The Analysis of Selected Characteristics of Secondary Heat Networks

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Abstract**—** *A heat network is a pipeline system through which the heat-transferring medium is conveyed, in the required amount and condition, from a source to a heating appliance. The heat loss depends on a number of parameters, such as the temperature of the medium, temperature of the environment where the analysed heat network is located, and the thickness and quality of the installed insulation. The present article deals with the efficiency of the heat distribution system relative to the temperature in the supply pipeline and in the return pipeline in overhead and direct-buried distribution systems, as well as the effect of the heat loss on such efficiency.*

Keywords—heat network, efficiency, heat loss, ambient temperature.

I. INTRODUCTION

When conveying heat trough heat networks, it is not possible to exclude heat losses that significantly affect the operation of a particular heat network and the overall cost-efficiency of the heat supply. Therefore, they must be paid more attention and it is necessary to understand the physics behind the heat loss formation in order to subsequently minimise it to the optimal level. It is also important to express the heat loss as the percentage of the distributed heat. The efficiency of the distribution system, with regard to the intact installed pipeline insulation, may acquire various values.

II. THE EFFECT OF THE TEMPERATURE ON THE HEAT NETWORK EFFICIENCY

The efficiency of a distribution system is determined by the ratio of the output (heat flux received from the system) to the input (heat flux supplied to the system).

The heat network efficiency may be mathematically expressed as follows:

- efficiency of the supply pipeline:

$$\eta_{\mathrm{SP}} = \frac{Q_{\mathrm{n}} - Q_{\mathrm{l}}}{Q_{\mathrm{n}}} \cdot 100 \ (\%) \tag{1}$$

Where Q_{n} is the heat network input (W) and Q_{l} is the heat network loss (W);

- efficiency of the return pipeline:

$$\eta_{\mathrm{RP}} = \frac{Q_{\mathrm{n}} - Q_{\mathrm{l}}}{Q_{\mathrm{n}}} \cdot 100 \ (\%) \tag{2}$$

Where Q_{n} is heat network input (W) and Q_{l} is the heat network loss (W).

Therefore, the total efficiency of the heat network may be expressed as follows:

$$\eta_{\mathrm{tot}} = \eta_{\mathrm{SP}} \cdot \eta_{\mathrm{RP}} \ (\%) \tag{3}$$

The distribution system efficiency only serves as an indicator for a particular heat network of certain length and may acquire different values, depending on the quantity of the supplied thermal capacity (MW) or the heat supplied (GJ).

The correlation between the heat distribution system efficiency and the temperatures in the supply and return pipelines is shown in Fig. 1 for the overhead system and in Fig. 2 for the direct-buried system. These curves apply to a theoretical heat network with the PIPO ALS insulation, at the design external temperature of -13 °C.

The diagrams indicate that in order to increase the efficiency of the heat network, the temperature in the supply pipeline must be reduced and the medium in the heating appliance must be cooled to the lowest possible temperature. Cooling the medium is limited by the used type of the heat exchanger. In practice, however, the required degree of cooling is never reached.

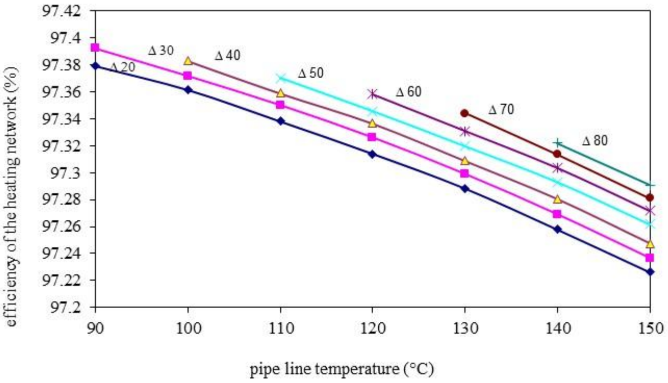

FIGURE 1 Relationship between the heat network efficiency and the temperature in the overhead supply pipeline

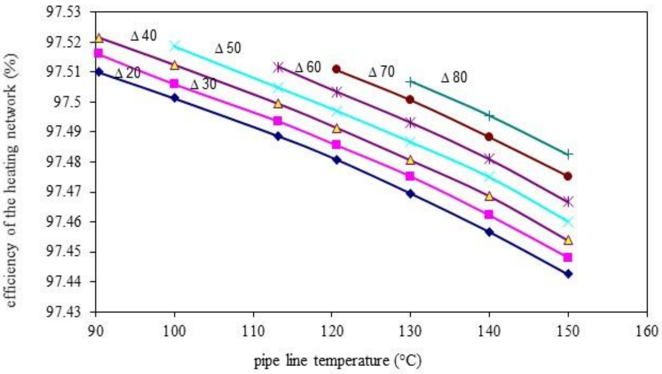

FIGURE 2 Relationship between the heat network efficiency and the temperature in the direct-buried supply pipeline

III. THE EFFECT OF THE TEMPERATURE ON THE SPECIFIC HEAT LOSS OF THE HEAT NETWORK

The heat loss depends primarily on the temperature of the conveyed medium, heat network type and length, and the thickness and quality of the used thermal insulation.

The specific heat loss per1 m of the overhead pipeline (OP) was calculated using the formula:

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

Where $q_{l,\mathrm{OP},1}$ is the specific heat loss for the supply pipeline ($\mathrm{W \cdot m^{-1}}$); $q_{l,\mathrm{OP},2}$ is the specific heat loss for the return pipeline ($\mathrm{W \cdot m^{-1}}$); $t_{i,1}$ is the temperature of water in the supply pipeline(K); $t_{i,2}$ is the temperature of water in the return pipeline (K), t_{a} is the ambient temperature (K); $R_{l,1}$ is the linear specific thermal resistance of the return pipeline ($\mathrm{m \cdot K \cdot W^{-1}}$); and $R_{l,2}$ is the linear specific thermal resistance of the return pipeline ($\mathrm{m \cdot K \cdot W^{-1}}$).

The linear specific thermal resistance during the heat transfer from the heat-transferring medium to the pipeline wall and the linear specific thermal resistance during the heat transfer through the wall of the steel pipe did not exceed 0.02 % of the total linear specific thermal resistance; hence, it may be ignored in the calculation and the formula to be used is as follows:

$$R_{l,1(2)} = \frac{1}{2\pi \cdot \lambda_{\mathrm{in}}} \cdot \ln \frac{d_3}{d_2} + \frac{1}{\pi \cdot d_3 \cdot a_{\mathrm{c},2}} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \tag{5}$$

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

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

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

or

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

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

Again, for this type of the pipeline, the calculation of the total linear specific thermal resistance R_l was made using only the formula for the linear specific thermal resistance of the insulation $R_{l,\mathrm{in}}$ and of the soil R_s.

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

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

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

$$R_{l,2} = \frac{1}{2 \cdot \pi \cdot \lambda_{\mathrm{in},2}} \cdot \ln \frac{d_3}{d_2} + \frac{1}{2 \cdot \pi \cdot \lambda_\mathrm{s}} \cdot \ln \frac{4 \cdot D_\mathrm{r}}{d_3} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \tag{9}$$

The resistance of the soil located between the two pipelines (degree of mutual effects) was calculated using the following formula:

$$R_\mathrm{s} \frac{1}{2 \cdot \pi \cdot \lambda_\mathrm{s}} \cdot \ln \sqrt{\left(\frac{2.D_\mathrm{r}}{C} \right)^2 + 1} \; (\mathrm{m \cdot K \cdot W^{-1}}) \tag{10}$$

And the calculation of the reduced depth of the pipeline D_r was made using the following formula:

$$D_\mathrm{r} = D_1 + \frac{\lambda_\mathrm{s}}{\alpha_0} \quad (\mathrm{m}) \tag{11}$$

whereD_1 (D_2) is the depth of the pipeline under the ground (supply, return) (m);$\lambda_\mathrm{s}$is the coefficient of thermal conductivity of the soil ($\mathrm{W \cdot m^{-1} \cdot K^{-1}}$);$\alpha_0$ is the coefficient of heat transfer from the surface of the ground to the external environment ($\mathrm{W \cdot m^{-2} \cdot K^{-1}}$); and C is the distance between the axes of the pipelines (m).

The total thermal resistance was calculated using the following formula:

$$R_l = R_{l,1} \cdot R_{l,2} - R_z^{\;2} \quad (\mathrm{m \cdot K \cdot W^{-1}}) \tag{12}$$

Figures 3 and 4 show the relationships between the specific heat loss and the temperatures in the overhead and direct-buried supply pipelines. The graphs apply to the theoretical heat network with the PIPO ALS insulation, for the external design temperature of -13 °C.

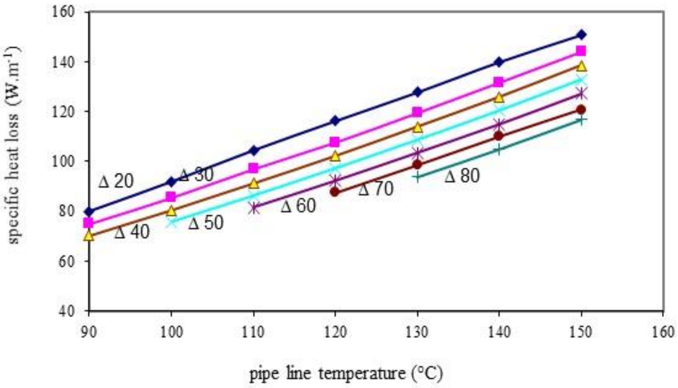

FIGURE 3 Relationship between the specific heat loss and the temperature in the overhead supply pipeline

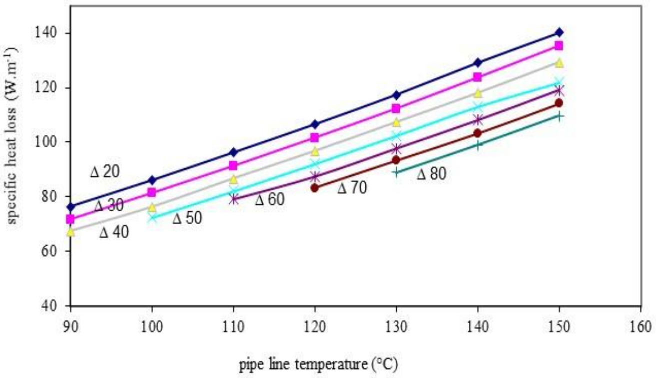

FIGURE 4: Relationship between the specific heat loss and the temperature in the direct-buried supply pipeline

In order to reduce the heat loss, it is necessary, similarly to the case of increasing the efficiency of the heat network, to reduce the temperature in the supply pipeline and ensure that the heat-transferring medium in the appliance is cooled to the lowest possible temperature.

Another important parameter affecting the quantity of the heat loss is the thermal insulation; it is therefore necessary to pay adequate attention to the selection thereof.

Fig. 5 shows the relationship between the specific heat loss and the pipeline DN for the overhead as well as direct-buried pipelines. The calculation of the specific heat loss were carried out assuming that the ambient temperature was -13 °C, the temperature gradient for the supply and return pipelines was Δ 20, and the used insulation was PIPO ALS. This insulation is made of mineral wool and organic resin. It has a shape of a hollow cylinder divided along its length, made of one or more segments, with the lock preventing from the heat loss through the longitudinal joint.

The PIPO ALS product comprises the aluminium foil as the surface finishing, reinforced with the fibre glass grating. Such thermal insulation may be used at temperatures ranging from -15 to +250 °C.

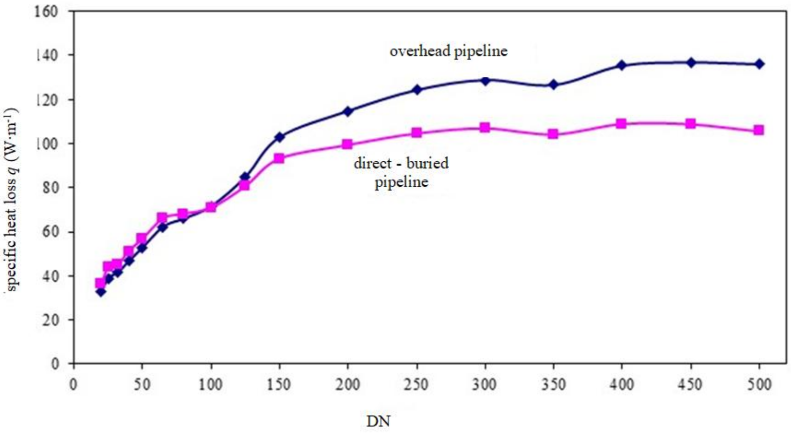

FIGURE 5: Relationship between the specific heat loss and the pipeline DN for overhead and direct-buried pipelines

Fig. 6 depicts the relationship between the efficiency of the supply and return pipelines and the specific thermal conductivity. Thermal conductivity belongs to the key parameters of insulation materials in terms of thermal protection. It represents the level of the heat transfer through the insulation.

The graph applies to the design external temperature of -13 °C and the temperature gradient Δ 40 for the supply and return overhead pipelines.

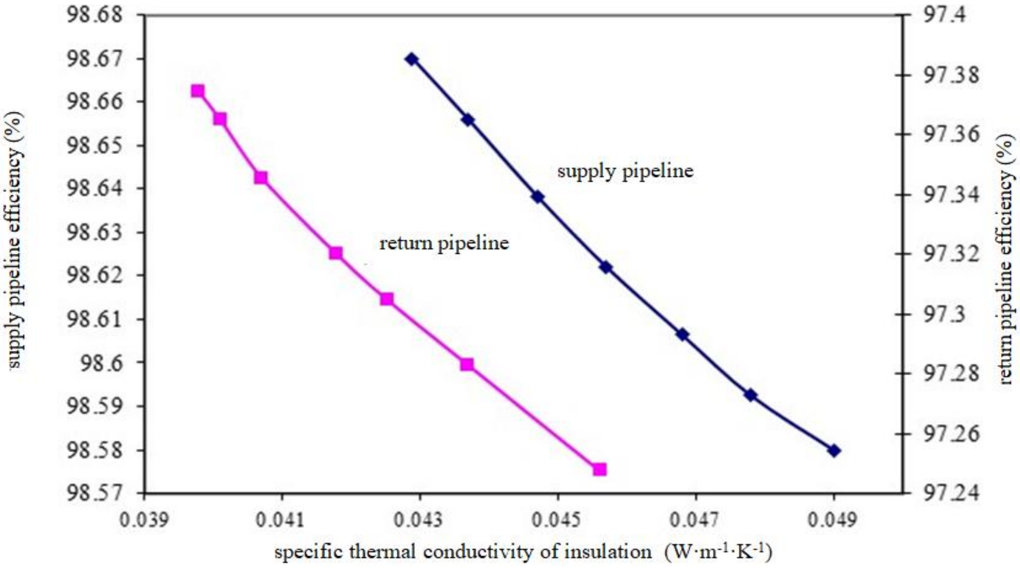

FIGURE 6: indicates that when identical insulation types are used, the heat loss is lower in the direct-buried pipeline

The graph clearly indicates that the higher the specific thermal conductivity of the insulation, the lower the efficiency of the heat network and the higher the heat loss.

IV. CONCLUSION

The heat loss of networks cannot be determined in general, only specifically for a particular network, because it largely depends on the network size and capacity. If the capacity of a particular heat network is not sufficiently used, the specific heat loss is high and such operation is not cost-efficient.

The graphs presented above indicate that the process of designing the heat distribution pipelines should be performed while considering the optimal parameters in order to achieve the minimum heat loss.

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