A MATHEMATICAL MODEL OF OIL SPILL DIFFUSION IN NEAR-SHORE ZONE OF GEORGIA

МАТЕМАТИЧЕСКАЯ МОДЕЛЬ РАСПРОСТРАНЕНИЯ НЕФТЯННОГО ПЯТНА В ПРИБРЕЖНОЙ ЗОНЕ ГРУЗИИ

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Abstract : *The oil products remain the main contaminant of the Black Sea, as well as of the entire world's oceans. A main amount of oil is transported by tankers and reloaded in port terminals. 12 per cent of overall marine pollution is the share of transportation, oil congestion and accidents losses. At the Caspian-Black Sea-Mediterranean area there are actively used the Black Sea ports of Batumi, Poti and Kulevi.*

A huge damage to the nature is doing by oil spills on the surface of the oceans and seas owing to transportation oil by tankers. These spills are associated with loading and unloading operations as well as with tankers accidents. In this case, the oil spreads as a spot on the surface of the sea.

Problems associated with environmental pollution from the oil spill in the sea, made necessity to develop mathematical models that describe the transportation and transformation processes of oil spills. The proposed mathematical model can be used for prediction of the spread of an oil spill during the process of spreading of oil products on the water surface, and it also enables to take into account the reduction of the area of spill due to the action of sea-surface winds and turbulence of the water surface.

KEY WORDS : *BLACK SEA, OIL SPILL, MATEMATIKAL MODEL, TRANSFORMATION PROCESSES.*

1. Introduction

The oil products remain the main contaminant of the Black Sea, as well as of the entire world's oceans. According to International Energy Agency, oil production is 91,3 million barrels per day, from which 3/5 – is transported by tankers, 2/5 – through pipelines, i.e., a main amount of oil is transported by tankers and reloaded in port terminals; 12 per cent of overall marine pollution is the share of transportation, oil congestion and accidents losses. Experts estimate that by 2020, the world consumption of crude oil will be increased by 1,2-1,5. Besides, the demand for oil in developing countries will be increased by 2,5-2,8, and in advanced countries – by 30-35%.

In the near future, the annual volume of oil transportation in the Black Sea may be increased to 220-250 million ton. Besides, it is expected to transport annually: 50 mln through the ports of Ukraine; about 60 mln – through the ports of Russia; about 30 mln – through the ports of Georgia; about 25 mln – through the ports of Bulgaria; about 35 mln – through the ports of Turkey. Without regard to accidents, only with technological loss at 0,01% of the volume of transported oil products, about 20 thousand ton of oil products may be discharged into the marine environment. During accidents, these losses may be increased tenfold.

At the Caspian-Black Sea-Mediterranean area there are actively used the Black Sea ports of Batumi, Poti and Kulevi. Navigation and the maritime transport objects of Georgia have significant impact on the Black Sea ecosystem.

A huge damage to the nature is doing by oil spills on the surface of the oceans and seas owing to transportation oil by tankers. These spills are associated with loading and unloading operations as well as with tankers accidents. In this case, the oil spreads as a spot on the surface of the sea. Just one liter of oil is enough for forming of spill of almost 1 hectare. Besides, depending on the quantity of oil and the velocity of spreading the spill can be appeared either in the form of “peak” emission or as a continuous ingress of oil within a certain period of time.

2. Preconditions and means for resolving the problem

Problems associated with environmental pollution from the oil spill in the sea, made necessity to develop mathematical models that describe the transportation and transformation processes of oil spills. Such models are used for prediction of the spread of an oil spill and for estimate of its characteristics required for planning and carrying out activities for the liquidation of spills in the events of accidents, as well as for assessment of environmental impact.

The process of spreading the oil spills in the sea is a fairly complex process, which depends on a large number of factors defining as the state of the environment so the properties of substance itself. Thus, the solution of this multifunctional problem requires a comprehensive and integrated approach.

When setting the problem on oil pollution transfer into the sea, it is necessary to adequately describe not only physical-chemical properties of oil itself and the character of the source of pollution, but also such characteristic as the diameter of oil spill.

The realized complex takes account for the following processes that occur with oil as the object under study: 1. Oil spread; 2. Displacement caused by the sea water flow and wind.

For the first process of spilling of liquid lighter than oil over the water surface, it is necessary to emphasize several merging one into another stages, from which the most important for spills less than 2000 m^3 is the phase of spreading under the action of forces of the superficial tension of oil so far as the spill remains a single whole. This process is thoroughly investigated through the experiments of John Fay by modified semiempirical formulas.

The oil spill diameter against the wind direction Ry is determined as follows::

$$\sigma = \left[\frac{\rho_W - \rho_0}{\rho_0}\right]^a$$

Here,

where, ρ_W - is the sea water density;

ρ_H - oil density; M – the volume of the initial spill of oil.

t – time of spill;

a, в, c – spreading coefficients of layer (a=42,5; в=1/3; c=1/4)

The oil spill diameter in the direction of wind R_X:

where, W – the wind velocity, m/sec;

β = 1,82; d=4/3; e=3/4.

2. The process of displacement of oil pill under the action of sea current and wind. пятна под действием течении моря и ветра; It is assumed that the oil products move by means of the following factors:

1. Sea water current;
2. The wave action arisen near the margin of coast of water area. .

The process of displacement is described by the expression:

$$V_t = K_W W_t + K_u U_t + K_S(L) F_t$$

where, $\mathbf{V_t}$ - the vector of velocity of the shift of the center of "micro-spill";

$\mathbf{W_t}$ - the vector of wind velocity at a height of 10 m from the surface of coast;

$\mathbf{U_t}$ - the vector of the total wind and flood currents;

$\mathbf{F_t}$ - the influence vector of the coast and its configuration;

K_W - the influence coefficient of wind – in the calculations it is assumed that each spill has its own coefficient of permissible range 2-4%;

K_u - the influence coefficient of the sea water current. In calculations it is taken as equal to 100%.

K_S - the influence coefficient of the coast by the distance from spillage.

3. The wave action arisen near the coast-line.

The coast-line has a significant influence on "micro-spills", since with decreasing water depth the waves turn toward the coast. This factor is especially evident when the angle between the coast normal and vector is under 90^0. When the distance to the coast is reduced this influence is more violent. The influence coefficients of the coast are the empirical values and they are determined during the experiments.

As the input data the following information is used:

1. The sea-coast configuration;
2. Meteorological situation for the entire period of modeling;
3. The real or calculated currents;
4. The place and dynamics of spillage of oil products.

The air temperature on the Georgian coastline during the most cold months – in January and February – is an average minimum of $4,3^0$C, $3,8^0$C, but some days it can be lowered to $-5,3^0$C, $-7,5^0$C. During the most warm

months – in July and August – the mean temperature of air is $22,3 – 23,1^0$C, the absolute maximum is $37,6 – 41,0^0$C.

For most of the year, the north-east winds blow in near-shore zone of Georgia, which are characterized by considerable velocity and duration, but in the winter they bring cooling. In the summer, the south winds are not unusual. The violent winds occur mostly in winter and autumn. The currents mostly depend on winds.

The process of merging of oil into the "micro-spills" occurs as follows:

a) by gravitational viscose forces and by surface tension forces, which move under the action of water and wind current during a certain period of time;

by the division of spill into individual particles under the action of wind and current (there is applied the Lagrangian method by using of the stochastic nature of the formation of spills by particles).

It turned out that right after the spillage, there begins the spreading and displacement of oil over the water area of reservoir; when reaching the specified thickness of lash, the spill is divided into individual N particles, each of which has a certain mass and henceforward is considered as the «micro-spill". Then for each particle there begins the iteration (repetitive_ process of calculating its displacement trajectory. This process proceeds for each particle: a) until it reaches the coast; b) until it goes beyond the boundaries of computational region.

The results of theoretical calculations have shown that the diameters of petrol and diesel fuel spill are not very different from each other. This is explained by their densities, the values of which are almost the same. Similarly, the diameters of the mazut and oil spill are also not different from each other, but their values are by 23% lower than the diameters of petrol and diesel fuel spill.

Fig. 1 shows the change of the oil spill diameter with the dependence on time of spreading. As is seen from the diagrams (Fig. 1), the diameter of spreading of oil spill depends significantly on the wind direction.

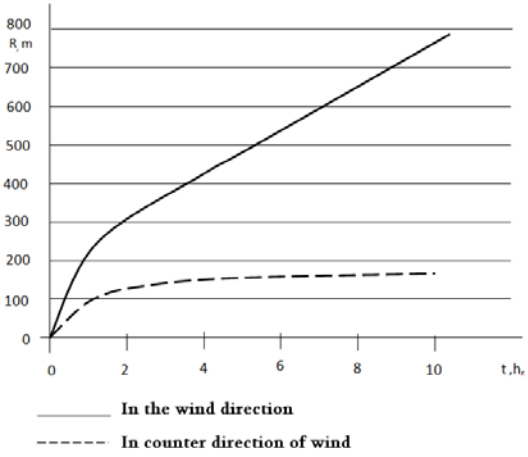

***Fig. 1**. The change of the oil spill diameter over the water surface with the dependence on time*

According to the results of studies (Fig. 2), there are constructed the diagrams of distribution of mazut both in the water area and in near-shore zone of Georgia.

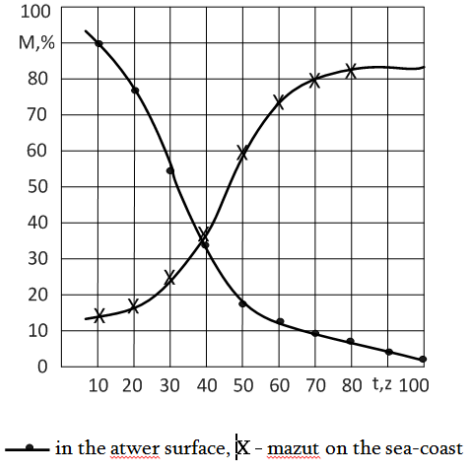

***Fig. 2.** . Distribution of mazut in the water area and near-shore zone of Georgia*

The movement of the layer of mazut spill in near-shore zone of Georgia and in the water area is determined by the field of wind, the state of the sea surface and physical-mechanical properties of the mazut itself. The use of the method of spill division into elementary particles allows assessing the quantity of distributed oil products within particular territories, as well as determining the trajectory of displacement of these particles.

3. Conclusion

It has been established by the calculations that the diameter of spill increases with increasing quantity of the spilt oil. The maximum diameter, which can be reached by oil spill also depends on the quantity of the spilt oil and oil products over the water surface.

The wind direction as well as its rate has more significant influence on the oil spill diameter than the density of oil and oil products.

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