

# Modeling Bottom Sediment Erosion Process by Swirling the Flow by Tangential Supply of Oil in the Tank

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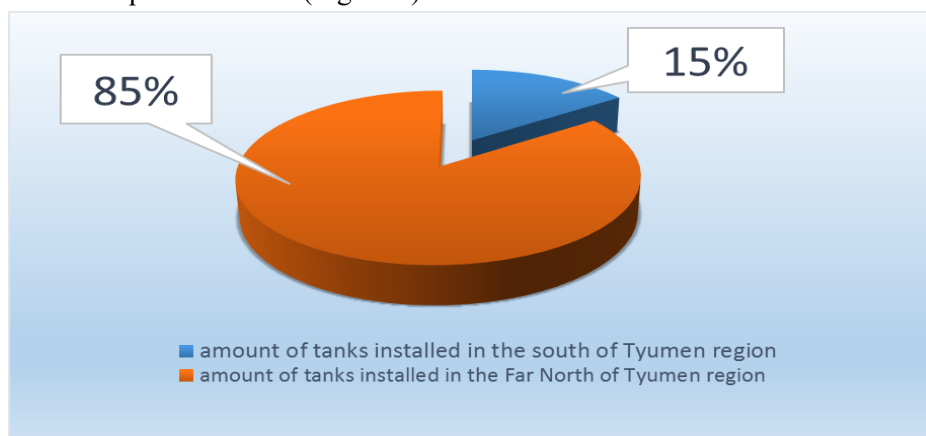
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**Abstract** The article carries out a statistical data processing of quantitative and territorial division of oil tanks operating in Tyumen region, intended for reception, storage and distribution of commercial oil through trunk pipelines. It describes the working principle of the new device of erosion and prevention of oil bottom sediment formation with tangential supply of oil pumped into reservoir. The most significant similarity criteria can be emphasized in modeling rotational flows exerting significant influence on the structure of the circulating flow of oil in tank when operation of the device described. The dependence of the distribution of the linear velocity of a point on the surface along the radius at the circular motion of the oil in the tank is characterized, and on the basis of this dependence, a formula of general kinetic energy of rotational motion of oil and asphalt-resin-paraffin deposits total volume in the oil reservoir is given.

## Introduction.

Trunk pipeline transport is one of the most important components of the Russian Federation transportation system. It performs more than half of cargo turnover by all means of transport.

A significant part of trunk oil pipelines, operating now, passes through the territories belonging to the regions of the Far North and localities equated to them. Thus, 172 tanks of VST mark (vertical steel tank) intended for the reception, storage and distribution of commercial oil are in operation in Tyumen region. Only 15% of the general fund of the tanks are installed in the south of region and 85% of tanks with total commodity capacity of 1.48 million m<sup>3</sup> are located in the territories of the Far North and localities equated to them (Figure 1).



**Figure 1.** Territorial distribution of trunk oil pipelines tanks of Tyumen Region

According to the "Energy Strategy of Russia for the period until 2030", one of the most important directions of development of national economy is implementation of comprehensive programs on energy development of the Eastern Siberia and the Far East, the North-West region of Russia, the Yamal Peninsula and continental shelf. And in accordance with the RF Government Decree of 04.15.2014, No 321 "On approval of the state program of the Russian Federation "Energy efficiency and energy development", expansion of energy and raw material infrastructure of the Far North should be implemented in the nearest future. Moreover, OJSC "AK "Transneft", implementing strategic development program developed for the period until 2020, plans to build about 800,000 m<sup>3</sup> of tank reservoirs for crude oil and about 720,000 m<sup>3</sup> for oil products, spending about 40 billion rub on tanks construction. Therefore, now there stands out a particularly urgent problem of energy-efficient operation of oil tanks providing a high level of technical and economic parameters of oil pipeline system on the territory of the Far North.

### Methods

An important indicator of the climatic characteristics of the Far North territory is reduced negative average annual ambient temperature. This factor acts as a catalyst of sedimentation rate of asphalt-resin-paraffin fractions (ARPF), that leads to the formation and accumulation of bottom sediment on the bottom and walls of oil tanks. ARPF deposits can reach ¼ of useful capacity of container per year.

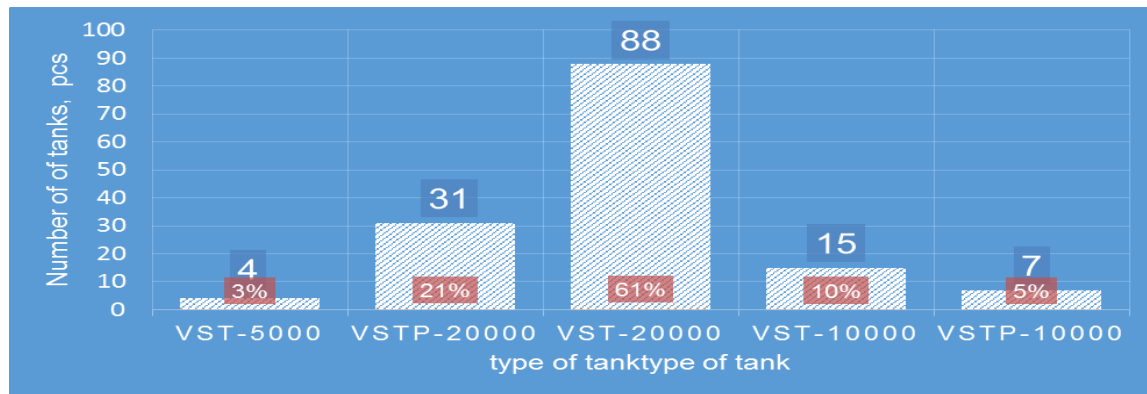
The "Transport of Hydrocarbon Resources" department of Tyumen State Oil and Gas University has developed and patented a new device of erosion and prevention of bottom sediments formation in the oil reservoirs VST [1]. However, for conducting field experiments at operating reservoirs it is necessary to carry out a number of laboratory experiments aimed at studying and modeling of process of hydrodynamic flow of the multiphase and multi-component mixture in the tanks VST using the developed device. While conducting field experiments, one should take into account the different heights and the uneven formation of bottom sediments, quantitative and qualitative composition of stored oil products, as well as constructive conditions and modes of reservoirs operation.

Erosion and preventing deposit formation is carried out due to large peripheral speeds of oil flow in a tank, due to which the separation of ARPF particles from the bottom and turning them into suspension is carried out. Rotational motion of the total volume of oil in a tank is carried out due to swirling a flow when the tank is being filled by the tangential supply of liquid through several peripheral openings in the common collector, routed around the perimeter of the tank bottom [2].

For the study of rotational motion of fluid in a tank by experimentation in laboratory conditions, it is necessary to comply with conditions fulfillment of geometric, kinematic and dynamic similarity.

Geometric similarity of rotational (circulating) flows is ensured by fulfillment of values equality condition of relative rotation radii of particles in a tank  $r_0/R = idem$ , and the relative roughness of tank walls  $k_0/R = idem$  [3].

As a result of statistical data processing, a tank VST-20000 has become a modeling object, as this type of tanks is 61% of the total number of tank capacities operating now in Tyumen region on the territory of the Far North (Figure 2).



**Figure 2.** Specific gravity of tank types operating in Tyumen region on the territory of the Far North

In modeling the rotational motion of fluid, it is almost impossible to achieve strict simultaneous compliance of all the conditions of dynamic similarity because of their large-scale incompatibility for streams having different linear scale, but the same physical properties (density, viscosity) and moving in the same gravitational field. Therefore, the following criteria in modeling the circulating motion of oil in a tank were selected as dominant:

- Reynolds Criterion:

$$Re = \vartheta \cdot D / \nu = idem , \quad (1)$$

where  $\vartheta$  – velocity of oil flow, m/s;  $D$  – tank diameter, m;  $\nu$  – kinematic viscosity of oil, m<sup>2</sup>/s;

- Euler criterion:

$$Eu = p_0 / \rho v_0^2 = idem , \quad (2)$$

where  $p_0$  – pressure on the rotation axis of fluid, Pa;  $\rho$  – oil density, kg/m<sup>3</sup>;  $v_0$  – peripheral flow velocity of oil in the tank, m/s;

The given criterion of considered totality defines the conditions (pressure) on the axis of flow rotation. The conditions significantly affect the structure of the circulation flow.

- Froude criterion:

$$Fr = v_0 / gR = idem \text{ or } Fr_r = \Pi = Fr \left( \frac{u_0}{v_0} \right)^2 = idem , \quad (3)$$

where  $R$  – tank radius, m;  $u_0$  – axial motion velocity of oil in tank, m/s.

For the considered circulating flow of an incompressible fluid, Euler and Froude criteria are compatible in scale, and their product can act as an additional or self-combined criterion, if necessary:

$$Eu \ Fr = p_0 / \rho gR = idem . \quad (4)$$

In the second form of a fixation of the Froude number on(4), attention should be paid to the ratio of characteristic peripheral and axial velocity, which determines the condition of kinematic similarity, and is one of the most significant in the analysis of circulating flows:

$$Ro_* = \frac{u_0}{v_0} = idem . \quad (5)$$

In modeling circulation flows of viscous incompressible fluid, three basic parameters are used as the kinematic similarity criteria: integral parameter of swirling of the full flow of quantity of motion (F), integral parameter of flow swirling in an arbitrary section ( $F_x$ ) and limit swirl angle of flow ( $\varphi\omega$ ) [4].

Integrated swirling parameter of the full swirl of motion quantity of flow shows the ratio of rotational quantity of motion to the axial projection of the total flow motion quantity on the scale of R and is determined by the formula:

$$\Phi = \frac{M}{K \cdot R}, \quad (6)$$

where  $M$  – axial component of flow of angular momentum:

$$M = 2\pi \int_0^R \rho \omega u r^2 dr; \quad (7)$$

$K$  – axial component of the total flow motion quantity:

$$K = 2\pi \int_0^R (p + \rho \omega^2) r dr, \quad (8)$$

where  $R$  – channel radius;  $r$  – current radius;  $p$  – pressure in the considered section;  $\rho$  – fluid density;  $u$  and  $\omega$  – rotational and axial components of flow velocity.

The integrated flow swirling parameter in an arbitrary section is a ratio of rotational quantity of flow motion to an axial in a scale R, which is defined by the formula:

$$\Phi_* = \frac{M}{K_x \cdot R}, \quad (9)$$

where  $K_x$  – quantity motion flow axial component:

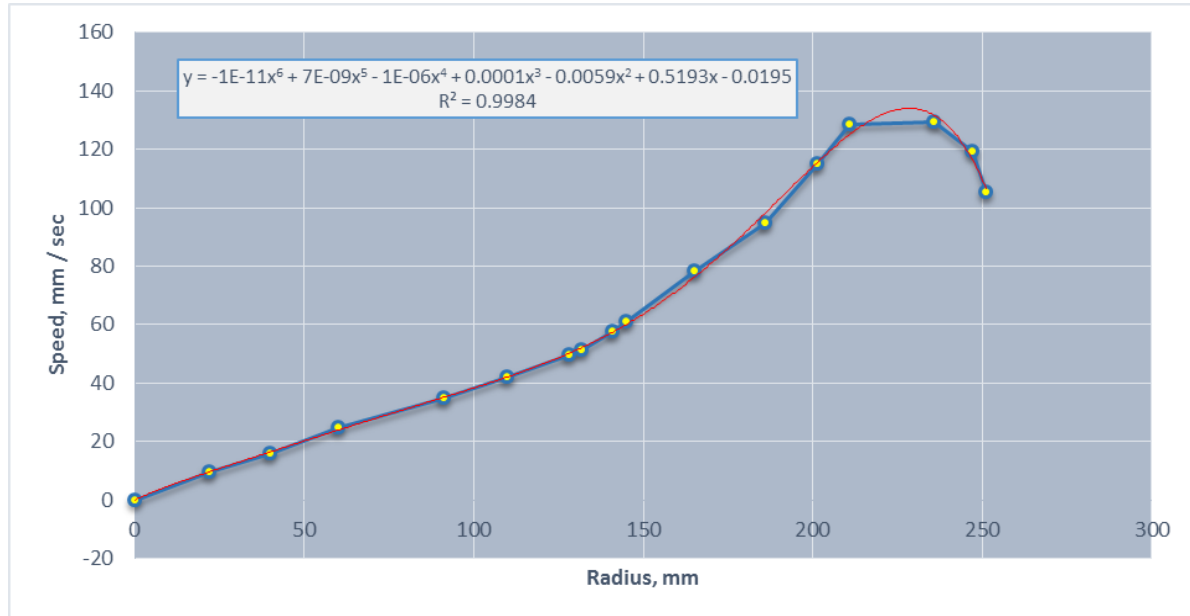
$$K_x = 2\pi \int_0^R \rho \omega^2 r dr \quad (10)$$

The limiting angle of flow swirling characterizes the deviation degree of the limiting stream line from the axial direction and is expressed by a dependence:

$$tg \varphi_\omega = \frac{\tau_{\varphi\omega}}{\tau_{x\omega}}, \quad (11)$$

where  $\tau_{\varphi\omega}$  and  $\tau_{x\omega}$  – projection of surface tension of friction on the coordinate axes.

As a result of the experiment and data processing, the dependence of the linear velocity distribution of a point on a surface along the radius at a circulating motion of oil in tank was determined (Figure 3).



**Figure 3.** Distribution of a point speed on the surface of oil along the radius at circulating motion of oil in a tank

It can be seen from the graph that this dependence is described by a polynomial of sixth degree with a standard deviation  $R = 0.9984$ :

$$v(r) = -1E-11r^6 + 7E-09r^5 - 1E-06r^4 + 0.0001r^3 - 0.0059r^2 + 0.5193r - 0.0195. \quad (12)$$

During research, a formula was obtained of the kinetic energy of rotational fluid motion in case of indirectly proportional change of peripheral velocity within the vortex core:

$$W = \pi \rho h_{cp} \int_0^R v^2 r dr, \quad (13)$$

where  $v=f(r)$ ,  $\rho$  – oil density,  $h_{cp}$  – the average level of oil innage in a tank.

## Conclusion

As a result of analysis of the country's energy strategy, the strategic development program of the largest oil transport company in Russia and a number of legislative initiatives, the preservation and further development of energy efficiency and conservation vector in fuel and energy sector of the Russian Federation can be concluded.

The modeling experience of rotational motion of the fluid indicates the impossibility of achieving an absolute similarity of circulation flows due to their large-scale incompatibility. Thus, during the modeling of axisymmetric rotational motion of continuous media, one must perform preservation of

similarity of the most essential criteria, providing dominant influence on the structure of circulating flow.

The dependence of velocity distribution on the surface of oil from the radius at a flow swirl by the tangential supply of fluid caused by the design of a new device was established. This dependence is indirectly proportional manifested in view of non-equidistant location of pressure tubes of flow swirling device from the tank center. On the basis of this dependence, a formula was obtained to determine the total kinetic energy of rotational motion of oil and ARPF in the oil tank in operation of erosion and prevention of oil sediments formation.

### References

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