

Assessment of geo-cryological conditions in the design and operation of pipelines in the Arctic zone of the Russian Federation

V V Golik, B V Moiseev, Y D Zemenkov and E N Kabes

Industrial University of Tyumen, 38 Volodarskogo st., Tyumen, 625000, Russia

E-mail: darkpaint@mail.ru

Abstract. The paper presents the methodology of calculations and technical justification for the use of new equipment. The section of the operating oil pipeline in the part of monitoring of heat engineering processes is considered. The main results of thermo-technical calculations of the pipeline section were described and the aureoles of thawing of the permafrost soil were simulated. As an example for replacement, a multilayer pipe with foamed polyurethane insulation and concrete casing was considered because of its better characteristics compared to the design one.

1. Introduction

The construction and operation of pipeline transport facilities for oil and oil products in the Arctic zone of the Russian Federation in which permafrost soils are widespread leads to significant changes in geo-cryological conditions. Progression of negative processes affecting the pipelines stability laid by underground method arises even with the slightest changes in the heat balance of the soil surrounding.

2. Methodology

The design of pipelines in the regions of the Far North and the Arctic zone of the Russian Federation is carried out in accordance with the current regulatory documents. When planning, it is necessary to provide for measures aimed at ensuring long-term and reliable operation of the pipelines to be laid, as well as to develop measures and select materials to minimize the negative impact on the soil and the environment as a whole [1].

To assess the temperature state of soils at the design stage of pipelines in the Arctic zone, thermal engineering calculations are carried out, specified by regulatory documents.

During the work on this subject, the existing normative documents [2] and calculation methods presented in the papers of the authors G.V. Porkhaev, E.Ya. Sokolov, A.F. Shapoval, and N.V. Nalobin were analyzed to increase the efficiency and accuracy of the calculated parameters and display the heat transferring process from the pipeline to the environment by software calculation [3-5].

On the basis of the department "Transport of Hydrocarbon Resources" of the Industrial University of Tyumen, studies have been carried out to simulate the thermal state of pipelines, their behavior in



the permafrost soils of the Arctic zone and to monitor the reliability characteristics of pipelines laid by the underground method.

Under the guidance of Professor B.V. Moiseev, a methodology has been developed for calculating and modeling the thermal state of the pipeline in permafrost.

The object of the study was a section of 77 km – 150 km of the Yarudeyskoye oil field located in the Nadym district of the Yamal-Nenets Autonomous District.

This field and the pipeline section were selected according to the following criteria:

- climatic zone with permafrost soil;
- soil composition;
- the presence of sites lying in the swampy terrain;
- pipeline laying by the underground method;
- pipeline defect - buckling of the pipeline (Figure1).



Figure 1. Defective pipeline section.

Table 1. Climatic characteristics of the studied area.

Characteristic	Nadym
Average annual outside air temperature, °C	-6.6
Average annual temperature of the summer period, °C	10
Average annual temperature of the winter period, °C	-14.9
Absolute maximum of the outdoor temperature, °C	35
Absolute minimum of the outside temperature, °C	-60
Average amplitude of temperature change, °C	24.9
Number of days in a year with a negative temperature	229
Average wind speed (January/July) m/s	4.5/4.0
Maximum wind speed m/s	5.0

Deposits in this area are represented by interstratification of clay-loamy rocks, with interlayers and individual lenses of fine, medium-sized and silty sandy loams and sandy loams. Deposits represent a complex mixture of marine, glacial-marine formations. The revealed thickness of clays reaches 15 m, that of loam - 13 m, that of sandy loam - 8 m and that of sand up to 6 m. The soils, drilled in April and May, are mostly in permafrost condition [6-8].

Based on the methodology developed by the team, the following tasks were performed:

- in accordance with the methodology developed, the thermo-technical calculation of the oil pipeline on the section of 77 km-150 km was carried out;
- analysis of calculations and selection of materials for the elimination of a defect were performed;
- software product for calculating the thermal properties of the soil was developed.

With the known climatic data, soil composition and technical characteristics of the pipes, it was necessary to determine heat losses in this pipeline section:

$$q = \pi k (t_v - t_n), \quad (1)$$

where k – coefficient of heat transfer from oil to the soil, t_v – temperature of the pumped medium, t_n – ambient temperature of the surrounding soil.

To calculate the heat transfer coefficient, it is necessary to calculate the actual thermal resistance for each layer of the insulation coating of the tested pipeline:

$$R_{in} = \frac{1}{2\pi\lambda_{in}} \ln \frac{D_n}{D_v}, \quad (2)$$

where D_n , D_v – the outer and inner diameters of the insulation layer, respectively, m ; λ_{in} – thermal conductivity of the insulating layer at an average insulation temperature.

Based on the calculations, the results are shown in Table 2 and Figures 2, 3. A new pipe was selected for this type of terrain and climate. It was namely multi-layer concrete coated pipe of the company "BT SVAP" ZUB Ballast having similar capacity, but meeting all the requirements for SP 86.13330.2014 Trunk pipelines.

Table 2. Design parameters of the pipelines under investigation.

Dimensions	Units of measurement	Multilayered concrete coated oil pipeline "ZUB Ballast"	Oil pipeline with foamed polyurethane insulation
Outside diameter d	m	0.639	0.503
Heat transfer coefficient k	W/m*K	0.176	0.599
Thermal resistance R	m*K/W	5.676	1.658
External temperature of the pipe t_{st}	°C/K	0.95/273.95	17/290
Initial product temperature on the section T_n	°C/K	55/328	
Final temperature on the section T_k	°C/K	51/327	43/316

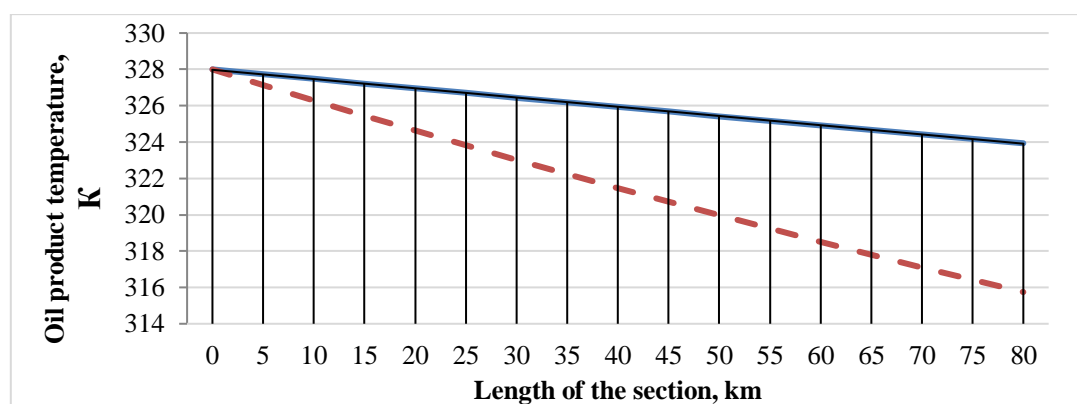


Figure 2. Temperature drop along the length of the oil pipeline:

- Multilayered concrete covered pipe "ZUB Ballast";
- - - Oil pipeline with foamed polyurethane insulation.

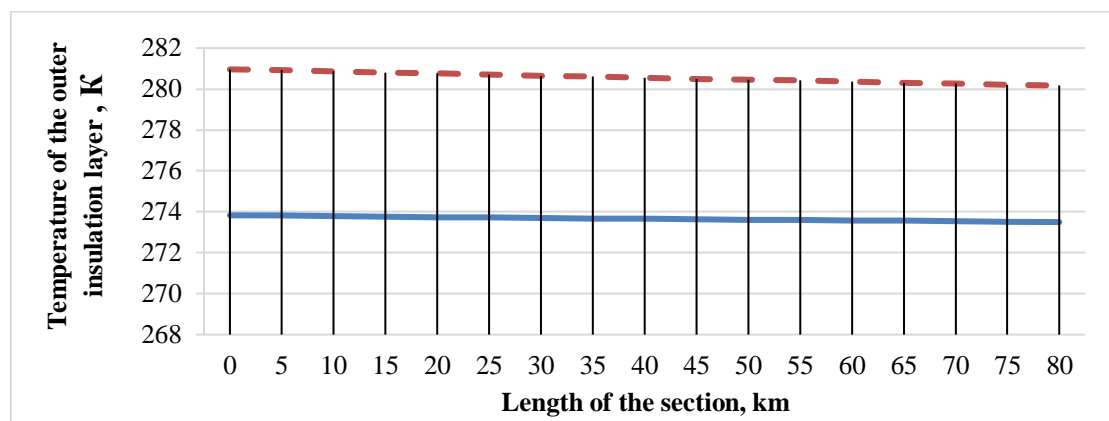


Figure 3. Temperature of the outer layer of insulation:
 — Multilayered concrete covered pipe "ZUB Ballast";
 - - - Oil pipeline with foamed polyurethane insulation.

3. Conclusion

Thus, the performance of heat engineering calculations of the interaction of an oil pipeline laid by underground method with permafrost soils is an important part of the design and operation process which allows making justified engineering decisions aimed at improving the reliability and durability of the facility with minimal environmental impact [9-10].

An integrated approach to the selection of optimal design solutions, including the simulation of thermal interaction in the pipe-ground system, allows the costs optimization without reducing reliability requirements.

The use of the latest software complexes in the simulation and creation of a specialized software product allows the automation of the calculation process and acceleration of the equipment selection.

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