Analysis of the accident consequences at the remote mooring facilities of the Caspian Pipeline Consortium

S I Pankina, L A Umanskaya, M N Lyutikova, S O Malakhov, E N Syusyuka
Admiral Ushakov Maritime State University, Novorossiysk, Lenin Avenue 93, 353918, Russia
Email sipankina@mail.ru

Abstract. The article discusses the issue of the practical aspect of determining the volume of emergency bottling of oil that took place on 08 July 2021. Dependences of oil spreading on time, temperature, air, water, waves have been determined. The novelty of the presented article constitutes the study of the change and influence of the main parameters of the oil spill, as well as in the multidimensional model of the combination of these pollution factors based on the theory of fuzzy sets.

Keywords: oil spill, fuzzy sets, accident, model, oil film area, slick diameter, oil percentage, ecology.

1. Introduction
The creation of the new vessels, equipped with the contemporary different navigation automatically controlled complexes, allows partially or in some directions to completely exclude selection and decision making by a human. Moreover, this totally exclude the possibility of the emergencies connected with a “human factor”.

Let us note several directions, connected with the application of the automatically controlled complexes, which make it possible to exclude possible neglects by navigator or untimely calculation of some factors with decision making in the operation of the vessels:

- excessive speed during the motion of a vessel;
- the selection of the way of a vessel in immediate proximity to the dangerous zones;
- the selection of maneuver in immediate proximity to a vessel (vessels);
- incorrect or untimely decision making in the optimal situation of convergence of vessels;
- violation of the requirements for the safe conduct of cargo operations, especially oil tankers and product tankers;
- incorrect or untimely accounting of hydrometeorological conditions (flow, wind, etc.), etc.

The oil is the product of prolonged disintegration and with the flood of oil very rapidly surface of water is covered with the dense layer of the petroleum film of that not allowing the air inlet and light. The ecological consequences from the floods of oil, especially on the large scales, are extremely negative. In this regard, the problem of research in the field of emergency situations of oil product spills is especially relevant [3].

It should also be noted that the oil spill is difficult to take into account, since it affects the relationships and habitats of all types of organisms, and also depends on further changes due to natural changes (wind, waves, etc.). This can have a negative impact in the long term [4]. Not only the animal and plant world suffers from accidents related to oil products, but the ecological structure as a whole is deformed [11].
Aspects of research on emergency situations and taking into account the parameters of spreading of oil products is also relevant from an economic point of view when eliminating the consequences of an accident [13].

Growing oil production leads to an increase in oil transportation and an increase in tanker vessels. Accordingly, during loading and transportation, oil product spills are possible and therefore sea transport is one of the main sources of pollution of the marine environment.

Violations associated with non-fulfillment or neglect of certain safety requirements or recommendations in shipping lead to a number of possible emergency situations, for example, discharges of pollutants, destruction of various mechanisms, systems or the hull of a vessel [5].

Processing the results of measurements and forecasting the area of oil pollution is based on the assessment of: properties of spilled oil products; boundary weather and climatic conditions; acting currents; various seasonal changes in hydrology; conditions of natural fencing (bay, inland water area, open sea, etc.).

The aim of the study is to analyze the main parameters of the oil spill and take into account the magnitude of the degree of danger and damage caused.

2. Materials and Methods

Nowadays, many marine vessels and tankers with oil have to carry out long-distance and large-scale transportation due to economic needs. Oil is the most persistent pollutant, leading to significant environmental problems. Therefore, issues related to the goal of improving the safety of navigation are directly related to the prevention of environmental pollution [6].

The issues of human health protection and environmental protection are priority in Russian environmental legislation. One of the international regulatory documents for the transboundary movement of hazardous wastes is the Basel Convention, adopted in 1989.

All vessels operating on inland waterways and vessels of mixed navigation have documents related to the prevention of pollution of the aquatic environment and regulated by MARPOL 73/78 [15-16].

Growing oil production leads to an increase in oil transportation and an increase in tanker vessels. Accordingly, during loading and transportation, oil product spills are possible and therefore sea transport is one of the main sources of pollution of the marine environment [11].

Emergency situations associated with the spill of oil and oil products during the transportation of goods are classified as emergencies, since they cause serious damage to the entire ecosystem in this area and require large costs for their elimination. The main causes of an oil spill include:

- damage to the vessel's hull;
- grounding the vessel;
- collision of vessels;
- fires and explosions on vessels;
- when bunkering the vessel;
- during loading and unloading operations;
- oil overflow losses;
- when discharging flushing and ballast water, etc.

In this case, the ecological situation in the regions of intensive navigation can be classified as follows: relatively satisfactory, stressed, critical, crisis and catastrophic. Depending on the degree of ecological trouble in the places of emergency situations of ships, there is a change in the aquatic environment and degradation of the natural ecosystem, leading to a change in the marine habitat.

The amount of damage caused in emergency situations of negative impact on the marine environment is determined by the formula (1) [14]:

$$Y = \sum_{i=1}^{5} Y_i = Y_1 + Y_2 + Y_3 + Y_4,$$  \hspace{1cm} (1)

where $Y_1$ is damage to the aquatic environment; $Y_2$ is damage to flora; $Y_3$ is damage related to the violation of the vessel structure; $Y_4$ is damage related to emergency work.

The damage caused by water pollution is calculated by the formula (2):
\[ Y_2 = \sum_{i=1}^{n} M_i \times 10^{-6} \times H_i \times K_e \times K_i \times K_{pcs}, \]  

(2)

where \( M_i \) is the mass of \( i \)-th pollutant, \( H_i \) is the base norm of pay for the discharge into the aqueous object \( i \)-th pollutant, \( K_e \) is the coefficient of ecological situation and ecological significance of aqueous object, \( K_i \) is the coefficient of the indexing of pay for the pollution of natural environment, \( K_{pcs} \) is the coefficient of exceeding standard.

As a rule, three groups are distinguished (three degrees of danger), which are indicated by numbers:
- 1 - high degree of danger;
- 2 - medium;
- 3 - low.

The amount of damage caused in emergency situations of negative impact on the marine environment is determined by the formula:
\[ Y = \sum_{i=1}^{5} Y_i = Y_1 + Y_2 + Y_3 + Y_4, \]  

(3)

where \( Y_1 \) is damage to the aquatic environment; \( Y_2 \) is damage to flora; \( Y_3 \) is damage related to the violation of the vessel structure; \( Y_4 \) is damage related to emergency work.

3. Results

A major oil spill resulting from an accident at the oil terminal of the Caspian Pipeline Consortium occurred on 7 August 2021.

In particular, Caspian pipeline consortium (CPC), the operator of VPU, reported bottling 12 cubometers of oil. The area of flood, according to the communications of operator it comprised 200 square meters and petroleum spot is operationally liquidated.

The subsequent refutations from the Institute of Space Research of the Russian academy of sciences reported about the area of pollution the minimum 80 of square kilometers. Satellite photograph is given in the Figure 1.

The area of emergency bottling was investigated for various scenarios of accidents and response of emergency forces and means. The crude oil, dispatched on the sea terminal of privately held company “CPC- R”, has a brand “mixture CPC” and possesses the following fundamental characteristics: kinematic viscosity is 19,18 cSt; density is 781 kg/m\(^3\) (with 20\(^{\circ}\)C); boiling point is 50\(^{\circ}\)C; the pressure of the saturated vapors is 37,9 kPa (with 37,8\(^{\circ}\)C). Oil with such properties is included in the first group of oils. Oil evaporates quickly enough, which affects the assessments of the response of emergency forces and means to oil spills.
Figure 1. Satellite image of oil spill at the VPU (operator of the Caspian Pipeline Consortium), dated 08.07.2021

The formation of a pollution spot visible on a satellite image is formed by the spreading of oil to a monomolecular layer. The most significant factors are oil viscosity, water temperature, hydrology of the area; surface tension; wind speed; excitement; the amount of oil that got into the water [3-4].

The state of the visible pollution factor is affected by the air temperature, which on 07.08.2021 in the area of the accident and oil release had the following dynamics: at the time of the accident is 30.0°C; practically before sunset is 30.0°C; after sunset is 29.0°C; by 12 p.m. is 28.0°C; to 6 a.m. is 26.0°C.

The specific gravity of the oil promotes bottling. As it spreads, the surface tension forces balance the specific gravity per unit area. We believe that the process occurs according to the exponential law, with the weighting factors of the influencing factors.

The established film contains a certain amount of oil. 5-7% of the film may dissolve in seawater. A small amount of 5-10% forms aggregates: high-molecular compounds of water and oil. In this case the greatest contribution is made by waves.

For the conditions of oil shipment to the TLU of CPC, we draw up a table for accounting for spreading parameters depending on the volume of oil that entered the sea, film thickness, contamination area, as well as the percentage of oil in the film (formation of high molecular weight oil compounds).

Measurements and data processing of oil bottling brand "CPC blend" are summarized in Table 1. Numerical methods are used to calculate experimental curves for each of the parameters:

- Diameter of the spot (m) \( y(d) = 0.4811d^2 - 3.3053d + 5.0833 \);
- Spill area (m\(^2\)) \( y(p) = 0.4811p^2 - 3.3053p + 5.0833 \);
- Percentage of oil in the pollution spot (excluding emulsion and water-soluble component) (%) \( y(N) = -0.7792N^2 + 2.8933N + 95.705 \);
- Thickness of the film (mm) \( y(T) = 0.0545T^2 - 0.9806T + 4.8333 \).

Table 1. Calculated parameters of oil spreading and film formation depending on time, determined empirically

| Parameter/time, h | 0.25 | 0.5 | 1.0 | 1.5 | 2.0 | 3 | 4 | 6 | 12 | 24 |
|------------------|------|-----|-----|-----|-----|---|---|---|----|----|
| d, m             | 115  | 133 | 150 | 168 | 186 | 198| 217| 251| 287 |422 |
| area, m\(^2\)    | 9000 |12000|16400|19700|22700|26600|30800|40100|51000|78800|
| Thickness, mm    | 4.3  | 2.9 | 2.0 | 1.5 | 1.5 | 1.0 | 0.9 | 0.6 | 0.4 | 0.3 |
| N% oil           | 99.4 | 98.4| 95.9| 93  | 90.1|84.6| 79.8| 71.8| 58.3| 44.9|
| t, °C            | 30   | 30  | 30  | 30  | 30  | 30 | 30 | 30 | 29  | 26  |

The actual indicators of oil pollution caused by oil bottling at the CPC remote terminal, summarized in Table 1, are shown in the figures: the dependence of the diameter of the oil spot on time (Figure 2); the dependence of the area of the oil film on time (Figure 3); the dependence of the percentage of oil of the brand "CPC mixture" in the total volume of pollution (Figure 4); the dependence of the thickness of the pollution film (mm) on the time of spreading of oil of the brand "CPC mixture" (Figure 5).
Figure 2. Dependence of the slick size on the spreading time of the "CPC blend" brand oil

Figure 3. Dependence of the slick size on the spreading time of the "CPC blend" brand oil

Percentage of oil(%)
Figure 4. Dependence of the percentage of oil of the brand "CPC blend" in the total volume of pollution

![Film thickness](image)

\[ y = 0.0545x^2 - 0.9806x + 4.8333 \]

Figure 5. Dependence of the slick size on the spreading time of the "CPC blend" brand oil

The polluting factors of oil pollution include the oil without water-soluble components. Over time, the component of oil as a polluting factor decreases due to the emulsification of oil and the evaporation of light fractions.

The combination of influencing pollution factors can vary depending on the direction and strength of the wind, sea waves, air temperature, currents. The cumulative influencing factors can be considered on a multivariate distribution model built in the algebra of fuzzy sets, as shown in Figure 6 [7].

![Surface Viewer: Progoz oil](image)

Figure 6. The model of multidimensional distribution of influencing factors on sea pollution with oil of the brand "CPC blend", built in the MATLAB package [8]
The value of the output variable obtained as a result of defuzzification is indicated in the upper part of the column with the name of the output variable (\( \text{Voil} = 7.63 \) tons of oil on the surface spot to the time estimate of 3 hours), which is shown in Figure 7.

![Figure 7](image)

Figure 7. Settings of the multidimensional distribution model of influencing factors on sea pollution with oil brand "CPC blend" (MATLAB system) [9]

4. Conclusions

The considered model built on in situ measurements of the accident with the oil spill of the brand "CPC mixture" in the area of the remote mooring devices VPU-1, VPU-2 at the Yuzhnaya Ozereevka terminal in Novorossiysk on 08/07/2021 at a temperature of 30\(^\circ\)C enables to determine the volume and level of pollution (points).

The obtained theoretical and practical data given for the oil stamps delirium “CPC blend” testifies about the quadratic dependence of the size of spot and volume of the spilled oil by the united equation of the form: the diameter of spot (m) \( y(d) = 0.4811d^2 - 3.3053d + 5.0833 \); the area of flood (m\(^2\)) \( y(p) = 0.4811p^2 - 3.3053p + 5.0833 \).

We consider the important conclusion presents determining the percentage of oil in the overall spot of pollution with exception of water-soluble component in the composition of pollution, and the level of the formation of emulsions and evaporations of characteristic for the oil of stamp brand “CPC blend”.

References

[1] Berridge A, Dean R, Fallows R, Fish A 1968 The properties of persistent oil at sea. Scientifica spectropollution of the sea by oil, Institute of Petroleum, London.

[2] Orujov E, Avdotin V, Bryanskaya I 2018 The problem of oil spills in Azerbaijan Journal School of Science Number 6 (6) 58-60.

[3] Dennis J, 1959. Oil pollution survey of the United States Atlantic coast American Petroleum Institute Washington.
[4] Cormack D 1999 The Oil-Water System. In: Response to Marine Oil Pollution Review and Assessment. Environmental Pollution, vol 2. Springer, Dordrecht.

[5] Giurco D, Cooper C 2012 Mining and sustainability: asking the right questions. Minerals Engineering, 29, 3-12.

[6] S Jacobsen, K Haver et al 2016 Overview of measures specifically designed to prevent oil pollution in the arctic marine environment from offshore petroleum activities Conference: Arctic Technology Conference

[7] Chang S, Stone J, Demes K, and Piscitelli M 2014 Consequences of oil spills: a review and framework for informing planning. Ecology and Society 19(2) 26.

[8] F Jaderi, Zelina Z, I Mohammad, R Zahiri 2019 Criticism analysis of petrochemical assets using risk based maintenance and the fuzzy inference system Technological safety and Environmental Protection 121 312-325.

[9] Leonenkov A V 2005 Fuzzy modeling in MATLAB and fuzzyTECH St. Petersburg: BHV-Petersburg 736.

[10] L De Miguel Jiménez, N Etxebarria, X Lekube, U Izagirre, I Marigómez 2021 Influence of dispersant application on the toxicity to sea urchin embryos of crude and bunker oils representative of prospective oil spill threats in Arctic and Sub-Arctic seas Marine Pollution Bulletin.

[11] Almeda R, Hyatt C, Buskey E 2014 Toxicity of dispersant Corexit 9500A and crude oil to marine microzooplankton Ecotoxicology and environmental safety

[12] Smies M 1983 On the relevance of microecosystems for risk assessment: Some considerations for environmental toxicology Ecotoxicology and Environmental Safety Volume 7, Issue 4 Pages 355-365.

[13] Gamzaev X 2009 Modeling of oil slick spreading over the sea surface Applied Mechanics and Technical Physics T 50, N= 3 pp. 127-130.

[14] Alyshanov G, Tarasenko A 2013 Decision-making on the possibility of localizing oil spills in the sea area The problem of emergency situations number 17 Pages 11-17.

[15] SOLAS (Consolidated text, as amended by the 1988 Protocol thereto, as amended). St. Petersburg: ZAO TsNIIMF, 2010. - 992 p.

[16] International Convention for the Prevention of Pollution from Ships (MARPOL) 2009 Book III revised edition. St. Petersburg: ZAO TsNIIMF 304 p.