

Modeling and thermal calculation of a pipeline insulation system

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Abstract. Energy efficiency of heating networks depends on the costs of the manufacture of insulation materials and components, its installation and exploitation of insulating jacket. As insulation materials for insulation of heating networks, products based on rock wool, polyurethane foam extruded polystyrene foam, foam rubber and polyethylene foam. In this contribution introduced basic principles of calculating the thickness of the thermal insulation of a pipeline by the value of the standard density of the heat flow are given using an example of the use of products based on polyethylene foam. Calculation of the heat flux from the surface of the heat-insulating structure is carried out at a given thickness of the heat-insulating layer if there is a need to determine heat loss (or cold loss). The basis for the calculation is a mathematical model of heat transfer, a developed calculation algorithm and a computer program. The method of installation of thermal insulation depends on the diameter of the pipeline and the selected type of product. Insulating cylinders or cylinders in combination with heat-insulating mats are used for pipelines of small diameters. Roll materials are used to isolate large diameters. Products are fixed on pipelines using mechanical fasteners.

1 Introduction

Energy efficiency and energy conservation are one of the priority programs for the development of the domestic construction industry. The current stage of technological development also imposes additional requirements for energy efficiency, reliability, environmental friendliness. [1-3]. The requirements for energy efficiency are also relevant for housing and communal services, including heating networks.

The determining component of the energy efficiency of heating networks is heat conservation, which, in turn, depends on the type of heat-insulating material, its thermal conductivity, the thickness of the heat-insulating layer and the methods of installation this system. As heat-insulating materials, products based on stone wool, polyurethane foam, extruded polystyrene foam, foamed rubber and polyethylene foam are used [4-6]. Each type of material is used in its temperature range of operation and in conditions of contact with the environment, as well as in the price range.

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For the correct selection and implementation of the pipeline insulation system, it is the purpose of the optimal thickness of the insulation layer, the calculation of which can be carried out by various methods [7-9]. The thickness of the insulating layer can be determined by:

- a given heat flux density
- set temperature on the insulation surface
- conditions for preventing moisture condensation on the insulation surface
- a predetermined decrease (increase) in the temperature of the substance transported by pipelines;
- conditions for preventing freezing (hardening) of a substance in a pipeline for a predetermined time in the event of suspension of its movement or time before freezing (hardening) of a substance in a pipeline

For pipelines operating in temperature ranges not exceeding 65 ° C, the use of polyethylene foam is optimal, and the calculation of the thermal insulation thickness can be based on a given heat flux density [10-12].

2 Materials and methods

Foamed polyethylene is an insulating material, which use is expanding in construction, due to its undoubted advantages: low heat conductivity, vapor permeability and water absorption, satisfactory strength characteristics and high operational stability. The features of this material are flammability and low resistance to ultraviolet radiation (intense solar radiation). Consideration of these features in the design of insulation systems is required [13, 14].

Products based on foamed polyethylene (tubes, sheets, rolls) are used in insulation systems of pipelines of heating networks of heating systems, hot and cold-water supply and other technological systems. In insulation systems, in addition to the main insulating materials, auxiliary and completing materials (accessories) are also used: coating materials (flexible shell and metal shell), suture glue, reinforced self-adhesive tape, sealant, bandage, self-tapping screws, etc.

The required thickness of the insulating layer can be determined by the normative density of the heat flux.

Calculation of the heat flux from the surface of the heat-insulating structure is carried out if it is necessary to determine the heat loss (or cold loss) at a given thickness of the heat-insulating layer of polyethylene foam products.

The linear heat flux density from 1 m of the length of a cylindrical heat-insulating structure (q_l , W / m) is calculated by the formula:

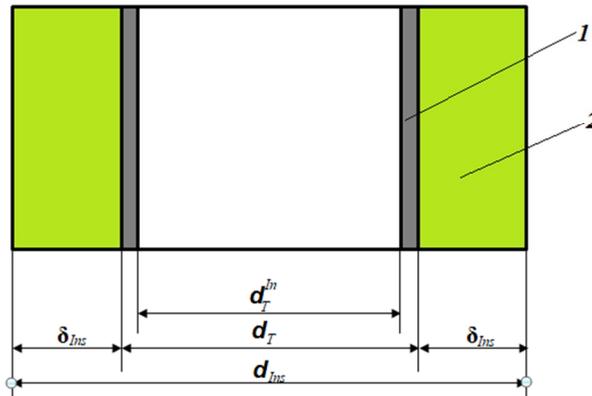
$$q_l = \frac{t_T - t_0}{R_{In}^l + R_{St}^l + R_{Is}^l + R_E^l} \quad (1)$$

where: R_{In}^l – is the linear thermal resistance to heat transfer from the substance to the inner surface of the wall of a planar insulated object, (m °C) / W;

R_{St}^l – linear thermal resistance to heat transfer of the wall of a flat insulated object, (m °C) / W;

R_{Is}^l – linear thermal resistance of a flat insulation layer, (m °C) / W;

R_E^l – linear thermal resistance to heat transfer from the outer surface of a flat heat-insulating structure to the ambient air, (m °C) / W



d_T^{in} – inner diameter of the pipeline; d_T – out-diameter of the pipeline; d_{Ins} – the outer diameter of the insulating layer; δ_{Ins} – thermal insulation splint; 1 – pipeline; 2 – pipe insulation.

Fig. 1. Isolation of the pipeline.

Thermal resistance of the insulating layer for a cylindrical surface (fig. 1):

$$R_{Ins}^l = \frac{1}{2\pi\lambda_{Ins}} \cdot \ln \frac{d_{Ins}}{d_T^{in}} \quad (2)$$

$$R_E^l = \frac{1}{\pi d_{Ins} \alpha_E} \quad (3)$$

$$R_{In}^l = \frac{1}{\pi d_T^{in} \alpha_{In}} \quad (4)$$

where d_T, d_T^{in} – outer and inner diameter of the pipeline, m;
 d_{Ins} – the outer diameter of the heat-insulating layer (heat-insulating structure), m.
 The outer diameter of the insulating structure is determined by the formula:

$$d_{Ins} = d_T + 2\delta_{Ins} \quad (5)$$

The heat flux from the surface of the insulated pipeline is determined by the area of this surface (calculated through the outer diameter of the insulation layer) and the thickness of the insulation [15, 16]. With pipeline diameters of more than 1 m, the heat transfer surface becomes more than a significant factor determining the heat loss. This fact changes the boundary conditions, making the accepted methodology inapplicable. Therefore, in the article only pipelines whose diameter does not exceed 1000 mm are considered.

3 Results

Using the mathematical apparatus of heat transfer and solving the equation for the heat flux through a multilayer cylinder under given boundary conditions, it was possible to obtain a system of equations that allows one to determine the thickness of the heat-insulating layer by the given heat flux density from the thermal insulation surface for pipelines and equipment with an outer diameter of 1400 mm or less:

$$\ln\left(\frac{d_T + 2\delta_{ins}}{d_T}\right) = 2\pi\lambda K\left(\frac{t_V - t_0}{q}\right) = C \quad (6)$$

$$\delta_{ins} = \frac{d_T}{2}(\exp(C) - 1) \quad (7)$$

- λ – thermal conductivity of thermal insulation, is taken equal to 0.04 W / (m·K);
- K – is the additional loss coefficient, we take equal 1.05;
- q – is the heat flux density;
- t_V – is the calculated temperature of the coolant (substance): for the return pipe - 50 °C; for a direct pipeline of 65 °C;
- t_0 – ambient temperature in the room, 18 °C;
- d_T – is the outer diameter of the pipeline, mm;
- C – is a constant obtained as a result of intermediate calculations.

The next step was the formation of an algorithm and the development of a computer program that allows calculating the thickness of the insulating layer depending on: thermal conductivity of the insulation (λ , W / (m·K)); design temperature of the heat carrier (t_V , °C); outer diameter of the pipeline (d_T , mm) and heat flux density (q , W / m).

The program interface is shown in fig. 2.

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Free Pascal Compiler version 2.6.2-8 [2014/01/22] for x86_64
Copyright (c) 1993-2012 by Florian Klampfl and others
Target OS: Linux for x86-64
Compiling main.pas
Linking a.out
27 lines compiled, 0.2 sec
./a.out/./a.out: warning: link.res contains output sections; did you forget -F?
lambda = thermal conductivity of thermal insulation, taking into account clause 10.2.4 of the SRT, is taken equal 0,04 W/(m·K) -the additional loss coefficient, in accordance with clause 10.2.3 of the SRT (Table 1.3), is assumed equal to 1,05;q - heat flux density, taken according to SP 61-13330-2012 table. 4 and 5;tB - settlement temperature of the heat carrier (substance): for the return pipeline - 50 ° C; for a direct pipeline of 65 ° C;t0 - ambient temperature in the room, 18 ° C; dtr is the outer diameter of the pipeline, mm;C - constant resulting from intermediate calculations.
lambda= 0.04
K= 1.05
q= 22
tB= 50
t0= 18
dtr= 100
C= 3.83650909090909E-001The thickness of the insulating layer q = 2.13842899909338E+002

...Program finished with exit code 0
Press ENTER to exit console.
    
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Fig. 2. Program interface.

The calculation of the thickness of the insulation, carried out according to the normative density of the heat flux adopted in accordance with the Code of Rules SP 61-13330-2012, allowed us to obtain the values of the optimal thickness of the thermal insulation of pipelines with an outer diameter of 22 to 1000 mm. The temperature of the coolant in the direct pipeline was taken equal to 65 ° C, and in the return pipe: 50 ° C. The calculation results are presented in table 1. The values of flux densities at 65 ° C were obtained by interpolating the values of flux densities between 50 and 100 ° C.

Table 1. Optimum thermal insulation thickness corresponding to the norms of heat flux density for pipelines with positive temperatures when located in the room and the number of hours of operation is more than 5000.

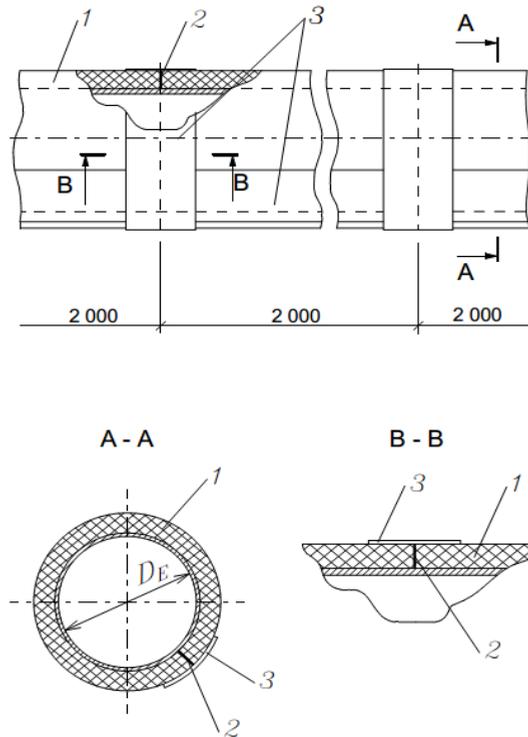
Conditional pass of the pipeline, mm	Outer diameter of the pipeline, mm	Norm of heat flux density at at t_{fn} , °C			Thermal insulation thickness, mm at t_{i2} , °C	
		50	100	65	50	65
15	22	6	14	8.4	32	36
20	28	7	16	9.7	32	36
25	35	8	18	11.0	32	36
40	48	9	21	12.6	36	38
50	60	10	23	13.9	39	42
65	76	12	26	16.2	39	43
80	89	13	28	17.5	40	46
100	110	14	31	19.1	44	49
125	133	16	35	21.7	45	51
150	160	18	38	24.0	46	54
200	219	22	46	29.2	50	57
250	273	26	53	34.1	51	59
300	325	29	60	38.3	52	62
350	377	33	66	42.9	53	63
400	426	36	72	46.8	54	64
450	473	39	78	50.7	54	64
500	530	43	84	55.3	54	66
600	630	49	96	63.1	56	66
700	720	55	107	70.6	58	68
800	820	61	118	78.1	59	70
900	920	67	130	85.9	60	70
1000	1020	74	141	94.1	61	71

The thickness of the heat-insulating material and the diameter of the pipeline suggest various methods of installation of the insulating sheath.

4 Discussions

In heat-insulating structures on pipelines, heat-insulating products in the form of tubes should be used as thermal insulation, and in the absence of the required tube size in the manufactured product range, heat-insulating products in the form of rolls.

Fastenings of heat-insulating products on pipelines, depending on the type of material, must be performed by the method recommended by the manufacturer. For fastening the pipes on pipelines, the longitudinal and transverse seams of the products should be glued with contact adhesive recommended by the manufacturer. It is recommended to additionally glue the product seams with self-adhesive reinforced tape.



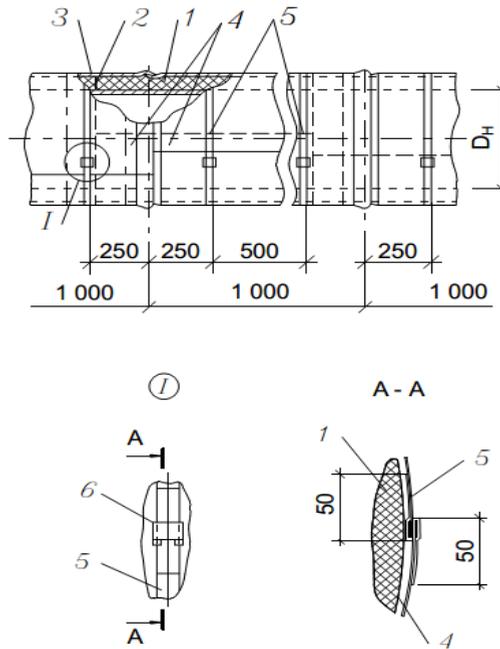
1 – tube made of insulating material; 2 – glue; 3 – tape reinforced self-adhesive.

Fig. 3. Thermal insulation design of the pipeline with a diameter D_E .

In fig. 3 shows a mounting option for a heat-insulating structure consisting of a heat-insulating tube, glue and a reinforced self-adhesive tape. When installing heat-insulating products in the form of rolls or mats on pipelines, bandages should be arranged located in increments of 500 to 600 mm.

It is allowed to use metal tapes with a corrosion-resistant coating of stainless steel, aluminum alloys or polyamide for the bandage. The material of the bandage used for attaching the coating layer must match the material of which the coating is made. The material used to make the buckle must match the material of which the band is made (galvanized or stainless steel, aluminum alloy sheets).

For fastening sheets (rolls) on pipelines, the joints of products should be glued with contact adhesive recommended by the manufacturer. It is recommended to additionally glue the product seams with reinforced self-adhesive tape, and also fix the products with reinforced self-adhesive tape bandages located in increments of 500 to 600 mm.



1 - a tube of heat-insulating material at $D_H \leq 160$ mm (sheet of heat-insulating material at $D_H > 160$ mm); 2- glue; 3- tape reinforced self-adhesive; 4- metal shell; 5- bandage (with buckle 6).

Fig. 4. Heat-insulating structure with bandage fastening.

In multilayer heat-insulating structures designed for pipelines, the installation of the second and subsequent layers of thermal insulation is performed with overlapping seams of each previous layer. The seams of all layers of thermal insulation are glued with contact adhesive. It is recommended to additionally glue the seams of the outer layer with a reinforced self-adhesive tape. Two-layer thermal insulation of a tee with a coating of metal shells and fastening with screws is shown in fig. 4.

Non-removable thermal insulation of coupling fittings installed on pipelines is made of products in the form of tubes or rolls together with thermal insulation of the pipeline. The cutout for the drive is performed at the installation site.

Installation of coatings (lining) should be done with an overlap of 40 to 50 mm along the longitudinal and transverse seams.

Fastening of the cladding from thin-sheet metal shells or other metal coatings is carried out using self-tapping screws or bandages. With a thickness of the heat-insulating layer from 13 mm and higher, self-tapping screws are used, which are installed in increments of 250 to 300 mm along the guide and 150 mm around the circumference. Bandages are installed in increments of 500 to 600 mm. Fig. 4 shows the construction of a thermally insulated pipeline with a metal sheath, using bandage fastening.

5 Conclusion

Polyethylene foam has not only low density and thermal conductivity, but also low water absorption and vapor permeability. Building insulation systems using polystyrene foam are widely used in construction practice. Sheets and rolls made of polyethylene foam (with foil or metallized coating, as well as without coating) are used in the insulating shells of frame buildings and cottages, for the isolation of frameless structures, in the construction of warm warehouses, agricultural products storage facilities, livestock housing. One of the promising

areas for the use of this material is construction in the northern regions, where the need for effective insulation, resistant to frost and inert to air humidity and water, is an urgent need.

The developed methodology for calculating the thickness of the insulating layer according to a given (normative) heat flux can be the basis for constructing a model for assessing the energy efficiency of insulation of pipelines with a diameter of up to 1000 mm. Regardless of the isolation method. The type and type of heat-insulating products can be any, and the choice of material is determined only by the operating conditions and requirements for operational stability and possible emission of harmful substances (for insulation indoors)

The heat flux from the surface of the insulated pipeline is determined by the area of this surface (calculated through the outer diameter of the insulation layer) and the thickness of the insulation. With pipeline diameters of more than 1 m, the heat transfer surface becomes more than a significant factor determining the heat loss. This fact changes the boundary conditions, making the accepted methodology inapplicable. Therefore, in the article only pipelines whose diameter does not exceed 1000 mm are considered.

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