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Influence of oil spills on tundra degradation

S I Chelombitko¹

¹Industrial University of Tyumen, Volodarskogo street 38, Tyumen, 625000, Russia

E-mail: sjlss@mail.ru

Abstract. Some aspects of the negative impact of oil spills on the tundra are considered. Oil pollution of the soil-plant layer leads to a significant increase in the absorption of radiant (solar) energy by the day surface, which leads to an increase in the power of the seasonally thawed layer. Swampy tundra conditions can lead to the development of thermokarst and subsequent degradation of the damaged area. Remediation of oil-contaminated areas in accordance with applicable regulations does not provide for the presence of permafrost. Planning and execution of the whole complex of works on remediation is not based on the simulation of heat and mass transfer processes for the period of complete restoration of the damaged area. The creation of vegetation cover of another species as a result of recultivation does not provide a similar absorption of solar energy by the day surface as in the natural (not polluted) territory, that can subsequently lead to the development of negative processes for the tundra. Taking into account the steady growth of oil-contaminated areas in the Northern regions and the severity of possible consequences, it is necessary to develop special regulatory documents for the remediation of oil-contaminated areas in the conditions of the cryolithozone.

Key words: oil spills, soil contamination, permafrost, reclamation, thermokarst, degradation.

1. Introduction

The main explored and developed hydrocarbon deposits of Russia are concentrated in its northern regions, which are characterized by harsh climatic conditions. The activities of oil and gas enterprises are complicated by low ambient temperatures, a long period of snow cover (more than six months), permafrost, as well as wetlands and a high moisture content in the soil. Despite the high reliability of the equipment used in the production process, the development of fields and the main transport accidental oil spills occur. Studies show that the areas of oil-polluted areas in the northern regions only increase every year and already exceed 1% of the total area of deposits [6]. As a result of long-term experience of development of oil and gas fields it is established that any technogenic influences are harmful for a northern country. So, for example, in [19] it is noted that "almost on any trace from the caterpillar there are ravines, sags and other violations of a relief. And ravines grow in the Subarctic region quickly 15-20 m/year... The Subarctic region nature as a peculiar resonator is capable to strengthen all actions: the pothole turns into the lake or a failure, a furrow - into a ravine". It has been established that self-recovery of damaged reindeer moss-the main feed of reindeer due to anthropogenic impact is possible only after a few decades [11]. Oil pollution of the soil-plant layer is a special type of technogenic impact, due to which soils acquire other physical characteristics that differ from the corresponding characteristics for natural (unpolluted) soil, sometimes very significantly[12,14]. It



turns out that components of oil can move within all seasonal and thawed layer, being left during long time without essential changes, getting into underlying permafrost soil [23]. As a result of special laboratory researches, also, movement of oil in frozen samples of soil at a temperature of crystallization of steam moisture is established [25]. Various researchers note that pollution by oil of territories with permafrost breeds are pernicious, often causing irreparable injury to the nature because of specificity of course of processes of self-restoration of natural northern landscapes [3, 6,8]. The most essential damage to the environment is caused at accidents on the main oil pipelines because of which oil spreads on a day surface. In such cases easy fractions of hydrocarbons evaporate, and some part of the poured oil appears in a soil and vegetable layer. Components of oil are pernicious for any biological organisms. But the main negative impact on the nature of the tundra consists in development processes of degradation (a thermokarst, a thermoerosion, etc.) because of essential increase in absorption of solar energy the damaged day surface. It turns out that any technogenic effects on the natural vegetation cover (mechanical from the passage of technology, oil spills) affect the formation of a seasonally thawed layer in the cryolithozone due to increased absorption of solar energy by the day surface. The increase in thawing depth can cause the development of thermokarst and lead to irreversible degradation of the tundra.

2. The impact of remediation on the affected areas of tundra

In accordance with the decree of the Government of the Russian Federation organizations responsible for environmental pollution are obliged to carry out remediation in accordance with applicable regulations. As a rule, the complex of restoration work is carried out in two stages: technical and biological. At the 1st stage, the concentration of hydrocarbons in the surface layer is reduced to the set limit by plowing and harrowing, creating conditions for further decomposition (oxidation) of oil components in the soil. The works of the 2nd (biological) stage begin to be performed from the next vegetative season, while the application of various fertilizers is carried out with the subsequent sowing of herbs. Regional features of the contaminated area are taken into account when selecting the type of vegetation, which should subsequently form a continuous vegetation cover. Normative documents do not oblige to restore the natural vegetation cover in the damaged area, it is not required, also, the creation of soil and vegetation cover, which would have a similar "thermal function", as in the natural (unpolluted) territory. It is established that the damage (destruction) of vegetation or replacement with another type of vegetation for regions with frozen soils can lead to various negative phenomena (thermokarst, thermoerosion), and subsequently to the degradation site [9,14]. The creation of a continuous vegetation cover with other vegetation leads to changes in thermal and mass transfer processes in the soil. This will inevitably lead to a change in the thickness of the seasonally thawed layer. As you know, the tundra vegetation consisting of mosses and lichens, has specific heat and mass transfer properties, which means that any violations can lead to negative consequences. Therefore, for the actual reclamation of the territory in the tundra after oil pollution is not enough just to create a continuous vegetation cover. The choice of the type of vegetation and technology of work should be based on a long-term forecast of the processes of heat and moisture transfer in the damaged area. Various biological methods are used for remediation of damaged areas, allowing to start work on the creation of a new vegetation cover even in winter [2, 4]. All of them are designed to create a vegetation cover or using the sowing of herbs, or counting on its self-recovery in the future by stimulating the flow of microbiological processes in the surface layer. As the main indicator of the feasibility of using this or that method in the restoration of damaged areas are considered biological indicators of plants (their possible survival in these climatic conditions, the productivity of biomass and others), it does not take into account the possible development of subsequently negative processes in regions with permafrost. As a result of any work on remediation there is a change in the physical properties of the surface layer (density, albedo, heat capacity, thermal conductivity, etc.), which leads to a different course of heat and mass transfer processes in comparison with the natural (unpolluted) terrain. For areas that do not have permafrost, this is not a threat to the normal further functioning of the restored area. Observations at the experimental sites near Nadym (Tyumen region) showed, that the temperature of the day surface can

differ by more than 10 degrees, and the depth of seasonal thawing - up to 120 cm depending on the type of vegetation [5]. In the process of remediation of the territory during the entire period of formation of sustainable vegetation cover (several years) will change the ability of the day surface to absorb solar energy. Therefore, the choice of technology for such work in areas with frozen soils should be based on a long-term forecast of the power dynamics of the seasonally thawed layer. Various biological methods of remediation are aimed at creating vegetation cover, rather than restoring the whole damaged area. As shown by observations, removal of vegetation or contamination of the day surface with oil in the Northern regions leads to an increase in the thickness of the seasonally thawed layer sometimes several times (depending on the physical properties and types of soils) [9]. Calculations of thawing depth for different types of soils for Ukhta region show [22] that the change only in the albedo of the day surface due to oil spills leads to an increase in thawing depth up to two times, and the combined effect of complete removal of vegetation cover and oil pollution leads to a corresponding increase of up to two meters and more for 5 years.

To clean the territories from oil pollution, other simplified methods of "restoration" are also used: burning the remaining oil together with damaged vegetation (prohibited), filling the site with a layer of imported soil (peat, sand), digging, harrowing, sowing herbs and others. These methods of restoration of territories can accelerate the flow of chemical and biological processes for the purification and restoration of soil. In the process of performing any such work is an external impact on the surface layer (burning the remaining oil together with contaminated vegetation, backfilling layer of imported soil, digging, harrowing, sowing herbs, etc.), leading to a change in the physical, mechanical and thermal properties of the treated layer. As a result of such measures, the functioning of the disturbed layer will differ from that which takes place in the intact nearby territory: a change in the physical and mechanical properties of the soil will lead to another mass transfer (moisture migration), and a change in its thermal and physical properties to another heat exchange. As a consequence, the depth of thawing during the summer period in the restored area will differ from the "due", namely in a big way due to the lack of grass cover for several years after recultivation (during the first two years, the day surface has virtually no vegetation). In General, currently used various methods of remediation of areas contaminated with oil spills, do not take into account the specific features of the terrain and lead to changes in the thermal properties of the surface layer. The absence of any recommendations to take into account the climatic and other features of the terrain (albedo, mechanical and physical properties of soil and soil) when performing such works in the Northern regions can lead to an increase in the capacity of the seasonally thawed layer in the years following the restoration. As you know, in such cases, under certain conditions, can begin destructive processes (increased humidity of the active layer, frost heaving, cracking, thermokarst), leading to the degradation of the tundra. The use of any of the known methods of remediation of oil-contaminated areas with permafrost does not guarantee a valid recovery, and can lead in the future to irreversible consequences for the damaged area.

3. Assessment of the consequences for not re-cultivated territories of the tundra

There are cases of the existence of contaminated oil territories without reclamation from various publications. The day surface polluted with oil has a much greater ability to absorb solar energy than the natural one, therefore, as a result of oil spill, the heat supply to the surface layer will increase significantly. It is known that in the cryolithozone the lower part of the seasonally thawed layer is characterized by high humidity. With the increase in solar energy absorption, the melting of frozen soil will be more intense due to the greater thermal conductivity of the wetter soil near the interface: thawed - frozen soil. This will lead to an increase in the power of the seasonally thawed layer, an even greater increase in the humidity of the thawed soil (due to the thawing of underground ice), and in winter-to the development of frost heaving, the formation of cracks in the moisture-saturated frozen soil and other destructive processes. Thus, non-restored oil-contaminated areas are subject to more intensive degradation in the conditions of permafrost soils, manifested in the subsidence of the surface, water filling of the resulting depressions, and subsequently to their further destruction. Examples of self-healing of oil-contaminated areas in the Northern regions of Western Siberia are not found in any publications.

4. About a possible prediction of degradation of the tundra because of its pollution

Mathematical modeling of heat and moisture transfer in the surface layer of the damaged area (as a result of oil spill, after restoration work) can be the basis for the forecast of possible degradation. The depth of the seasonally thawed layer is one of the most important factors affecting the development of thermokarst. The calculation of the thawing depth and the formation of the seasonally thawed layer for several years can be performed using the known numerical models of the Stefan problem (calculation of the freezing-thawing depth in the presence of permafrost) [18, 19, 22]. Estimation calculations to determine the thickness of the seasonally thawed layer for oil-contaminated areas can be performed, knowing the thickness and properties of the layer containing oil. These values can be determined experimentally in the laboratory by sampling and analysis of contaminated soil. Oil trunk pipeline ruptures lead to large-scale oil spills when sampling contaminated soil becomes a serious problem. In such cases, the depth of oil infiltration can be determined by calculation on the basis of the known Darcy filtration law of the following type [20]:

$$m \frac{dy}{dt} = k \frac{h + h_k + y}{y},$$

where: y – the depth of infiltration of oil; m – free soil porosity; t – time; k – filtration coefficient; h – the thickness of the layer of oil on the surface; h_k – the height of the capillary rise of oil.

It is known that most of the oils of Western Siberia contain paraffin, which at a temperature close to the ambient temperature, is in the oil in the form of solid fractions. It was established experimentally that in the process of oil filtration the pore channels [24], as a result of which the permeability of the porous medium decreases. This phenomenon can significantly affect the depth of oil infiltration depending on the content of solid paraffin fractions. To be able to account for changes in the permeability of the porous medium in the filtration of such oil, the corresponding dependence of [17] was used, as well as the experimental data from [24] were processed. The solution of the original differential equation (Darcy's law) taking into account the variable filtration coefficient is obtained in the following implicit form:

$$t = \frac{t_0}{1 - A \frac{us^2}{2D} t},$$

where:

$$t_0 = \frac{m}{k} \left[y - (h + h_k) \ln \left(1 + \frac{y}{h + h_k} \right) \right],$$

$$k = k_0 / (1 + A \frac{us^2}{2D} t),$$

k_0 – the permeability of contaminated soil; u – the initial rate of oil flow; s – the volume content of the dispersed phase in paraffin oil; D – the effective diameter of the pore channels of the soil; A – empirical coefficient ($A = 0,003\text{--}0,018s$).

5. Conclusion

When recultivating oil-contaminated areas in the tundra, it is necessary to restore the damaged area, and not the soil and vegetation cover or soil layer to prevent further possible degradation of the territory.

The increase in the area of oil-contaminated areas in the Northern regions of Russia indicates the need to tighten penalties for damage caused to nature.

To restore areas with permafrost after oil pollution, it is necessary to use specially created methods of reclamation, developed on the basis of mathematical modeling of heat and mass transfer processes. This would allow to take into account the specific features of the area when planning the necessary work, to prevent the subsequent degradation of the damaged area.

One of the methods of numerical simulation of the formation of the seasonally thawed layer can be used to predict the possible course of heat and mass transfer processes after recultivation of the territory. This would make it possible to justify the physical, technical and thermal parameters of the created layer, so that later the power of the seasonally melted layer in the restored territory would be close to the power of the seasonally melted layer in the non-polluted territory.

Areas contaminated with oil or petroleum products under cryolithozone conditions should be under special control of environmental services until they are truly fully restored.

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