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Reconstruction of a moss layer in permafrost conditions

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Abstract. The object of research in this work is the relationship between the feasibility of secondary use the moss layer and the thermal characteristics of an oil pipeline, which was laid underground in permafrost conditions. The purpose of the work is to determine the expediency of the secondary use of the moss layer with underground laying of the pipeline in the permafrost conditions. The choice of the object and purpose of the study is motivated by the intensive development of territories with permafrost soils, by the relevance of problems related to the construction and operation of the energy transport system, by its impact on the ecological development of the permafrost zone and by the need for further research aimed at solving these problems. The following tasks were formulated to achieve this goal: a) to determine the main thermal factor affecting the expediency of the secondary use of the moss layer; b) to consider the possibility of restoring the moss layer at various permafrost soils; c) to determine the feasibility of restoring the moss layer for underground laying pipeline with various types of energy resources; d) to determine the economic component of the secondary use of the moss layer. The equivalent of the Zapolyarye–Purpe Oil pipeline theoretical model of the underground oil pipeline is presented in this work for research. The inexpediency of the secondary use of the moss layer in the underground laying of the oil and gas pipeline is justified by the thermal and economic characteristics of the soil. Future considerations of this topic are related to the study of the economic indicators of underground pipelines in conditions of multi-layered permafrost soils.

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1. Introduction

The object of research in this work is the relationship between the expediency of secondary use the moss layer and the thermal characteristics of the oil pipeline, which is laid underground and transports energy resources in permafrost conditions.

The choice of the research object is caused by the intensive development of territories with permafrost soils, the relevance of problems connected with the construction and maintenance the energy transport system, its impact on the ecological development of the permafrost zone, and the need for further research aimed at solving these problems.

In developing the topic of this work, the authors pay attention to the following facts.

It is known that there are three methods of laying pipelines in the world experience. These are underground, land, and aboveground methods [1–4]. Each of them has advantages and disadvantages.

However, there are often situations in our lives when only underground pipeline laying is possible. Herewith, it's impossible to avoid a negative impact on the environment.

According to the authors, one of the main issues is the study of the feasibility of restoring the moss layer on the surface of the soil that has been developed because the use of moss layer restoration technology in permafrost conditions will require significant additional financial and time resources [2, 4].

Analysis of the scientific literature has shown that the choice of the most effective technology for underground pipeline laying in permafrost conditions is a serious problem. It requires a comprehensive analysis, which is aimed not only at solving technical problems but at the impact of the construction process on the ecosystem also [5–9].

During the search of effective technologies for underground laying of pipelines, some authors [10–18] describe various factors and approaches to finding optimal technical solutions during the installation and operation of pipelines in permafrost distribution areas. However, these works are experimental in nature and do not reflect the relationship between pipeline laying technology and its effect on the temperature condition of permafrost soils. There is no information about the necessity of the secondary use moss layer here.

On the other hand, some authors [19–26] describe the relationship between various physical and mechanical properties of frozen soil and negative phenomena occurring in array of permafrost soils (frosty heaving, formation soil cracks, etc.).

These are theoretical works. They do not reflect the relationship between the technological operations during the construction of the pipeline (restoration the moss layer) and the process of thawing frozen soil.

As the analysis of scientific literature shows, some authors have conducted researches, which were related with the influence of the moss layer and the temperature mode of permafrost soils [27–30]. However, we have here the observation of the soils temperature mode with moss layer during long-term operation. There is not analysis of the expediency of restoring the moss layer during pipeline construction.

Thus, a review of the scientific literature has showed the lack of solution to the problem of the relationship between the secondary use of moss and the thermal parameters of permafrost soils during underground pipeline laying. And the purpose of the research has been obviously.

The purpose of the study is to determine the expediency of the secondary use moss layer during the underground laying of the pipeline in permafrost conditions.

We need to solve the following tasks in order to achieve the goal:

- to determine the basic thermal factor defining the expediency secondary use of the moss layer;
- to consider the possibility of restoring the moss layer with different types of permafrost soil;
- to determine the expediency of restoring moss layer for underground laying of pipeline with various types of fuels;
- to determine the economic effect of the secondary use moss layer.

2. Model and Methods

Research model

When the authors determined the design of the model for study, they relied on researches that were conducted in the field of interaction pipeline – frozen soil system [10, 11, 17, 19].

In the issue, it was decided to consider the model for study as the theoretical model of the oil pipeline, which was installed underground by analogy with the well-known Zapolyarye–Purpe Oil pipeline [15, 16]. Oil with a temperature of 60 °C was used as the transported raw material.

Design scheme of research model is shown in Fig. 1.

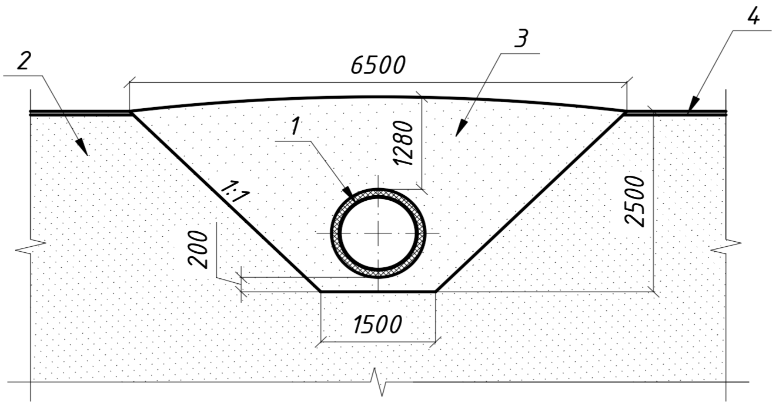

Figure 1. The researched model of the underground oil pipeline: 1 – oil pipeline, 2 – the studied permafrost soil, 3 – the soil of backfill (imported sand), 4 – moss layer.

The study of the feasibility of restoring the moss layer during underground pipeline laying in permafrost conditions was carried out using the calculation method in the PLAXIS 2D software package. Temperature fields and soil thawing indicators were determined in August of the first year operation of the pipeline. The temperature of 11.1 °C was assumed to be the edge condition on the ground surface. This temperature was determined on the basis of the technical report engineering and geological surveys of the Ust-Mom city Sakha Republic.

The main characteristics of frozen soils, backfilling soil, and moss layer were adopted on the basis of normative documents of the Russian Federation, technical reports of engineering, geological surveys and are presented in Tables 1, 2 and 3.

Table 1. Main characteristics of the moss layer.

Name title	Value
Layer thickness, mm	50
Density, kg/m^3	231
Specific heat, J/kg·°C	6170
Heat conductivity factor, W/m·°C	0.15

The pipeline is modeled as a steel pipe in a polyurethane foam shell construction with a diameter of 1020 mm. The wall thickness of the oil pipeline was determined by the methodology which was described in the normative document.

The formula for determining the thickness of the shell construction is presented below:

$$\delta = \frac{n \cdot p \cdot D_n}{2 \cdot \left(R_1 + n \cdot p \right)},$$

where n is load reliability factor; p is operating (standard) pressure, MPa; D_n is outside diameter of the pipeline, cm; R_1 is calculated compression resistance, MPa.

As a result, the thickness of the oil pipeline was accepted at 12 mm, and the thickness of the polyurethane shell construction was accepted at 100 mm.

Imported sandy soil with the characteristics given in Table 2 was considered as a backfilling soil.

Table 2. The main characteristics of the backfilling soil.

Name title	Value
Density, kg/m^3	2000
Elasticity modulus, MPa	40
Angle of internal friction, deg	40
Specific cohesion, kPa	1
Specific heat, J/kg·°C	835
Heat conductivity factor, W/m·°C	2.22

Sandy loam, loam, and clay, which are most often found in permafrost conditions, were considered as the studied soil. The characteristics of these soils are presented in Table 3.

Table 3. Main characteristics of permafrost soils.

Name title	Type of soil		
	Soft sandy loam	**Soft plastic loam**	**Plastic frozen sandy light clay**
Density, g/cm^3	1.82	1.82	1.67
Solid particles density, g/cm^3	2.7	2.71	2.73
Poisson number	0.3	0.34	0.35
Relative density, kg/m^3	1820	1820	1670
Angle of internal friction, deg	18	15	14
Total water content, %	23	26	30.6
Airspace ratio	0.82	0.88	1.128
Index of plasticity	0.06	0.09	0.208
Modulus of deformation, MPa	8	7	3.19
Specific cohesion, kPa	9	15	36
Total ice content, %	34	39	2.7
Ground freezing point, °C	–0.67	–0.68	–0.25
Yearly average temperature at a depth of 10 m, °C	–7	–7	–7
Specific heat, J/kg·°C	850	950	950
Volumetric heat capacity of frozen soil, kcal/ m^3·°C	487	535	667
Heat conduction coefficient of thawed soil/ frozen soil, kcal/ m·hr·°C	1.69/1.92	1.45/1.65	1.14/1.36

To maximize the approximation of the computational model in the PLAXIS 2D PC with real conditions, the monthly values of atmospheric temperature in Ust-Moma of the Sakha Republic were taken by authors. These values ranged from 14.8 °C (July) to –44.9 °C (January) [16].

The research task has been to determine the modification the thermal parameters of the pipeline-soil system.

3. Results and Discussion

During the modeling process, the distribution of these indicators was obtained for the oil pipeline of the pipe-ground system. The oil pipeline was installed underground in permafrost soils: sandy loam, loam, and clay.

Despite the numerous available factors affecting the thermal condition of the oil pipeline-soil system, the authors have accepted the depth of thawing and the width of the thawing halo effect as the studied factor, which determines the feasibility of restoring the moss layer during underground laying of the oil pipeline.

According to the authors, these indicators can cause negative natural hazards (frost heaving, soil slaking, etc.) and lead to loss bearing capacity of frozen soils and, as a result, to loss stability of the oil pipeline itself [10, 14].

During the study the theoretical model of the underground oil pipeline, which was installed in various soils with an existing moss layer, the authors obtained temperature fields where the depth of thawing and the width of the thawing halo were determined (Figs. 2–4). (The white contour line corresponds to a temperature equal to 0 °C.)

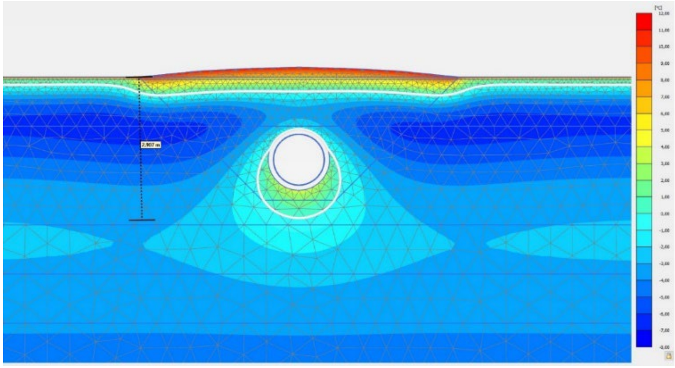

Figure 2. Thermal parameters of the oil pipeline in the conditions of frozen sandy loam (the thawing depth is 2.907 m, the halo width is 1.55 m).

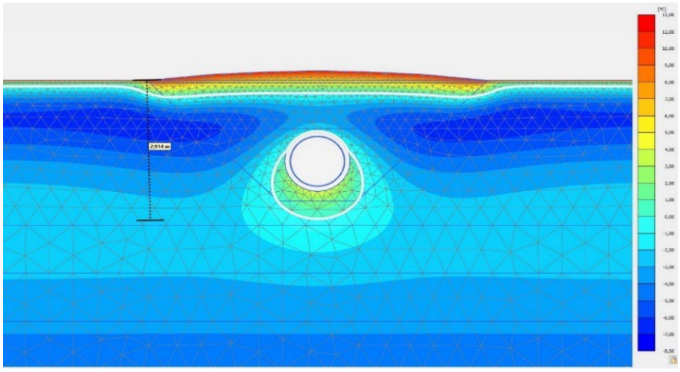

Figure 3. Thermal parameters of the oil pipeline in the conditions of frozen loam (the thawing depth is 2.914 m, the halo width is 1.67 m).

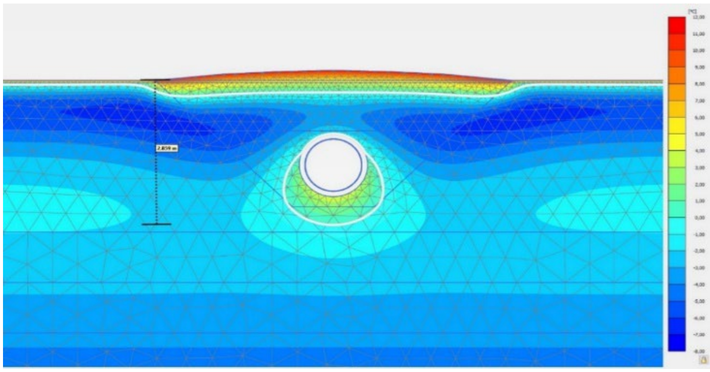

Figure 4. Thermal parameters of the oil pipeline in the conditions of frozen clay (the thawing depth is 2.859 m, the halo width is 1.73 m).

Then, the authors conducted a study and analysis the thermal parameters of the oil pipeline temperature fields with a restored moss layer in different soils. This research allowed us to have question answered about the expediency of restoring the moss layer of the underground oil pipeline (Figs. 5–7).

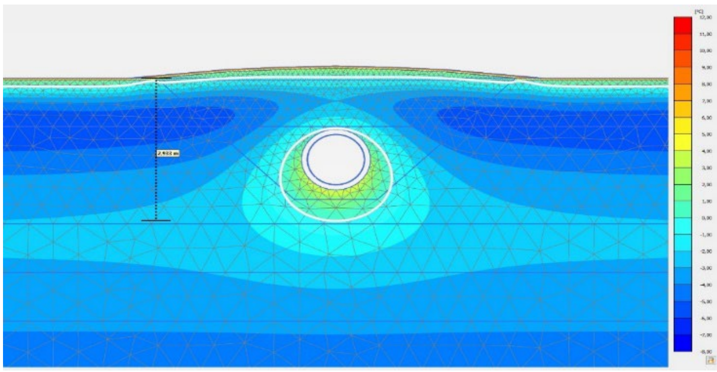

Figure 5. Thermal parameters of the oil pipeline with the restored moss layer in the conditions of frozen sandy loam (the thawing depth is 2.933 m, the thawing halo width is 1.91 m).

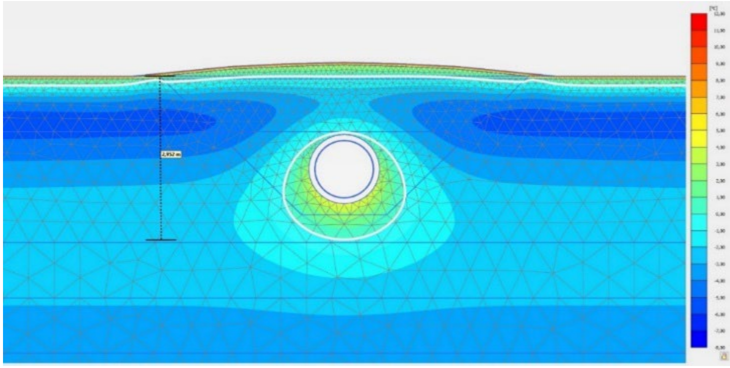

Figure 6. Thermal parameters of the oil pipeline with a restored moss layer in the conditions of frozen loam (the thawing depth is 2.952 m, the thawing halo width is 2.01 m).

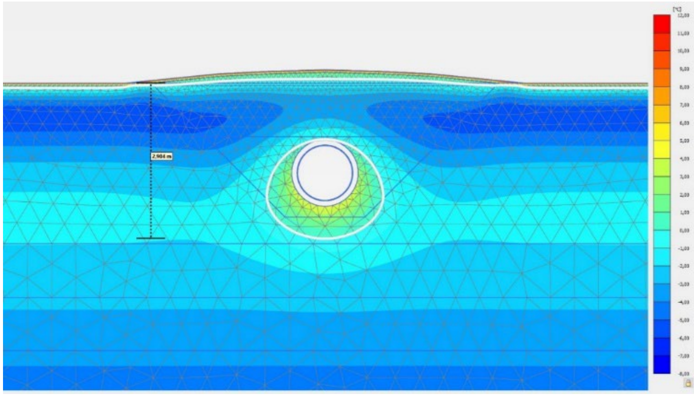

Figure 7. Thermal parameters of the oil pipeline with a restored moss layer in the frozen clay conditions (the thawing depth is 2.904 m, the thawing halo width is 2.08 m).

The authors obtained the following results when comparing the temperature fields of an underground oil pipeline with an undisturbed moss layer and an oil pipeline with a restored moss layer (secondary use):

- the depth of thawing during the secondary use of moss for all soils increased slightly (for frozen sandy loam by 0.9 %, for frozen loam by 1.3 %, for frozen clay by 1.6 %);
- the width of the thawing halo during the secondary use of moss for all soils increased significantly (for frozen sandy loam by 23.2 %, for frozen loam by 20.4 %, for frozen clay by 20.2 %);
- during the secondary use of moss, the horizontal propagation of the heat front around the oil pipeline is clearly traced.

The same research was conducted by the authors regarding the laying of the underground gas pipeline. And, here the results of the study were similar, with the only difference that the depth of thawing here is maximized up 4.2 %, and the width of the thawing halo is maximized up 41.2 %.

4. Conclusions

Thus, analyzing the obtained results, it is obvious that the secondary use of the moss layer in underground construction of the pipelines is impractical:

- the presence and growth of the horizontal component of the temperature fluctuation can cause substantial damage with longitudinal and transverse deformations, pipeline floating-up and negative effect of frost heaving;
- it is necessary to take into account the practical significance of the obtained result. Such as the additional economic costs of restoring the moss layer and the cost of associated works and equipment.

Thus, the cost of restoring one square meter of moss layer after underground laying of the pipeline is on the average 18870 rubles (the cost of loading moss, transporting it from the storage site to the installation site, renting equipment, and value added tax do not include this value).

In the future, the authors plan to continue the research work of the pipeline-permafrost system both in terms of temperature effects and in terms of the economic component of laying pipeline in permafrost conditions.

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