

# Impact of soil moisture on heat losses of pipelines of district heat supply networks at underground channel-free gasket

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## Abstract

The issues of influence of soil moisture, heat insulation type and heat carrier temperature on heat losses of district heat supply networks pipelines are considered. Calculations were carried out to change the efficiency of insulation of polyurethane foam and polymineral foam for four different modes of operation of district heat supply networks pipelines with gradual moistening of soil from 0 to 48% with channel-free lying; insulation is not wetted. The reasons and consequences of different temperature levels in district heating networks in Russia and Western Europe are considered. The calculated distribution temperatures in the central heating system pipeline were 75.85/49.85°C. The results show that the thermal losses of the pre-insulated pipelines increase many times depending on the soil moistening. In addition, calculations showed that in absolutely dry soil heat loss of pipelines of heat networks laid channel-free for all considered modes is less than calculated. But absolutely dry soil is a condition characteristic of deserts rather than the Middle Volga region.

**Keywords:** district heating networks, pipe insulation, heat loss.

## 1 Introduction

The first district heating plant was constructed in 1876 in Lockport, New York, United States. After 50 years, Europe operated more than 200 district heating systems. After 100 years, 800 cities in the Soviet Union were provided with centralized heat supply. Now nearly 150 years later, centralized heat supply is a proven, efficient and most economical way of heating during cold times in many regions and countries. In most works related to the development of heat supply systems [1,2] following problems are considered: air pollution reduction [3], real carbon savings, energy efficiency improvements [4], lower energy prices and dependence on fossil fuels, renewable energy [5], reduced heat losses during transportation [6], determination of thickness of thermal insulation [7].

In recent years, China has seen a significant increase in publications on the efficiency of district heat supply. A significant reduction in carbon dioxide emissions, which, with centralized heat supply, can be achieved at a lower cost than alternatives, taking into account Sweden's positive experience in this area [4,8,9]. The development of district heating in areas of Southern China may contribute to the reduction of energy consumption. Debate on whether South China should provide centralized heating to the residential sector, using a system widely used in North China was analysed by authors [10]. Not only does the climate seriously influence the choice of heat supply system, but also economic and political factors. For example, the Governments of Georgia, Armenia and Romania have abandoned the district heat supply to cities and have taken the path of decentralization of heat supply to consumers. Experts noted insufficient introduction of pipe insulation in Kyrgyzstan, Armenia, Turkey, Georgia, Montenegro and Serbia.

Reducing heat losses from pipeline networks in district heating systems is one of the main problems [11]. Energy conservation is becoming an increasingly important issue [12], specialists consider the economic and environmental consequences of insulation of district heating pipelines [13].

Environmental impact from the use of district heating systems is given in the works [7,13–16]. In studies devoted to the optimal thickness of insulation layer for pipes of different diameters [7,11] the effects of insulation thickness on cost parameters and corresponding savings in the heat supply system are considered.



In work [17] Invention proposes the use of hybrid heat insulation pipes, in which the innermost part of heat insulation consists of vacuum insulation panels held in place by polyurethane foam. In article [18] results of thin-film coating effect in the design of heat insulation of heat networks pipelines on reduction of heat losses are given. Among the heat insulation materials that appear on the construction market, natural fibre-based materials can be distinguished separately [19].

The Russian district heating systems have their own features related to regulation, heat carrier parameters, high percentage of wearing and considerable length of heat networks. Let us consider the change in the efficiency of heat insulation of heat supply networks pipelines at underground channel-free laying operating in the conditions of flooding in the city of Kazan. Kazan is a city in Russia, the capital of the Republic of Tatarstan, a major port on the left bank of the Volga River. The city is located in the middle course of the Volga River and is broken by the channel of the Kazanka River into the Northern and Southern part of the city. Waterproofing, karst, subsidence, conservation processing, flooding of soils with leaks from water-bearing services are widespread [25]. The city's system of engineering protection against flooding, established in the 1950s, has almost failed. Today in Kazan 25 % of the territory is in a state of constant flooding. The groundwater level in Kazan became much higher (from 0 to 3 m) after the creation of the Kuibevsky Reservoir in 1957. Geologists state that the construction of Kazan metro was a serious geological issue. For example, in the area of Gorki station (opened in 2005) the metro became a kind of underground dam [26].

Such conditions have a significant effect on the thermal loss of the subterranean heat channels. The total length of Kazan heat networks is 1,158.5 km (in single-tube terms. Soil humidity is not constant during the year. Maximum soil humidity is observed during the spring period, during snow cover melting. In this regard, it is interesting to evaluate the effect of the soil moisture volume on the thermal flows in the zone of underground channel-free thermal pipelines, to determine the value of linear thermal losses  $q$ , W/m.

## 2 Methods

When selecting a heat insulation material for thermal networks, the thermal conductivity coefficient is not the only criterion. For heat lines laid channel-free in the ground, it is important that their design has physical and technical characteristics that allow protecting the steel pipe from corrosion and heat loss, at the same time freeing the heat line from perception of external loads.

In the SP 124.13330.2012 "Thermal networks" in the section "thermal isolation" (item 11.10) it is recommended to consider two groups of thermal line structures when selecting structures for channel-free gaskets of thermal networks:

Group "a" - heat lines in the sealed steam-tight hydraulic containment. Representative structure - factory made thermal lines in polyurethane foam heat insulation with polyethylene shell according to GOST 30732;

Group "b" - heat lines with steam-permeable hydraulic protection coating or in monolithic heat insulation, the outer compacted layer of which must be waterproof and simultaneously steam-permeable, and the inner layer adjacent to the pipe - protect the steel pipe from corrosion. Representative structures - thermal pipelines of factory manufacture in foamed polymeminerall or reinforced concrete heat insulation.

Therefore, two types of heat insulation were chosen to calculate heat losses through the insulated surface of heat network pipelines at underground channel-free gasket: polyurethane foam insulation  $\delta_{is}=90$  mm,  $\lambda_{is}=0.33$  W/(m·°C) and polymer-mineral foam insulation  $\delta_{is}=60$  mm,  $\lambda_{is}=0.043$  W/(m·°C). Diameter of heat conductors  $D_{\gamma}=500$  mm. In both cases, the horizontal distance between the pipe axes  $K_{1,2}=1.0$  m. Calculations were made for different modes of thermal pipelines operation with simultaneous moistening of soil from 0 to 48 % (insulation is not wetted). Soil - loam, average soil density 1600 kg/m<sup>3</sup>.

Polymer-mineral foam is a monolithic vapor permeable structure with variable cross-sectional density, created by molding in a single technological operation. Material developed more than 20 years ago, used in thermal insulation structures of pipelines with diameter up to 500 mm. It is

characterized by integral structure combining functions of heat-insulating layer and waterproofing coating. It has application temperature up to 150 °C, heat conductivity coefficient at 25 °C – 0.047 W/(m·°C). It belongs to the group Г1 which means low-burning. Pipelines in polymer-mineral foam insulation are operated in various cities of Russia (Moscow, St. Petersburg, Kazan, Vladimir, Rostov-on-Don, Naberezhnye Chelny, Kolomna, Yaroslavl, Dubna, etc.).

Pipes in polyurethane foam insulation first appeared in the late 1960s. It is a monolithic structure that includes: a steel pipe, a heat insulation layer made of polyurethane and a protective shell. Thermal conductivity of polyurethane foams has been studied by specialists for more than 20 years [20]. When using pipes with polyurethane foam insulation, it should be taken into account that the allowable temperature of polyurethane foam application is 130 °C, but short-term exposure to temperature up to 150 °C. Expanded polyurethane foam is prone to aging and accordingly to breaking at high temperatures. At the constant temperature of 120 °C, the service life of the polyurethane foam is 30 years and at 150 °C it is only 1.5 years. The fact that in reality in heat networks high temperatures operate for a very short time saves. Evaluation of the technical condition of pipes after natural or artificial ageing (accelerated ageing was carried out by applying three different elevated temperatures) is considered in the study [21].

We will carry out calculations of change of thermal insulation efficiency of structures of pipelines of groups "a" and "b," operating in conditions of flooding and quality control of heat release according to temperature schedule 130/65 °C, adopted at Kazan combined heat and power plants, when the temperature of the network water varies depending on the temperature of the outside air.

### 3 Results and Discussion

Average distribution temperatures in district heating systems in the supply and return pipelines were determined by formulas (1-3):

$$t_{\hat{a}} = \frac{(\tau_{m1}n_1 + \tau_{m2}n_2 + \dots + \tau_{m12}n_{12})}{(n_1 + n_2 + \dots + n_{12})}, \quad (1)$$

$\tau_{m1}, \tau_{m2}, \dots, \tau_{m12}$  – average water temperature in the supply and return pipelines by months, determined by the schedule of the central quality regulation depending on the average monthly outside air temperature;

$n_1, n_2, \dots, n_{12}$  – number of hours by month.

$$t_{\hat{a}1} = (92,02 \cdot 744 + 90,62 \cdot 672 + 77,06 \cdot 744 + 70 \cdot 720 \cdot 3 + 70 \cdot 744 \cdot 4 + 74,8 \cdot 720 + 86,53 \cdot 744) / 8760 = 75,85 \text{ } ^\circ\text{Ñ} \quad (2)$$

$$t_{\hat{a}2} = (54,8 \cdot 744 + 54,27 \cdot 672 + 50,18 \cdot 744 + 48,1 \cdot 720 \cdot 3 + 48,1 \cdot 744 \cdot 4 + 49,51 \cdot 720 + 53 \cdot 744) / 8760 = 49,85 \text{ } ^\circ\text{Ñ} \quad (3)$$

In the 1980s in the countries of Western Europe there was a tendency to decrease the temperature in the supply line of the heating network to 110-120 °C. This trend continues. Currently most systems operate with temperatures of about 80-90 °C and the challenge for the future is to reduce it to 50-55 °C to enhance the use of renewable energy. Table 1 shows the typical annual average temperatures of the heat carrier in the water heating networks existing in Russia, Sweden and Denmark and in the low-temperature district heating systems planned in the EU. Researches [22–24] show that the main incentive for lower temperatures in district heat supply systems is to lower heat supply costs and losses in heat distribution, and to reduce thermal deformations of the pipeline.

The decrease in temperature leads to the need to increase the flow rate of the network water and increase the diameters of the pipelines. In Russia in the 40-s of the last century the water temperature

in the supply pipeline was accepted 120-130 °C. In 1950-s it rose to 150 °C, and thermal power experts discussed the possibility of raising the temperature to 180 °C. The following reasons for increasing the parameters can be mentioned: reduction of capital expenditures in thermal networks; imperfect thermal insulation and high heat loss; increasing the share of hot water supply load in the structure of heat supply system loads. At present, in Kazan heat supply networks, as in many cities of Russia, requirements to ensure reliability of heat supply at considerable network wear led to the need to optimize design parameters of 130/65 °C schedule, by 115/65 °C.

**Table 1.** Temperature levels in district heating networks.

Existing and planned heating systems	Typical average annual coolant temperatures in water thermal networks, °C	
	feed line	return line
Russia	65-90	50
Kazan combined heat and power plants	75.85	49.85
Sweden	86	47
Denmark	77	42
Future 4th Generation District Heating Systems	50-55	20-25

The thermal conductivity of the soil is also not a constant value, it depends on the humidity. Maximum soil humidity is observed during the spring period, during snow cover melting. Soil thermal conductivity increases dramatically as humidity increases because the thermal conductivity of air displaced by water from rock pores is approximately 25 times less than the thermal conductivity of water.

Calculations were carried out for the following cases: design mode; absence of insulation on the return pipeline; absence of insulation on the supply pipeline; no insulation on both pipelines.

Thermal losses of double-tube heat networks at channel-free laying, W/m, located in the soil at the same distance from the surface to the axis of pipes, are determined by formulas:

$$q_1^L = \frac{(t_{a1} - t_e)(R_{is2}^L + R_s) - (t_{a2} - t_e) \cdot R_i}{(R_{is1}^L + R_s)(R_{is2}^L + R_s) - R_i^2} K; \quad (4)$$

$$q_2^L = \frac{(t_{a2} - t_e)(R_{is1}^L + R_s) - (t_{a1} - t_e) \cdot R_i}{(R_{is2}^L + R_s)(R_{is1}^L + R_s) - R_i^2} K, \quad (5)$$

where

$t_{a1}, t_{a2}$  – coolant temperature in supply and return pipelines of heat network annual average, °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 soil, m·°C/W;

$R_i$  – thermal resistance caused by thermal interaction of two pipes, m·°C/W;

$K$  - coefficient of additional losses.

Calculation results and comparison of specific heat losses with normative ones are summarized in tables 2 and 3.

**Table2.** Comparison of heat losses through isolated surface of pipelines of district heat supply networks at underground channel-free gasket for polyurethane foam insulation.

Soil dampness, %	Norm of density of thermal Flow as per SP 61.13330.2012 Thermal insulation of equipment and pipelines, W/m	Thermal losses of heat conductors, W/m, at $D_y = 500$ mm			
		Design mode	Lack of isolation on the return pipeline	Lack of isolation on the giving pipeline	Lack of isolation on both pipelines
0	164.4	37.87	46.61	63.43	64.65
16		58.52	114.54	183.18	188.04
32		63.54	152.95	253.49	260.63
48		66.28	183.98	310.66	319.83

Note: table shaded thermal losses exceeding the rated

From the data of Tables 2 and 3 it can be seen that in absolutely dry loam with average density of  $1600 \text{ kg/m}^3$ , pipelines of heat networks laid without channel can operate in the absence of insulation on both pipelines (heat losses  $64.65 \text{ W/m}$  almost three times less than the rated  $164 \text{ W/m}$ ). But absolutely dry soil does not belong to real conditions for Kazan.

**Table3.** Comparison of heat losses through isolated surface of pipelines of district heat supply networks at underground channel-free gasket for polymer-mineral foam insulation.

Soil dampness, %	Norm of density of thermal Flow as per SP 61.13330.2012 Thermal insulation of equipment and pipelines и трубопроводов, W/m	Thermal losses of heat conductors, W/m, at $D_y = 500$ mm			
		Design mode	Lack of isolation on the return pipeline	Lack of isolation on the giving pipeline	Lack of isolation on both pipelines
0	164.4	47.25	51.65	63.77	64.65
16		86.35	124.99	183.86	188.04
32		98.35	164.9	254.29	260.63
48		103.19	196.8	311.52	319.83

Note: table shaded thermal losses exceeding the rated.

Natural moisture content of soil is 16 %. As can be seen from Tables 2 and 3, in this case the thermal losses of the design mode of pipelines operation with different insulation do not deviate from the norm of heat flux as per SP 61.13330.2012 Thermal insulation of equipment and pipelines.

Comparison of the results obtained in Tables 2 and 3 shows that in case of a channel-free gasket with polyurethane foam insulation, thermal losses of pipelines depending on soil moistening increase 1.75-4.95 times; with polymer-mineral foam insulation thermal losses increase 2.18-4.95 times. In terms of heat loss under flooding conditions, polyurethane foam is the most optimal heat insulation. In addition, the waterproofing coating of the pre-insulated pipes eliminates the possibility of wetting the insulation during operation. The outer protective shell is made of polyethylene, which allows laying pipes directly into the trench on the sand fill instead of building an expensive channel. The design of pipelines with polyurethane foam insulation advantageously differs from other pipelines. It also has an

operational remote control system - ODK, the cost of which is 1 % of the cost of the pipeline. The presence of the ODK system on pipelines with polyurethane foam insulation allows detecting the resulting defect in a timely manner and, at its prompt elimination, to ensure the standard service life of this pipeline. As a result, operating costs are reduced by 9 times.

#### 4 Conclusions

Energy saving and heat loss reduction are strategic tasks of district heat supply. Calculations were made to change the efficiency of polyurethane foam and polymer-mineral foam insulation for four different operation modes of district heat supply networks pipelines with gradual moistening of soil from 0 to 48 % at underground channel-free gasket, insulation is not wetted. Dependence of efficiency change of pipelines thermal insulation and thermal losses of pipelines operating under conditions of soil moisture change is obtained, while SP 41-103-2000 "Design of thermal insulation of equipment and pipelines" methods do not contain instructions on the procedure of soil moistening accounting in different conditions. The results obtained are compared with the standard values.

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