DETERMINATION OF OIL SPILL PARAMETERS IN THE PROCESS OF OIL AND OIL PRODUCTS SPREADING ON THE WATER SURFACE

ОПРЕДЕЛЕНИЕ ПАРАМЕТРОВ НЕФТЯНОГО ПЯТНА В ПРОЦЕССЕ РАСТЕКАНИЯ НЕФТИ И НЕФТЕПРОДУКТОВ ПО ВОДНОЙ ПОВЕРХНОСТИ

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***Abstract**: The growing marine pollution by oil strengthens the interest not only in the methods of combating their causes, but in methods of their forecasting as well on the basis of modeling and calculation of spreading oil spreading on the sea for some reason or other.*

The paper dwells on a mathematical model of calculating the area of oil spill spreading. The developed methodology for calculating change in the radius and area of oil spill is represented by function of three arguments: oil product density ρ_o, spillover volume V and spreading time t.

The proposed model allows forecasting the initial stages of oil spreading. The given methodology enables to determine transit time of the process of oil spill spreading from the first phase to the second one, and from the second to the third one, and the radius and area of oil spill spreading.

***KEY WORDS**: MATHEMATICAL MODELING, POLLUTION, WATER AREAS, OIL. OIL PRODUCT; SEA.*

1. Introduction

In recent years, the interest in studies of mechanism of oil spreading in the marine environment has grown significantly. Total ingress of oil products into the sea at a first approximation is proportional to the volume of the world oil production that conditions the growing marine pollution hazard. Marine pollutions caused by tanker and other ship accidents are the most hazardous because they are not predictable and besides they are of the local nature at their high power. Despite permanent tightening of safety standards, the accidents during transportation of oil products still remain pernicious for the environment.

While planning and carrying out works on combating accidental spills on the sea, there will usually be a need to forecast oil spreading on the sea. These forecasts allow, in particular, warning of possibility of coastal zone pollution by oil, crossing the areas of intensive economic activities by oil spill, vessels' courses and so on.

2. Prerequisites and means for solving the problem

As is well-known, Black Sea is a landlocked water object, which is of considerable transport importance, based on rapidly developing port infrastructure, which is oriented on the export of oil and oil products. At the same time, this water object has a huge recreation potential, whose development and even its existence can be endangered.

In the near future, the annual volume of oil transportations over Black Sea may be increased to 220-250 tons. Herewith, through the port terminals of: Ukraine there is anticipated to transport up to 50 mln tons per year, Russia – up to 60 mln tons, Georgia – up to 30 mln tons, Bulgaria – up to 25 mln tons and Turkey – about 35 mln tons per year.

Despite permanent tightening of safety standards, transportation of oil products still remain pernicious for the environment. The main problem in sealift transportation of oil and oil products is safeguarding the operation of tankers in part of preventing oil spills, explosions and fires.

Studies of processes associated with oil and oil products spreading on the water surface were performed by many famous scientists. The papers [1,2,3] dwell on spreading of oil slick, which is formed at oil spill on the sea and dynamics of oil pollution in the sea coastal zone. There is proposed a mathematical model of this process.

3. Mathematical model

The modern scientific and technical literature on studies of physical processes of oil spreading on the water surface [4], [5] mostly dwells on three methodologies of calculating the time variations of the radius of oil spill. In these methodologies, the radius of oil spill is represented by function of three arguments: oil product density ρ_o, spillover volume V and spreading time t.

There is conducted the analysis of the developments in the field of estimating parameters of oil spill during its spreading on the water surface. As a basic one, there has been chosen the Fay methodology, which envisages the phase changes of physical processes during the spreading of oil spill.

In Fay's theory, oil spreading occurs under gravity and surface tension at different stages by forces of inertia and viscosity [6].

According to Fay methodology [5], oil spreading on the surface usually has three phases: inertial, gravitational-viscose and surface tension phase.

At an initial stage, of high importance are gravity and inertia forces.

(1) $$R(t)_D = k_i \cdot \left[g \cdot V \cdot \left(\frac{\rho_w - \rho_o}{\rho_w} \right) \cdot t^2 \right]^{\frac{1}{4}}.$$

In the gravitational-viscose phase (second one) of oil pollution spill spreading, there are taken into account viscose friction forces in the slick. In this case calculations are made in accordance with formula

(2) $$R(t)_D = k_v \cdot \left[g \cdot V^2 \cdot \left(\frac{\rho_w - \rho_o}{\rho_w} \right) \cdot t^{\frac{3}{2}} \cdot \frac{1}{\nu_в^{\frac{1}{2}}} \right]^{\frac{1}{6}}.$$

During the third phase of oil pollution spill spreading, most prevailed are surface tension forces (surface tension phase). In this case calculations are made by

(3) $$R(t)_D = k_t \cdot \left[\sigma^2 \cdot t^3 \cdot \left(\frac{1}{\rho_w^2 \cdot \nu_w} \right) \right]^{\frac{1}{4}}.$$

In these expressions, the methodologies for assessing the radius R(t) of oil spill spreading, there are used the following designations: ν_w – coefficient of kinematic viscosity of water, m^2/sec; k_i = 1,14; k_v =1,45; k_t = 2,3. σ – resulting surface tension, which according to [6] equals 0,02...0,03 N/m;

Table 1. *Variation time (min) of oil spill spreading phases*

Name	Spillover volume , m³									
	25		50		100		200		300	
	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2	t_1	t_2
Fuel oil	13,9	22,8	17,5	36,2	22,1	57,5	27,8	91	31,8	119
Oil (hard)	10,5	30,2	13,3	47,9	16,7	77,0	21,0	120	24,9	158
Diesel oil	9,68	32,8	12,2	52,0	15,4	82,6	19,4	131	22,2	171
Petrol	8,4	38,0	10,5	60,2	13,3	95,6	16,7	151	19,1	198

A peculiarity of the selected methodology is the necessity of determining the transfer time from the first stage of spreading (inertial one) to the second one (gravitational-viscose), and from the second one – to the third one (surface tension forces phase).

A moment of transfer time (t_1) in the calculations of oil radius according to Fay methodology from the first stage of oil spill spreading to the second one is determined by the formula

(4) $$t_{1D} = 2{,}6173 \cdot V^{\frac{1}{3}} \left\{ \left(1-\frac{\rho_o}{\rho_w}\right)\cdot g \right\}^{-\frac{1}{3}} \cdot \nu^{-\frac{1}{3}}.$$

A moment of transfer time (t_2) in the calculations of oil radius according to Fay methodology from the second stage of oil spill spreading to the third one is determined by the formula

(5) $$t_{2D} = \frac{1{,}02 \cdot V^{\frac{2}{3}} \cdot \left(1-\frac{\rho_o}{\rho_w}\right)^{\frac{1}{3}} \cdot \nu^{-\frac{1}{3}} \cdot \rho_w}{\sigma}.$$

Time required for reaching the maximum oil spill in the surface tension phase (third phase) is determined by the following formula:

(6) $$t_{\max D} = \left[\left(R_{\max}^4 \cdot \rho_w^2 \cdot \nu_w\right)/\left(K^4 \cdot \sigma^2\right)\right]^{\frac{1}{3}}.$$

where, К=2,3.

Maximum radius of oil spill for $\tau_{\max}$ is calculated by the formula:

(7) $$R_{\max D} = \sqrt{\frac{V}{\pi \cdot h_{\min}}}.$$

At a certain stage, surface tension changes its sign, and spreading is stopped. As the observations have shown, that occurs, when the thickness of oil slick is reduced to 0,00003 – 0,0001 (m).

The thickness of oil slick (h) dependent on spreading time is calculated by the following formula:

(8) $$h=V/(\pi R^2)$$

By using above mentioned formulas, there have been carried out the model calculations of time variation (t), radius (R) of oil spill spreading and the area. Basic amount of spreading oil and oil products are in volumes $25m^3$, $50m^3$ $100m^3$, $200m^3$ and $300m^3$ (Table 1).

The current radius of oil spill at an initial stage of gravity and inertia forces for $0<t<t_1$ is determined by formula (1).

The current radius of oil spill in the gravitational-viscose phase (second one) of oil spill spreading for $t_1<t<t_2$ is determined by formula (2).

The current radius of oil spill in the third phase of surface tension for $t_2<t<t_{max}$ is determined by formula (3).

Table 1 presents the calculated magnitudes of transit time (min) of oil spill spreading process from the first phase to *the second (t_1), and from the second one to the third one (t_2).*

Analysis of calculations carried out has shown that maximum time (Table 1) of oil spill spreading by phases at the same power of point source depends essentially on the type of oil and oil products and spillover volumes.

At the accidental spillover volumes $25m^3$-$100m^3$, duration of the gravitational viscose phase of oil spreading may vary from 38 min to 95,6 min dependent on the type of oil products.

At large accidents with spreading of oil and oil products in the volume of 100 m^3, the transit time from the gravitational-viscose stage of spreading to the phase of surface tension forces is approximately 119,6 min for the most dense oil product (fuel oil) and exceeds 198,9 min at spreading of petrol.

4. Results and discussion

Actually, in response to accidental spill spreading of oil and oil products spill in t he areas of Georgian ports the time from the moment of oil dumping to the beginning of works on gathering the oil-watery mixture is not less than 38 min, i.e. in future, the first stage of spreading may be excluded from consideration (1).

Figures a and 2 show the dependence on the variation time of the radius (R) of spill spreading and area on the example of oil with density of 870 kg/m^3.

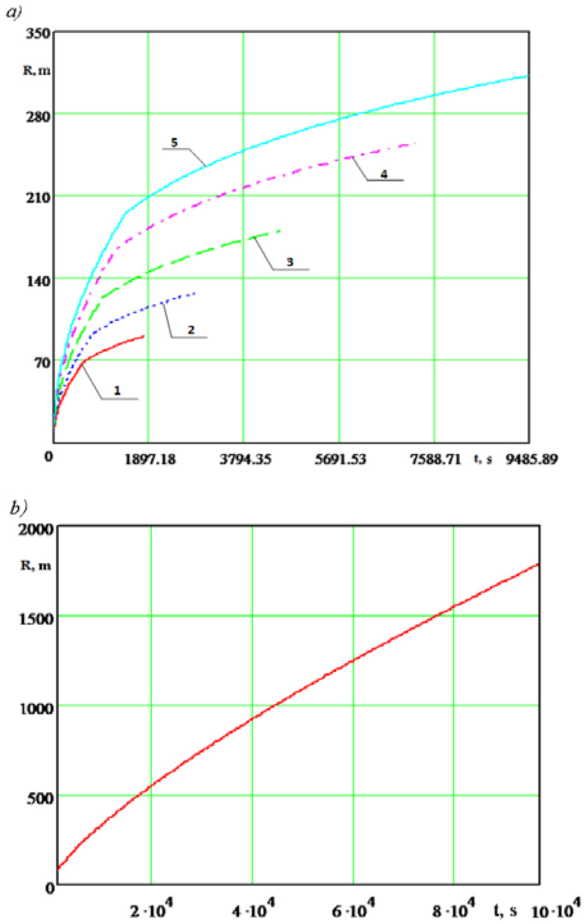

Fig. 1 *Dynamics of oil spill in the first-second (a) and third (b) phases: 1 - V=25 m^3; 2 - V=50 m^3; 3 - V=100 m^3; 4 - V=200 m^3; 5 - V=300 m^3*

The analysis of these diagrams (Fig. 1) has shown the nature of change of the radius of oil spill dependent on density and volume is the same. Change of the magnitude of oil spill radius mainly depends on its density and volume.

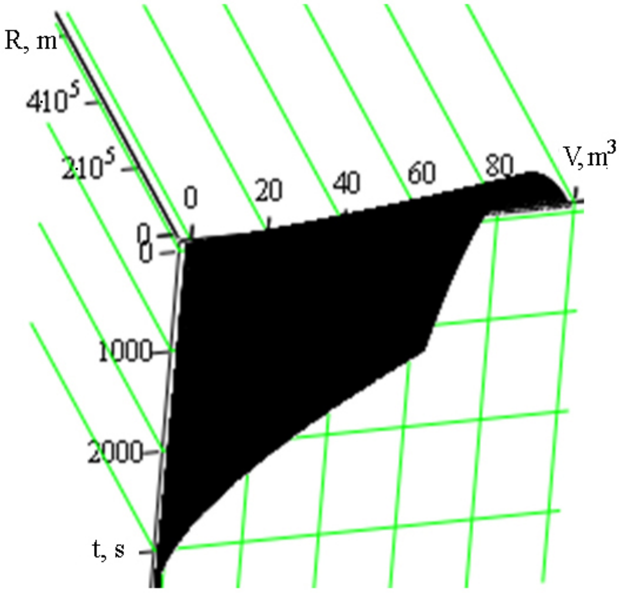

Fig.2. *Dependence of the area of oil spill (m2) on spillover volume (1…100 m^3) and time of diesel fuel spreading*

5. Conclusion

The proposed model allows forecasting the initial stages of oil spreading. The given methodology enables to determine transit time of the process of oil spill spreading from the first phase to the second one, and from the second to the third one; the radius and area of oil spill spreading; to assess the required means of oil spill localization, in particular – the length of boom containments.

6. References

1. Гамзаев Х. М. Моделирование растекания нефтяной пленки по поверхности моря. Прикладная механика и техническая физика. 2009. Т. 50, № 3.
2. Иванов А. В., Макаров К. Н. Математическая модель динамики разлива нефтепродукта. Известия Сочинского государственного университета, 2012. №3(21).
3. Пушкарь И.Ю. Моделирование процесса разлива нефти в Черном море. Материалы IV международной научно-технической конференции студентов, аспирантов и молодых ученых. – Донецк, ДонНТУ – 2013, Том 1).
4. Яковлев В. В. Нефть. Последствия аварийных ситуасий, СПб, 2003.
5. Альхименко А. И. Аварийные разливы нефти в море и борьбе с ними. СПб, 2004.
6. Venkatesh, S. The oil Spill Behaviour Model of the Canadien Atmosferic Enviroment Service Theory and model Evaluation / S. Venkatesh-Atmosferic Enviroment Service 4905 Dufferin Street. Downsview,Ontario.