Method of assessment of the accidental leakage of trunk the pipeline in the winter

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Abstract. Some features of emergency leaks from oil trunk pipelines in winter, when there is snow cover, are considered. The increase in the intensity of accidents and the scale of oil spills in the Northern regions are of concern to both the public and scientists, who are increasingly calling what is happening an environmental disaster. According to various estimates, the rivers of Western and Eastern Siberia annually carry 0.7 to 2 million tons of oil into the sea, and lists of rivers where MPC of pollutants are several times higher than permissible. The same applies to large rivers in their lower reaches, there was a sharp decline in valuable species of fish in their places of historical mass habitat. In rivers and streams that feed them oil products fall primarily with floodwater and sewage. According to the normative documents, the localization (limitation) of the oil slick in winter is carried out by compacting snow, and the first stage of reclamation of oil-contaminated territories (mechanical) involves plowing and harrowing, i.e. the beginning of restoration work is possible after thawing of the soil. This leads to the fact that after the snow melts, the remaining oil after the collection together with flood waters rushes into streams, rivers and other reservoirs. The remaining oil on the surface of the day or seeps into the soil, or after plowing is filtered into the ground with rain and melt water, polluting groundwater. It is established that oil-contaminated mosses and lichens die, vegetation cover with meadow grasses is restored in more than 15-20 years. Therefore, studies that make it possible to realistically assess the consequences of accidental oil spills and to compensate for the damage caused to nature are important and relevant. The proposed method of estimating the amount of spilled oil in winter is based only on the results of a survey of the contaminated area and does not concern either the causes of the accident or the parameters determining the formation of an oil slick, which may be inaccessible or distorted for certain purposes.

1. Introduction

The main explored and developed hydrocarbon deposits of Russia are concentrated in its northern regions, which are characterized by harsh climatic conditions. To transport oil through the territory of Russia, oil trunk pipelines with a total length of 46800 km are used [9], most of which have developed their regulatory resource. It is established that the number of accidents on oil pipelines only increases every year, with an increase in accident rate of 5-9% [13, 14]. Only in Western Siberia through damage to oil pipelines occurs up to 35000 times a year, with oil emissions of more than 10000 tons of about 300 [12]. In Nizhnevartovsk district of Tyumen region about 10 accidents occur on oil pipelines every day [12]. According to various data from the main oil pipelines of the Russian Federation is poured into the environment annually from 10 to 15 million tons of oil, with the largest leaks occur in Western Siberia, where more than 80% of oil is extracted. The total number of accidents on Russia's
oil trunk pipelines has increased by almost 20% over the past few years, according to official data [14]. Operation of oil trunk pipelines in the Northern regions of the Russian Federation is carried out in harsh climatic conditions at low ambient temperature, high soil moisture, long-term snow cover (more than six months). This significantly complicates the repair and restoration works, as well as the subsequent remediation of the contaminated area in the event of an accident. Accidental oil spills in the winter are essential features that must be considered when liquidation of consequences and the planning of the rehabilitation works. First of all, in the presence of snow cover, the boundary of the oil slick is mobile and not visible for observation. Therefore, the position of the oil circuit can only be determined by a direct survey of the contaminated area. Snow cover and low load-bearing capacity of swamps create serious problems in the performance of work on the localization of oil spills and collection of spilled oil. For example, in a swampy water-saturated area, soil freezing for the safe movement of road equipment occurs within a few months, and some peat bogs remain impassable all year round. This leads to the fact that the collapse of the oil slick in winter sometimes takes time several times more than the requirement of regulations. During this time, the oil spreads over the frozen surface of the day through a porous snow environment, increasing the scale of pollution. As is known at low temperatures, oil losses from evaporation and infiltration into the frozen soil and vegetation layer are small and neglected in engineering practice. Therefore, it is possible to estimate the amount of emergency leakage from the damaged pipeline in winter by means of experimental determination of the amount of spilled oil located on the day surface and within the snow cover. The use of numerical mathematical models of the process of oil distribution in the snow cover is difficult due to the lack of the necessary reliable information from the leakage and the conditions of formation of the oil spill.

2. Determination of spilled oil volume in case of significant leakage from the main oil pipeline

Significant leakage from the pipeline occurs when the pipe breaks and is accompanied by the release of soil from the trench, possible gushing of oil for a certain time in the process of reducing the pressure in the pipeline. An open stream of "warm" oil is formed around the pipeline damage, which spreads over the day surface and melts some part of the snow cover. In the future, the oil cooled to 0 degrees and below in the form of a semi-pressure flow is filtered in a porous snow environment under the influence of gravity and pressure. The primary task of emergency and recovery services upon arrival at the scene of the accident is to localize the oil slick on the surface of the day by sinking the soil or compaction with snow. As a result of survey of the polluted territory after its collapse it is possible to allocate 3 characteristic sites:

- $S_1$ - the area of the polluted area around the leak site where the oil has an open surface equal to the area of the oil spill;
- $S_2$ - the area of the polluted area around the open oil slick where, due to the melting of some part of the snow, the oil is within the snow cover of a smaller thickness than the unpolluted area;
- $S_3$ - the area of the peripheral part of the contaminated area where the oil cooled to negative temperatures is within the snow cover.

In order to be able to use some of the physical properties of snow to assess its oil capacity, special experimental studies have been conducted in a wide range of changes in its porosity (raft-news). As a result of the data processing it was found that for engineering calculations, the oil capacity of snow can be taken equal to its moisture capacity, while the error does not exceed 5% [17]. This makes it possible to use some of the results of wet snow studies to assess the oil content of snow cover (for example, to express the free porosity of snow through its density).

Winter in the Siberian regions is characterized by a long period of low temperatures, when there is no film moisture in the snow cover. In this case, the snow is considered to be "dry" and its porosity is unambiguously expressed through its density with the help of a known formula:
\[ n = 1 - \frac{\rho}{\rho_s} \cdot \]

To be able to estimate the amount of spilled oil in the snow cover and on the day surface around the site of a significant leak, the following relationship is obtained [7]:

\[ V_n = \left( h_{mc} - \frac{\rho}{\rho_s} \cdot h_c \right) \cdot S_1 + \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot (h_i^{(2)} - h_{c,h}) - \frac{\rho}{\rho_s} \right] \cdot \left( h_c - h_i^{(2)} \right) + \left[ 0.5 - 0.55 \frac{\rho}{\rho_s} \right] \cdot h_{h,c} \right] \cdot S_2 +
\]

\[ + \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot (h_i^{(3)} - h_{c,h}) + \left( 0.5 - 0.55 \frac{\rho}{\rho_s} \right) \cdot h_{h,c} \right] \cdot S_3, \quad (1) \]

where: \( \rho \) - the average thickness of the density of snow; \( \rho_s, \rho_i \) - the density of water and ice respectively; \( h_c \) -average thickness of snow cover around the contaminated area; \( h_{c,h} \) - the average on surface-area \( S_1 \) thickness of the liquid layer “oil and water”; \( h_i^{(2)} \) - the average thickness of the snow cover surface \( S_2 \); \( h_{h,c} \) - the height of capillary rise of oil in the snow; \( h_i^{(2)} \) - thickness of the contaminated snow layer on the surface \( S_2 \); \( h_i^{(3)} \) - the thickness of the contaminated layer of snow on the surface \( S_3 \).

As is known, at a snow temperature greater than \(-10^\circ C\), snow contains moisture in the form of a film, and with an increase in temperature, the moisture content increases, which leads to a decrease in the free porosity of snow. When obtaining the formula for determining the amount of spilled oil in the contaminated area, when the snow is "wet", the following known dependence is used [23,25]:

\[ n = 1 - \frac{\rho}{\rho_s (1 - 0.083 \alpha)} \cdot \]

where \( \alpha \) - snow humidity.

The formula found for this case is as follows:

\[ V_n = \left[ \left( h_{mc} - \frac{\rho}{\rho_s} \cdot \frac{1}{(1 - 0.083 \alpha)} + \alpha \right) \cdot h_c \right] \cdot S_1 - \frac{\rho}{\rho_s} \left( h_c - h_i^{(2)} \right) \cdot \left( \frac{1}{1 - 0.083 \alpha} + \alpha \right) \cdot S_2 +
\]

\[ + \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot (h_i^{(2)} \cdot S_2 + h_i^{(3)} \cdot S_3) + (S_2 + S_3) \cdot \left( 0.5 - 0.55 \frac{\rho}{\rho_s} \right) \cdot h_{h,c} \right] \cdot S_3, \quad (2) \]

Thus, the obtained formulas (1) and (2) make it possible to determine the volume of spilled oil as a result of significant leakage /rupture/ on the oil pipeline in winter both at low ambient temperature (less than \(-10^\circ C\)), when the snow cover does not contain moisture, and in the case of "wet" snow, when the air temperature is more than \(-10^\circ C\).

3. Determination of spilled oil volume in case of small leakage from the main oil pipeline

A minor leak in engineering practice are emergency the expiration of oil through the corrosion holes with a small volumetric flow, resulting in emission of soil from the pipeline trench. The oil flowing out of the hole is filtered into the surrounding ground space, sometimes flows along the pipe downhill and comes to the surface in a lowered place. The difficulty of detecting fistula leaks due to the impossibility of their establishment by conventional methods used in practice leads to large and even huge losses of oil. Thus, as a result of fistula (corrosion) oil leaks from the oil pipeline in the Usinsk region of the Komi Republic in August 1994, 79000 to 100000 tons of oil and possibly more [ 19, 20,
were spilled. Fistula leaks are most often established by visual detection of an oil spot on the day surface during the over flight of the oil pipeline route. The ratio of the amount of spilled oil to the amount of oil in the ground environment depends mainly on the physical properties of the soil (permeability, humidity), the slope of the terrain and the position of the groundwater level [3,4,18].

As a result of heat exchange with the environment facing the surface of the oil prices as a result of the fistula leakage has a lower temperature than the temperature of the oil in the pipeline, so depending on the time of the formation of impurities and conditions of heat exchange (temperature of oil and the environment, snow cover thickness and physical properties of snow and other) possible 3 the following situation.

- Oil is completely within the snow cover and does not have an open surface, while the thickness of the snow cover remains unchanged. This is possible when the output on the daily surface of the cooled oil with a temperature below 0°C.
- In the oil-contaminated area, the snow cover has partially melted, but the oil does not have an open surface.
- On some part of the day surface oil forms an oil slick, on the rest of the contaminated area oil is contained within the snow cover.

For the experimental determination of the amount of spilled oil due to the operation of a small leak for these 3 cases, you can use, respectively, the following dependencies:

- in the first case:

$$V_a = \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot h_x + \left( 0.5 - 0.55 \cdot \frac{\rho}{\rho_s} \right) \cdot h_{x,\nu} \right] \cdot S, \quad (3)$$

where:
- $S$ - area of contamination of the day surface;
- $h_x$ - the average thickness of the snow layer containing oil in the form of "gravitational».

- in second case:

$$V_a = \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot (h_x^{(2)} - h_{x,\nu}) - \frac{\rho}{\rho_s} \cdot (h_x - h_x^{(2)} + \left( 0.5 - 0.55 \cdot \frac{\rho}{\rho_s} \right) \cdot h_{x,\nu} \right] \cdot S_2 +$$

$$+ \left[ \left( 1 - \frac{\rho}{\rho_s} \right) \cdot (h_x^{(3)} - h_{x,\nu}) + \left( 0.5 - 0.55 \cdot \frac{\rho}{\rho_s} \right) \cdot h_{x,\nu} \right] \cdot S_3 \quad (4)$$

- in the third case, formula (1).

In the case of "wet" snow and small (corrosive) leakage it is proposed to use the following dependencies:

- in the first case:

$$V_a = \left[ \left( 1 - \frac{\rho}{\rho_s (1 - 0.083\alpha)} \right) \cdot h_x + \left( 0.5 - 0.55 \cdot \frac{\rho}{\rho_s} \right) \cdot h_{x,\nu} \right] \cdot S, \quad (5)$$

- in second case:
\[ V_n = \left[ 1 - \frac{\rho}{\rho_s (1 - 0.083\alpha)} \right] h_{c}^{(2)} - \frac{\rho (h_c - h_{c}^{(2)})}{\rho_a} \left( 1 - \frac{1}{1 - 0.083\alpha} + \alpha \right) \cdot S_2 + \right.
\]
\[ + \left[ 0.5 - 0.55 \frac{\rho}{\rho_a} \right] \cdot h_{w,\alpha} \cdot S_3 + \]
\[ + \left[ 1 - \frac{\rho}{\rho_s (1 - 0.083\alpha)} \right] h_{c}^{(3)} + \left( 0.5 - 0.55 \frac{\rho}{\rho_a} \right) \cdot h_{w,\alpha} \right] \cdot S_3 \]

(6)

- in the third case, formula (2).

4. Conclusion
Determination of the volume of spilled oil in winter due to through damage of trunk pipelines is important and relevant for the quality planning of repair and restoration work, remediation of contaminated areas, as well as for the assessment of damage to the environment.

Measurement of characteristic parameters of the snow cover and the oil slick in the course of inspection of the contaminated area allows you to perform estimates using the proposed dependency (1) to (6).

In case of emergency oil spills with an open surface of the oil spill, the formula (1) for "dry" snow and the formula (4) for "wet" snow should be used during the calculations.

When estimating the amount of spilled oil contained on the daily surface in the snow cover in the absence of an oil spill, it is recommended to apply formulas (2)-(3) in the case of "dry" snow and formulas (5)-(6) for "wet" snow.

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