

Calculation of soil temperature at the intersection of the heating line of the underground gasket and gas pipeline taking into account real operating conditions

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Abstract. Distances from the insulation shell of pipelines during channelless laying to utility networks are recommended by regulatory documents, but in real conditions it is not always possible to comply with these parameters. Calculations have been made to verify that the gas pipeline can be laid next to the supply pipeline of the heating network in the problematic section of the installation where these restrictions are not met. The soil temperature on the wall of the gas pipeline case is determined to exclude the heating condition of polyethylene pipes above 40 °C for the entire period of operation. Soil temperatures at the intersection of the heating line and the gas pipeline were determined taking into account the real operating conditions of the district heating networks, the peculiarities of regulating the coolant parameters of the Russian heat systems and the state of thermal insulation.

Keywords: district heating networks, soil temperature, heat waste.

1 Introduction

According to SP 42-103-2003 «Design and construction of polyethylene gas pipelines and renovation of underground gas pipelines» at the intersection or parallel laying of the polyethylene gas pipeline with the heat path of the underground gasket, the distance between them is specified by calculation based on the conditions for excluding the possibility of heating polyethylene pipes above 40 °C for the entire period of operation.

Pipes in polyurethane foam insulation are a monolithic structure that includes: a steel pipe, a thermal insulation layer made of polyurethane and a protective shell. The thermal conductivity of polyurethane foams has been studied by experts for more than 20 years [1], and for the first time pipes in polyurethane insulation foams appeared in the late 1960s. The assessment of the technical state of pipes after natural or artificial aging (accelerated aging was carried out by applying three different elevated temperatures) is considered in the study

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[2]. The dependence of specific heat loss of the main pipes pre-insulated with polyurethane foam on coolant temperature in the range of 70-150 °C is given in the work [3].

Most works on insulation of pipelines consider the tasks of reduction of heat losses during transportation [4-7], the effect of insulation thickness on cost parameters and corresponding savings in the heat supply system [5, 8], reduction of air pollution and real savings of carbon emissions [9-10], impact on the environment of flue gases, the impact on the environment from the use of district heat supply systems [11] and district heating systems [12-16]. Studies [17-19] show the possibility of using pipelines made of polymer materials with high-efficiency thermal insulation in district heat supply systems. Thermal insulation materials as a tool for energy saving are considered in the work [20].

Russian district heating systems have their own features related to regulation, coolant parameters and a large percentage of wear and tear. When determining soil temperature and heat loss, it is important to take into account the real operating conditions of pipelines, since regulatory and design data are not always reliable [6].

Studies [21-22] numerically simulate the temperature field of the soil and calculate the temperature field of the soil around the underground pipeline during oil transportation, analyze the safety limits required for the temperature of the external surface of insulation of pipelines with the flow of superheated steam. The authors [23] consider the boundaries of the potential thermal impact zone provided that there are external ignition sources in case of possible emergency depressurization of the gas pipeline.

Since the issue of determining the soil temperature for underground pipelines was not considered in detail by the researchers, there is no detailed analysis of determining the soil temperature at the point of intersection of communications. Thus, this study is aimed at solving the problem of assessing the soil temperature at the intersection of the heating line of an underground gasket and a low-pressure gas pipeline, taking into account the real operating conditions of the heat supply system, the state of thermal insulation and soil humidification.

2 Materials and methods

It is necessary to prove the possibility of laying a gas pipeline at a distance of 0.4 m horizontally from the axis of the supply pipeline of the heat network of the underground channelless gasket in Kazan, on G. Barudi Street. The gas pipeline is located at a depth of 2.6 m from the ground surface, the depth of the heat pipeline is $H=1.6$ m. Standards allow for the smallest vertical clear distance of 0.2 m from the insulation casing of pipelines in a channelless laying to the gas pipeline. This condition is fully fulfilled with a large margin. The distance between the axes of the pipes of the heat network horizontally $K_{1,2}=0.5$ m. Design parameters of the coolant are 130/70 °C. The average annual soil temperature at the depth of laying is $t_o=6.3$ °C, the soil characteristic is clay and loam, with a density of $\rho_{dry}=1600$ kg/m³, the thermal conductivity of dry soil is $\lambda_{dry}=0.33$ W/(m·°C). Heat pipelines operate under flooding conditions, which significantly affects the heat loss of underground heating lines. Soil humidity is not constant during the year. In this regard, it is of interest to evaluate the influence of volumetric soil humidity on heat flows, to determine the value of linear heat losses q , W/m, and soil temperature at the intersection of heat pipelines with a low-pressure gas pipeline. The heating line is a double-pipe gasket made of steel pipes with diameter of $D_y=125$ mm in polyurethane insulation foam, $\delta_{is}=46$ mm, $\lambda_{is}=0.033$ W/(m·°C).

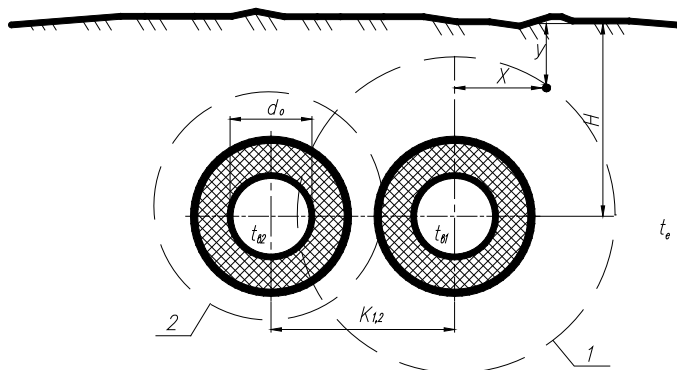


Fig. 1. Diagram of a double-pipe channelless gasket: 1– approximate temperature field formed in the soil around the supply pipeline of the heat network; 2 – same around return pipeline.

Temperature at any point of soil around double-pipe heat pipe of channelless gasket is determined by formula:

$$t = t_e + \frac{q_1}{2\pi\lambda_s} \ln \sqrt{\frac{x^2 + (y + \hat{I})^2}{x^2 + (y - \hat{I})^2}} + \frac{q_2}{2\pi\lambda_s} \ln \sqrt{\frac{(x - \hat{E}_{1,2})^2 + (y + \hat{I})^2}{(x - \hat{E}_{1,2})^2 + (y - \hat{I})^2}} \quad (1)$$

where t_e – temperature of soil, or outdoor air, °C, (see fig. 1); q_1 and q_2 – specific heat losses from supply and return pipelines in soil, W/m; λ_s – soil thermal conductivity coefficient, W/(m·°C); x and y – the distance of the considered point from the axis of the supply pipeline of the heat network and from the soil surface; H – the depth of laying of an axis of the pipeline, m; $K_{1,2}$ – the distance between the axes of the heat pipes, m, (see fig. 1).

With a double-pipe channelless gasket, as a result of heat losses around pipelines, temperature fields are formed in the soil, which contribute to reducing the heat loss of each pipe separately. Reducing heat loss will be the greater, the higher the soil temperature around the adjacent pipeline.

Heat losses of double-pipe heat networks during channelless laying, W/m:

$$q_1^L = \frac{(t_{a1} - t_e)(R_{is2}^L + R_s) - (t_{a2} - t_e) \cdot R_i}{(R_{is1}^L + R_s)(R_{is2}^L + R_s) - R_i^2} K \quad (2)$$

$$q_2^L = \frac{(t_{a2} - t_e)(R_{is1}^L + R_s) - (t_{a1} - t_e) \cdot R_i}{(R_{is2}^L + R_s)(R_{is1}^L + R_s) - R_i^2} K \quad (3)$$

where t_{a1} , t_{a2} – coolant temperature in supply and return pipelines of heat network, °C; t_e – temperature of the external environment, °C; R_{is1}^L , R_{is2}^L – thermal resistance of supply and return pipelines insulation, m·°C/W; R_s – thermal resistance of the soil during channelless laying, m·°C/W; R_i – thermal resistance caused by thermal interaction of two pipes, m·°C/W; K – coefficient of additional losses.

Thermal resistance insulation of supply and return pipelines:

$$R_{is1}^L = \frac{1}{2 \cdot \pi \cdot \lambda_{is}} \cdot \ln \frac{d_{o1} + 2\delta_{is1}}{d_{o1}}, \quad (4)$$

$$R_{is2}^L = \frac{1}{2 \cdot \pi \cdot \lambda_{is}} \cdot \ln \frac{d_{o2} + 2\delta_{is2}}{d_{o2}}, \quad (5)$$

where d_o – outer diameter of pipes, m (as shown in Fig. 1).

The thermal resistance of the soil during channelless laying, $m \cdot ^\circ C/W$, is determined by the Forgheimer formula:

$$R_s = \frac{1}{2 \cdot \pi \cdot \lambda_s} \cdot \ln \frac{4H}{d} \tag{6}$$

$$R_s = \frac{1}{2\pi\lambda_s} \ln \left[\frac{2H}{d} + \sqrt{\left(\frac{2H}{d}\right)^2 - 1} \right] \tag{7}$$

Where λ_s – soil thermal conductivity coefficient, $W/(m \cdot ^\circ C)$; H – depth of laying of an axis of the pipeline, m ; d – outer diameter of pipes taking into account thermal insulation thickness, m .

Thermal resistance caused by thermal interaction of two pipes:

$$R_i = \frac{\ln \sqrt{1 + \left(\frac{2H}{K_{1,2}}\right)^2}}{2\pi \cdot \lambda_s}, \tag{8}$$

where $K_{1,2}$ – distance between pipe axes horizontally, m .

3 Results and discussion

According to SP 42-103-2003 «Design and construction of polyethylene gas pipelines and renovation of underground gas pipelines» at the intersection or parallel laying of a polyethylene gas pipeline with a channelless heat distribution, the distance between them is specified by calculation based on the conditions for excluding the possibility of heating polyethylene pipes above $40 \text{ }^\circ C$ for the entire period of operation.

In Kazan, combined sources of thermal and electric energy provide most of the heat load of the city. The calculated parameters of the temperature schedule are $130/65 \text{ }^\circ C$, with optimization on $115/65 \text{ }^\circ C$ (supply / return) as shown in fig. 2. The average monthly coolant temperatures in January is $92.1/54.9 \text{ }^\circ C$ - according to temperature schedule $t_e = -11.6 \text{ }^\circ C$.

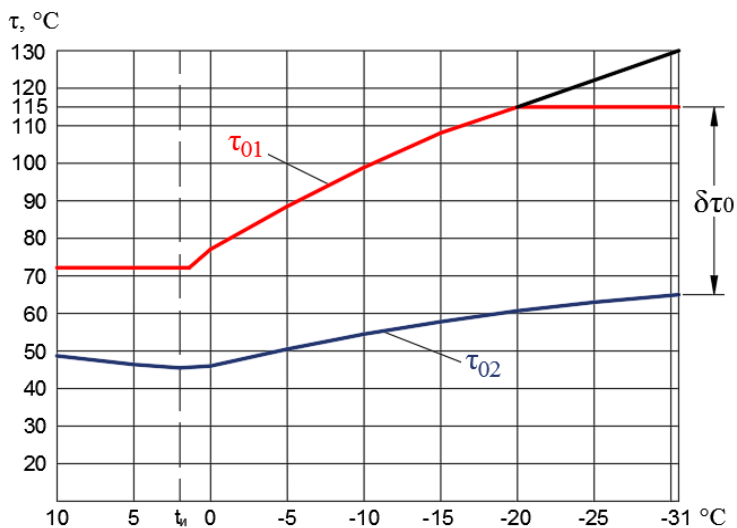


Fig. 2. Water temperature chart in supply and return lines of the heat network with qualitative regulation of heating load.

Calculations were made for various modes of operation of thermal conductors with simultaneous moistening of the soil from 0 to 48 % (insulation is not moistened). The thermal conductivity of the soil is also not a constant value, it depends on humidity. The thermal conductivity of the soil increases dramatically as humidity increases, since the thermal conductivity of the air displaced by the water from the soil pores is approximately 25 times less than the thermal conductivity of the water. Influence of soil thermal conductivity coefficient on heat losses from pre-insulated pipes during operation is considered in the study [24].

Dependence of the coefficient of thermal conductivity of wet soils on mass humidity:

$W_s = 0\%$, $\lambda_s = 0.33 \text{ W/(m}\cdot\text{°C)}$ – absolutely dry soil; $W_s = 16\%$, $\lambda_s = 0.96 \text{ W/(m}\cdot\text{°C)}$ - wet soil (natural humidity); $W_s = 32\%$, $\lambda_s = 1.33 \text{ W/(m}\cdot\text{°C)}$ - wet soil; $W_s = 48\%$, $\lambda_s = 1.63 \text{ W/(m}\cdot\text{°C)}$ - water-saturated soil.

Calculations were carried out during the design operation mode of the pipelines and in the absence of insulation on both pipelines, for the following conditions:

- average annual coolant parameters are 65/50 °C and average annual soil temperature is $t_e = 6.3 \text{ °C}$;
- calculated parameters of the coolant are 130/70 °C, and soil temperature in January is $t_e = 3.1$, at a depth of laying of a heating conduit is $H = 1.6 \text{ m}$ [25];
- average monthly coolant temperatures in January is 94/55 °C and soil temperature for January is $t_e = 3.1 \text{ °C}$;
- calculated parameters of the coolant are 115/60 °C, and soil temperature in January is $t_e = 3.1 \text{ °C}$, at a depth of laying of a heating conduit is $H = 1.6 \text{ m}$ [25].

The results of the calculations are summarized in tables 1-4. Using the calculation procedure of SP 61.13330.2012 «Designing of thermal insulation of equipment and pipelines,» it is not possible to take into account the partial destruction of polyurethane foam insulation, therefore, calculations are carried out for the most unfavorable conditions in the absence of insulation on both pipelines. No humidification of polyurethane foam insulation is provided - humidification coefficient $K = 1.0$ is used in the calculation for low-moisture, wet and water-saturated soil, since the modern waterproofing coating of pre-insulated pipes eliminates the possibility of humidification of insulation during operation. In the previous version of building codes for polyurethane foam insulation, this coefficient changed in the range $1.0 \div 1.1$.

Table 1. Soil temperature at the point of intersection of double-pipe heat networks with low-pressure gas pipeline. Average annual coolant parameters are 65/50 °C, average annual soil temperature is $t_e = 6.3 \text{ °C}$.

Soil moisture, % (clays and loams)	Calculation mode of the pipelines		If there is no insulation on both pipelines	
	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case
0	$q_1^L = 27.45$ $q_2^L = 16.92$	23.23	$q_1^L = 28.76$ $q_2^L = 17.48$	23.95
16	$q_1^L = 32.57$ $q_2^L = 21.17$	19.98	$q_1^L = 43.14$ $q_2^L = 26.22$	23.95
32	$q_1^L = 40.28$ $q_2^L = 27.86$	14.98	$q_1^L = 86.28$ $q_2^L = 52.44$	23.95
38	$q_1^L = 40.92$ $q_2^L = 28.43$	14.92	$q_1^L = 92.23$ $q_2^L = 56.06$	23.95

Table 2. Soil temperature at the point of intersection of double-pipe heat networks with low-pressure gas pipeline. Design parameters of coolant are 130/70 °C, soil temperature for January is $t_e=3.1$ °C

Soil moisture, % (clays and loams)	Calculation mode of the pipelines		If there is no insulation on both pipelines	
	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case
0	$q_1^L = 63.06$ $q_2^L = 20.91$	34.95	$q_1^L = 66.31$ $q_2^L = 21.20$	36.28
16	$q_1^L = 73.66$ $q_2^L = 28.06$	28.85	$q_1^L = 99.47$ $q_2^L = 31.80$	36.28
32	$q_1^L = 89.32$ $q_2^L = 39.65$	19.45	$q_1^L = 198.93$ $q_2^L = 63.60$	36.28
38	$q_1^L = 90.60$ $q_2^L = 40.64$	18.67	$q_1^L = 212.65$ $q_2^L = 67.99$	36.28

Table 3. Soil temperature at the point of intersection of double-pipe heat networks with low-pressure gas pipeline. Average monthly coolant temperatures in January is 92.1/54.9 °C, soil temperature is $t_e=3.1$ °C.

Soil moisture, % (clays and loams)	Calculation mode of the pipelines		If there is no insulation on both pipelines	
	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case
0	$q_1^L = 43.57$ $q_2^L = 17.44$	26.28	$q_1^L = 45.77$ $q_2^L = 17.81$	27.25
16	$q_1^L = 51.09$ $q_2^L = 22.81$	21.84	$q_1^L = 68.66$ $q_2^L = 26.71$	27.25
32	$q_1^L = 62.25$ $q_2^L = 31.45$	14.99	$q_1^L = 137.32$ $q_2^L = 53.42$	27.25
38	$q_1^L = 63.16$ $q_2^L = 32.19$	14.25	$q_1^L = 146.79$ $q_2^L = 57.10$	27.25

Table 4. Soil temperature at the point of intersection of double-pipe heat networks with low-pressure gas pipeline. Design parameters of coolant are 115/60 °C, soil temperature is $t_e=3.1$ °C.

Soil moisture, % (clays and loams)	Calculation mode of the pipelines		If there is no insulation on both pipelines	
	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case	Heat loss, W/m	Soil temperature on the wall of the gas pipeline case
0	$q_1^L = 55.89$ $q_2^L = 17.25$	30.83	$q_1^L = 58.79$ $q_2^L = 17.44$	31.98
16	$q_1^L = 65.20$ $q_2^L = 23.39$	25.52	$q_1^L = 88.18$ $q_2^L = 26.15$	31.98
32	$q_1^L = 78.94$ $q_2^L = 33.40$	17.34	$q_1^L = 176.36$ $q_2^L = 52.31$	31.98
38	$q_1^L = 80.06$ $q_2^L = 34.26$	16.65	$q_1^L = 188.52$ $q_2^L = 55.91$	31.98

Table 1-4 shows that the minimum heat loss is typical for dry soil and they increase many times depending on soil humidification. Soil temperature on the wall of the gas pipeline case for the design mode of operation of pipelines in this case is the maximum, but does not exceed the allowable 40 °C.

In case of complete absence of insulation on the pipeline, the maximum temperature on the wall of the gas pipeline case is 36.28 °C in January, with calculated coolant parameters of 130/70 °C and soil temperature $t_e = 3.1$ °C at the depth of the heat pipeline $H = 1.6$ m.

4 Conclusions

Based on the studies performed, a solution was obtained to the current scientific and practical task of assessing the soil temperature at the intersection of the heating line of the underground gasket and the low-pressure gas pipeline, taking into account real operating conditions.

The received results show that use of a polyethylene case of PE100 GAZ of SDR11-225x20.5 is admissible since temperature on a case will not exceed 40 °C at calculated parameters of the coolant of 130/70 °C even with total destruction of thermal isolation.

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