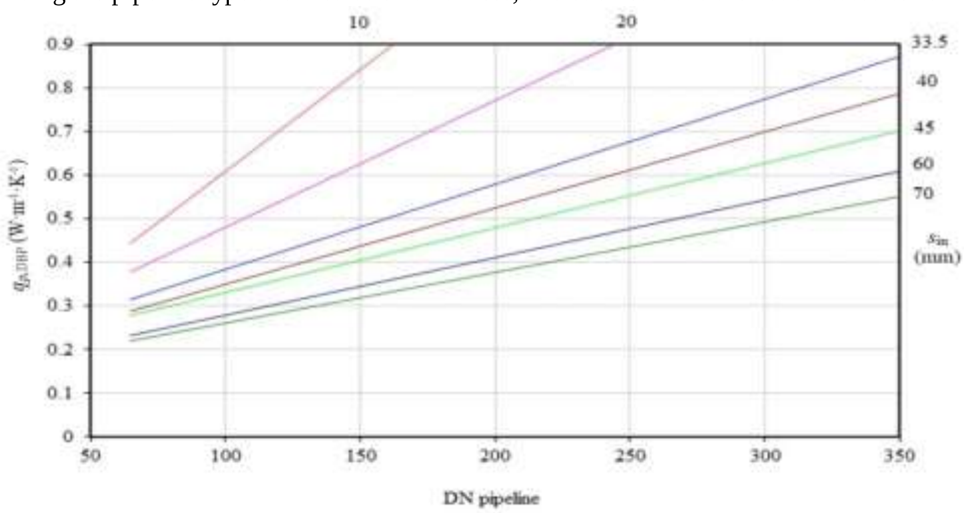

Figure 1. Unit specific heat loss in the direct-buried heat pipeline.

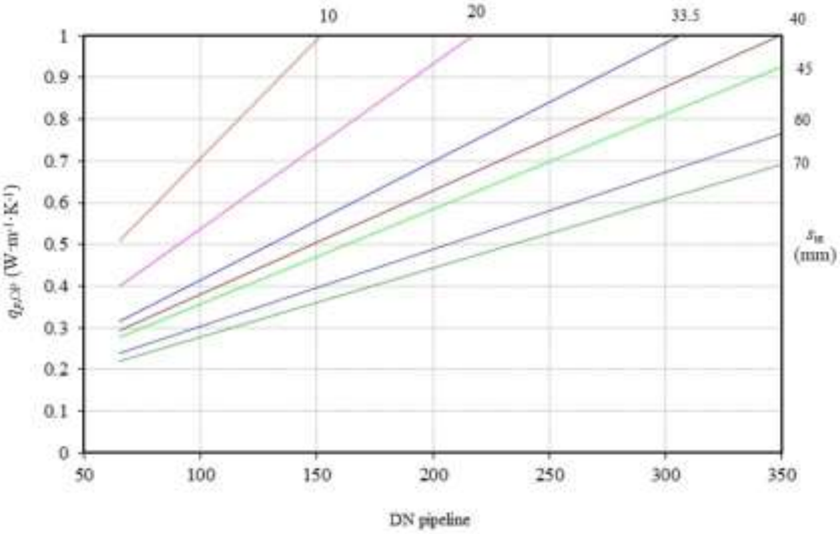

Figure 2. Unit specific heat loss in the overhead pipeline.

The graphs were drawn while assuming the following conditions:

- The unit specific heat losses for individual pipeline types, depending the pipeline DN and insulation thickness, were calculated using the following formulas:

$$q_{p,\mathrm{OP}} = \frac{1}{R_{l,1,2}} \quad \text{or} \quad q_{p,\mathrm{DBP}} = \frac{R_{l,1,2} - R_s}{R_l}$$

- The calculations of the linear specific thermal resistances in point 1 above were made for the following temperatures in the supply and return pipelines:

t_1/t_2 = 70/55 °C	t_1/t_2 = 65/55 °C	t_1/t_2 = 60/55 °C
t_1/t_2 = 70/50 °C	t_1/t_2 = 65/50 °C	t_1/t_2 = 60/50 °C
t_1/t_2 = 70/45 °C	t_1/t_2 = 65/45 °C	t_1/t_2 = 60/45 °C
t_1/t_2 = 70/40 °C	t_1/t_2 = 65/40 °C	t_1/t_2 = 60/40 °C

The design external temperature was t_a = -13 °C. The insulation material considered for the calculation purposes was PIPO ALS, including all its characteristics. The calculations were made while considering the mean value of the thermal conductivity of the insulation □$_{in}$ as the function of the temperature of the conveyed water (□$_{in}$=0.04 W·m^{-1}·K^{-1}) and the coefficient of heat transfer from the insulation surface to the surrounding environment □$_{c,2}$ = 3 W·m^{-2}·K^{-1} [1].

CONCLUSION

The herein presented method of identifying heat losses in heat networks is very simple. On the basis of the known temperatures of water in the supply and return pipelines and the external temperature, it is easy to identify the value of the specific as well as total heat loss in a particular heat network.
This method may be practically applied within operating heat networks and for the purpose of verification of the heat network cost-efficiency.

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REFERENCES

1. M. Rédr, M. Prihoda, “Základy tepelnej techniky”, Praha, SNTL, 1991.
2. J. Cikhart, “Sústavy centrálneho zásobovania teplom”, SNTL Praha, 1977.
3. J. Prokop,” Tepelné izolace”, SNTL Praha, 1982.
4. H. Steidl, “Úvod do proudění tekutin a sdílení tepla”, ACADEMIA, Praha, 1975.
5. A. Ljubenko, A Poredoš et al. Performance Analysis of a District Heating System, Energies 6, 2013.