Improving the safety of operation of tanks with a floating roof in the winter period

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Abstract. Tanks with a floating roof (VST FR) allow reducing losses from evaporation of light oil fractions and petroleum products by 90-98%. However, their use in areas with high snow cover, which includes the Tyumen Oblast, is difficult because the accumulation of a large amount of snow on the roof can lead to sinking, and uneven distribution of the snow cover causes its skew and further jamming on the rails racks. Such accidents have occurred and caused enormous damage.

1. Introduction
The export of oil, natural gas and petroleum products is the main source of income of the budget of the Russian Federation. Effective use of these energy resources is impossible without the constant updating and development of technologies used in the exploration, production, transportation and storage of hydrocarbons. Over the years, steel vertical cylindrical tanks have been used to store oil and petroleum products. In our country there are more than 50,000 such structures.

The expected decline in world oil reserves, the rise in the cost of its extraction with the offshore production, the transfer of these processes to northern and other areas with complex natural and climatic conditions require the creation of new tank farms.

In our country, due to difficult climatic conditions, vertical cylindrical tanks with a fixed roof with a pontoon or without (VSTP, VST) are most widely used. Conical and spherical stationary roofs are designed and widely used. Such roofs are technologically productive, effective under uniform loads. However, the most technological is the design of a floating roof tank, both single- and double-deck.

2. Materials and methods
Tanks with a floating roof (VST FR) allow reducing losses from evaporation of light oil fractions and petroleum products by 90-98%. However, their use in areas with high snow cover, which includes the Tyumen Oblast, is difficult because the accumulation of a large amount of snow on the roof can lead to sinking, and uneven distribution of the snow cover causes its skew and further jamming on the rails racks. Such accidents have occurred and caused enormous damage.

A normative document [1] regulates the allowable height of the snow cover for tanks in operation, depending on the snow regions of the Russian Federation. The allowable height of the snow cover is determined for both uniform and uneven distribution of snow on the floating roof. The methods and recommendations for the calculation of floating roofs are given in the following effective regulatory documents: GOST 31385-2008 "Vertical cylindrical steel tanks for oil and petroleum products. General technical specifications", RD-23.020.00-KTN-079-09 "Rules for repair and reconstruction of oil storage
tanks with a volume of 1000 - 50000 cubic meters", STO-SA-03-002-2009 "Rules for the design, manufacture and installation of vertical cylindrical steel tanks for oil and petroleum products.”

To date, the surface of the floating roofs of tanks is cleaned manually, if a snow thickness is more than 100 mm. The process of cleaning the snow is very laborious, since a complex snow-ice mixture can form on the floating roof, which at a thickness of 10 cm on a tank of 50,000 m³ weighs about 28.7 tons. Experience of the operation of floating roof tanks has shown that the snow cover on the floating roof is distributed unevenly over the surface. This is due to the influence of wind during snowfall. Uneven distribution of snow loads leads to a heeling moment, which contributes to a failure in operability or even to flooding of the floating roof. The cases of drowning of floating roofs of tanks, which were exploited in areas with a snow load of 1.5 kPa and above, were noted. The uneven distribution of the snow load is due to the geometric parameters of the tank, the velocity and direction of the wind flow during snowfall, the height of the liquid level in the tank.

![Figure 1. Structure of a VST with a floating roof.](image)

1 - receiving and distributing branch pipe with gate valve; 2 - spare gate valve cable; 3 - stiffening rings; 4 - tank wall; 5 - annular stiffening platform; 6 - flame arrester; 7 - pipeline of foam solution; 8 - supporting pillars of floating roof; 9 - water intake of atmospheric precipitation; 10 - pipeline of irrigation of the tank wall; 11 - floating roof; 12 - supporting truss; 13 - reeling ladder; 14 - edge of foam retention; 15 - supporting truss; 16 - peripheral ring pontoon of floating roof; 17 - the seal (shutter) of floating roof; 18 - transition platform; 19 - shaft ladder; 20 - tubular floating roof guide; 21 - drainage system; 22 - tank bottom

Cleaning the roof of even one tank is very labor-intensive. At present, the cleaning procedure is carried out as follows: the tank to be cleaned is filled with oil to the maximum level to raise the roof, then a team of 4-5 people manually shovels the roof for four days. After cleaning is complete, the procedure is repeated for other tanks at the farm. The area of the floating roof of a VST FR of 20,000 m³ volume is more than 1600 square meters, hence such a long time. For example, in Surgut UMN, VST roof cleaning is carried out about five times during the winter period.

A possible solution to this problem may be connected to the melting of snow due to the heat of the stored product, namely oil. Here, it is necessary to calculate the balance of energy required for melting snow on the roof, and the heat flow from the oil. In this paper, the process of melting snow is considered at the time of its fall, with water draining into the drain pipe of the drainage system 21, Figure 1
The energy required to melt snow on the metal surface of the roof is composed of the following quantities:

1) Energy input for heating snow from air temperature to 0°C

\[ Q_{sn} = G \cdot C_{sn} \cdot (t_{melting} - t_{air}) \]  

(1)

where \( G \) – snowfall rate, kg/hour, we choose from the "Construction climatology" and the ratings of precipitation in the region;

\( C_{sn} \) – heat capacity of snow, \( C_{sn} = 2100 \frac{kJ}{kg \cdot ^\circ C} \);

\( t_{air} \) – average air temperature over the period under study.

2) Energy input for melting ice:

\[ Q_{melt} = G \cdot \lambda \]  

(2)

where \( \lambda \) – specific heat of melting ice, \( \lambda = 335 \frac{kJ}{kg \cdot ^\circ C} \);

3) Energy input for heating water (heating water after melting snow is necessary for draining it into the drainage system of the tank):

\[ Q_{hw} = C_{wr} \cdot G \cdot (t_{water} - t_{melting}) \]  

(3)

where \( C_{wr} \) – heat capacity of water, \( C_{wr} = 4200 \frac{kJ}{kg \cdot ^\circ C} \)

In this case, it is necessary to consider the entrainment of thermal energy \( Q \) from the surface of a floating roof by wind.

\[ Q = \alpha \cdot S_{roof} \cdot (t_{roof} - t_{air}) \]  

(4)

where \( \alpha \) – coefficient of heat transfer from the roof;

\( S_{roof} \) – roof area;

\[ \alpha = Nu_a \cdot \lambda_a / l \]  

(5)

where \( \lambda_a \) – coefficient of thermal conductivity of air.

\( l \) – linear dimension. This parameter depends on the value of the roof surface unoccupied with snow which prevents heat loss and is a natural heat insulator;

\[ Nu_a = 0.032 \cdot Re_a^{0.8} \]  

(6)

\[ Re_a = \frac{w \cdot l}{\nu_a} \]  

(7)

where \( w \) – wind velocity above the roof surface;

\( \nu_a \) – kinematic viscosity of air.

Calculations show that at an air temperature of -20°C, for the floating roof of RVSPK-20000, the heat flow density required for operational snow heating is about 140 W/m².

In this paper, we will consider heat transfer from oil through a two-deck roof, since its calculation represents maximum interest and complexity.

The main types of floating roofs currently in use are shown in Figure 2:

Figure 2. Main types of floating roofs currently in use:

a) single-deck; b) single-deck with central float; c) single-deck with stiffeners; d) single-deck with floats; e) double-deck; 1 - closed ring pontoon; 2 - sheet roofing; 3 - central float; 4 - stiffeners; 5 - float; 6 - radial bulkhead; 7 - annular bulkhead
The double-deck floating roof of the oil tank includes concentrically arranged roof segments containing interconnected compartments, the compartments being arranged such that the smaller of the tangential surfaces of the compartment of the first segment adjoins a portion of its surface to a part of the surface of the larger tangential surface of the compartment of the second segment. The roof comprises a radial frame belt that is connected to one pair of compartments of neighboring roof segments adjacent to each other by parts of their tangential surfaces, further joining them together; wherein the radial frame belt has such a length that it essentially connects the central part of the roof and the side sheet.

In a confined space, free convection develops differently, since the motion near surfaces having different temperatures is interrelated. In narrow gaps, flat and annular channels, layers of different shapes, the heat flow density \( q \) is calculated from the formulas of stationary thermal conductivity in a flat wall, introducing the concept of the equivalent thermal conductivity coefficient:

\[
q = \lambda_{\text{equiv}} \Delta t / l \tag{8}
\]

where \( \lambda_{\text{equiv}} \) – equivalent thermal conductivity coefficient;

\( l \) – distance between the top and bottom decks of a floating roof;

\( \Delta t \) – temperature difference between the top and bottom decks of a floating roof.

In our case, we set the boundary temperatures of the top and bottom surfaces of the roof, namely: the top deck - +5\(^0\)C, the bottom deck - the temperature of the oil. The choice of these temperatures is due to the following factors: the need to melt the snow and maintain the water temperature above zero for unimpeded drain into the drainage system along the top deck surface. The temperature of the bottom deck is equal to the temperature of the oil, since heat losses during the oil-wall heat exchange can be neglected.

The equivalent thermal conductivity coefficient is determined by the formula:

\[
\lambda_{\text{equiv}} = \varepsilon_c \lambda_a \tag{9}
\]

where \( \lambda_a \) – coefficient of thermal conductivity of air in a closed compartment of a floating roof;

\( \varepsilon_c \) – convection coefficient, a correction that takes into account an increase in the heat flow due to free convection in the closed space of the floating roof compartments.

When calculating the convection coefficient \( \varepsilon_c \), first, one should consider a change in the physical properties of air, such as the kinematic viscosity \( \nu_a \), the coefficient of temperature expansion \( \beta \), the Prandtl \( Pr_a \) criterion, depending on its temperature, as they vary within fairly wide limits and strongly affect the results.

Air properties are determined by the average temperature of the closed compartment:

\[
T = \frac{T_1 + T_2}{2} \tag{10}
\]

where \( T_1 \) and \( T_2 \) – top and bottom deck temperatures.

The convection coefficient is calculated depending on the product of the Grashof and Prandtl criteria for air in the closed space of a double-deck roof:

- for the product of \( [Gr_a*Pr_a] \) from \( 10^3 \) to \( 10^6 \) the convection coefficient \( \varepsilon_c \) is calculated by the formula:

\[
\varepsilon_c = 0.105^{[Gr_a*Pr_a]}^{0.3} \tag{11}
\]

- for the product of \( [Gr_a*Pr_a] \) greater than \( 10^6 \) the convection coefficient \( \varepsilon_c \) is calculated by the formula:

\[
\varepsilon_c = 0.4^{[Gr_a*Pr_a]}^{0.2} \tag{12}
\]

Preliminary calculations show that if the temperature of the oil is maintained at +35\(^0\)C, the heat flow from it is sufficient to exceed the energy input for snow heating during snowfall.

3. Conclusion

Calculations show that at an air temperature of -20\(^0\)C, for the floating roof of RVSPK-20000, the heat flow density required for operational snow heating is about 140 W/m\(^2\).

Preliminary calculations show that if the temperature of the oil is maintained at +35\(^0\)C, the heat flow from it is sufficient to exceed the energy input for snow heating during snowfall.
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