STUDY OF THE EVOLUTION OF AN OIL SPILL ON WATER SURFACE

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This paper presents the evolution of an oil spill on the water surface. Authors compare the results obtained in the laboratory with the results of a computer simulation in the same environment conditions. The simulation is performed with Pisces II, a program used to assess the consequences of water pollution with oil.

Keywords: pollution, oil spill, simulator

1. Introduction

The paper starts with the determination physical properties of the petroleum product which is later on used in the laboratory, to study the development of oil spill on the water surface. The results are then compared to the results of a simulation performed in the same environmental conditions, on Pisces II simulator.

2. Determination of the petroleum product physical properties

The petroleum product used in the practical experiment is a crude, undistilled oil (REBCO - Russian Export Blend Crude Oil), obtained from S.C. Oil Terminal S.A. The sample was extracted from Western Siberia and the accompanying analysis report indicates the following characteristics:

- Water and sediment content: maximum 1.2%;
- Sulphur content: maximum 1.8%;
- Paraffin content: maximum 6%;
- Chloride content: maximum 0.05%;
- Concentration of salts: maximum 100 mg/l.

The following measurements were performed in the S.C. Oil Terminal S.A. laboratory in Constanta, where authors determined the properties of the specific crude oil sample, at 20 ºC, the value of temperature:

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- the density (ρ_p) was determined by using a digital densimeter DMA 48, operating under the principles given by the law of harmonic oscillations. The obtained value is $\rho_p = 888.77$ kg/m^3;

- the Dynamic viscosity of the oil product (η_p), was determined using an Ubbelohde type capillary viscousimeter with suspended-level ($\eta_p = 0.013$ Pa·s). The cinematic viscosity of the oil product (υ_p) was determined by using the following relation:

$$\upsilon_p = \frac{\eta_p}{\rho_p}. \qquad [\mathrm{m^2/s}] \tag{1}$$

From equation (1), authors obtained the value of the kinematic viscosity: $\upsilon_p = 1.46 \times 10^{-5}$ m^2/s.

- Surface tension of the oil product (σ_p), was determined by the drop method, using a stalagmometer,

$$\sigma_p = \sigma_a \frac{n_a}{n_p} \frac{\rho_p}{\rho_a}, \qquad [\mathrm{N/m}] \tag{2}$$

where σ_p, σ_a the surface tension of oil respectively water; the water surface tension is known from tables [1, 2] (e.g. at 20 ºC its value is 0.07275 N/m); n_p *and* n_a are the number of oil/water droplets leaking from the stalagmometer's constant volume tank; ρ_p *and* ρ_a are the densities of oil/water at the working temperature.

Solving (2), authors obtained the surface tension of the oil product: $\sigma_p = 0.0297$ N/m.

- Surface tension at the oil-water interface (σ_{p-a}), was determined by using the relation

$$\sigma_{p-a} = \sigma_a \frac{n_a}{n_p} \frac{\Delta\rho}{\rho_a}, \quad [\mathrm{N/m}] \tag{3}$$

where σ_{p-a} is the surface tension at oil-water interface; σ_a the surface tension of water; $\Delta\rho$ is the density difference of the two liquids, water and oil; n_p, n_a is the number of oil respectively number of water drops.

Following equation (3), the surface tension at the oil-water interface $\sigma_{p-a} = 0.0182$ N/m.

- The net scattering coefficient of oil spill on the water surface (σ) was determined by the relation [1, 2]

$$\sigma = \sigma_a - \sigma_{p-a} - \sigma_p \text{. [N/m]} \quad (4)$$

Net scattering coefficient is σ = 0.02485 N/m.

3. Laboratory determination of the oil spill parameters

Experimental works were conducted in the research laboratory depending on the Fire Officers Faculty - "Alexandru Ioan Cuza" Police Academy (Fig. 1) and are aimed at quantifying the changes in the geometric parameters of the oil spill instantly discharged on the water surface.

Fig. 1. Experimental laboratory stand used to visualize an oil spill on the water surface

The geometrical parameters of the spill were determined by using photo processing software [3], applied on the pictures that were taken during the physical process of mechanical scattering, in order to identify its characteristic regimes.

The experimental stand is shown schematically in Figure 2 and consists of a metal tank (2) with a length of 1.5 m and a width of 1 m, above which was placed a digital camera (1), fixed in an immobilization system (3), and a halogen lamp which produced an uniform illumination, necessary to obtain a high contrast between water and oil product. In the range of the camera was set a timer that measures tenths of a second.

At the bottom of the tank, below the water surface, it was connected a tube with a syringe (4), that was used to inject almost instantaneously well-defined different volumes of oil. This process is similar to an accidental instant oil pollution, at time $t = 0$.

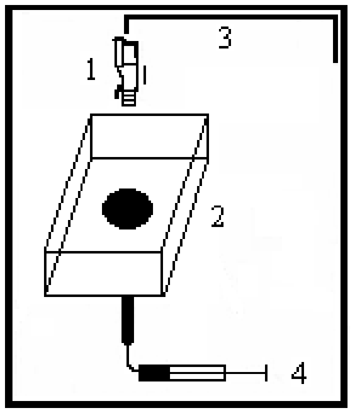

Fig. 2. Scheme of experimental stand used to view an oil spill on the water surface

For these measurements authors used tap water and REBCO oil product (whose characteristics have been previously determined) at 20 ± 0.5 ºC ambient temperature.

Photographs taken from experimental work (Fig. 3) were further processed using image analysis software Sigma Scan Pro (Fig. 4), which can clearly differentiate oil spill [1, 4], by using a color filter method. The area of the oil spill evolution in time (fig. 5) was identified by analyzing the photographs.

Laboratory works were conducted on a well defined 1 ml volume of oil with the physical previously established properties.

Fig. 3. Photo with the state of the spreading oil spill at one moment in time

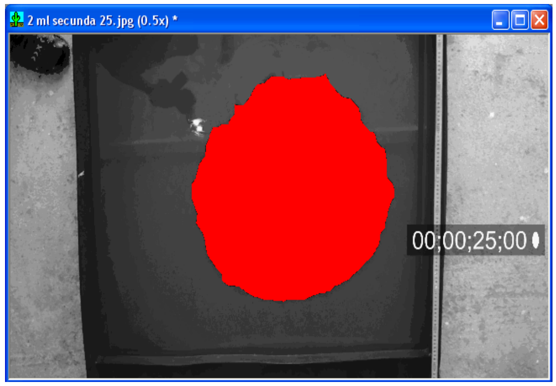

Fig. 4. Results obtained after image processing with Sigma Scan Pro

For analysis and identification of the scattering regimes of the Fay model [1, 4], authors define the following geometrical parameters:

- average thickness of the film (Fig. 6), $h = \frac{V}{A}$, where V is the volume of oil introduced and A is the area of the spill;

- the approximate radius of the spill (Fig. 7), $l = \sqrt{\frac{V}{\pi \cdot h}}$, where V is the volume of introduced oil and h is the average thickness of the spill;

- the scattering speed (Fig. 8), $v(t) = \frac{dl}{dt}$, where l is the approximate radius of the spill and t is time.

The following studies determined the geometrical parameters of the oil spill in Table 1.

Table 1

Laboratory results for a volume of 1 ml of oil

Time [s]	Spill area [cm^2]	Average film thickness [mm]	Average radius of the spill [cm]	Spreading speed [cm/s]
1	3.987472	2.507854	1.126896	0.040544
2	681.6831	0.014669	14.73448	13.60758
3	1599.997	0.00625	22.5733	7.83882
4	2623.257	0.003812	28.90405	6.330752
5	3520.538	0.00284	33.48698	4.582928
6	4208.364	0.002376	36.61103	3.12405
7	4781.263	0.002091	39.02637	2.41534
8	5152.084	0.001941	40.50628	1.47991
9	5293.085	0.001889	41.06002	0.55374
10	5323.181	0.001878	41.18009	0.12007
11	5330.132	0.001876	41.20204	0.02195
12	5338.988	0.001873	41.23502	0.03298

Time [s]	Spill area [cm^2]	Average film thickness [mm]	Average radius of the spill [cm]	Spreading speed [cm/s]
13	5346.07	0.001871	41.25706	0.02204
14	5359.047	0.001866	41.31229	0.05523
15	5379.798	0.001858	41.40114	0.08885
16	5393.314	0.001854	41.44577	0.04463
17	5409.011	0.001849	41.50177	0.056
18	5411.5	0.001848	41.513	0.01123

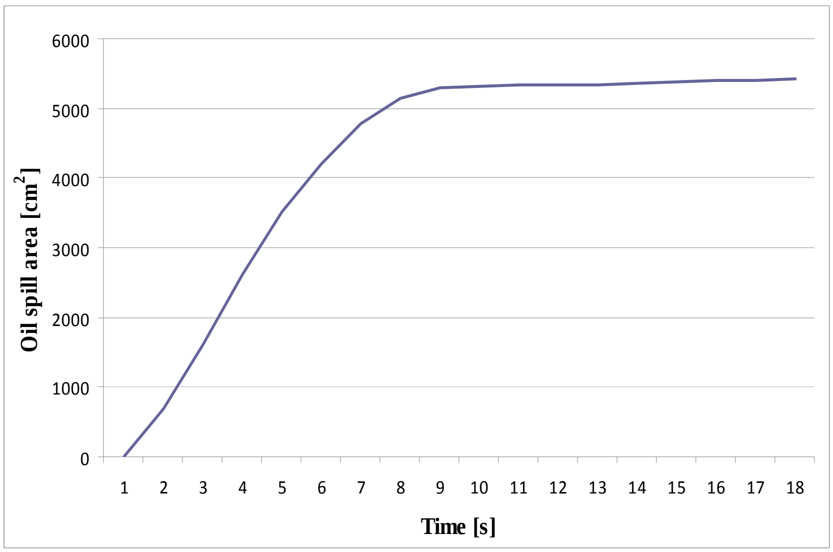

Fig. 5. Variation of the oil spill area

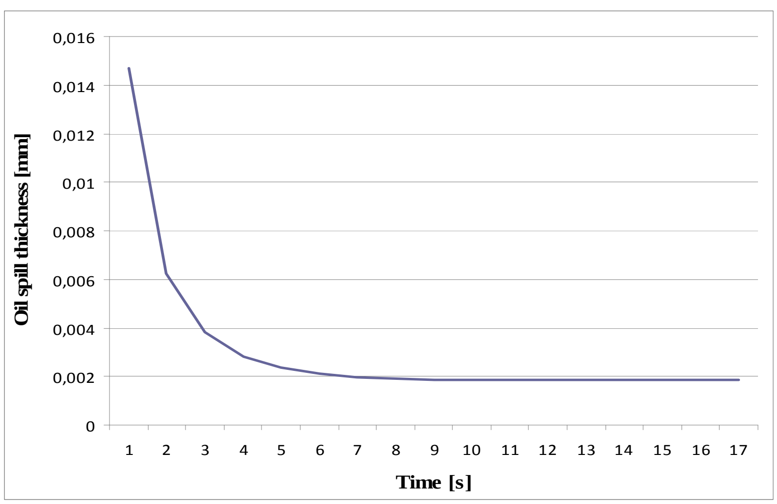

Fig. 6. Variation of the oil spill thickness

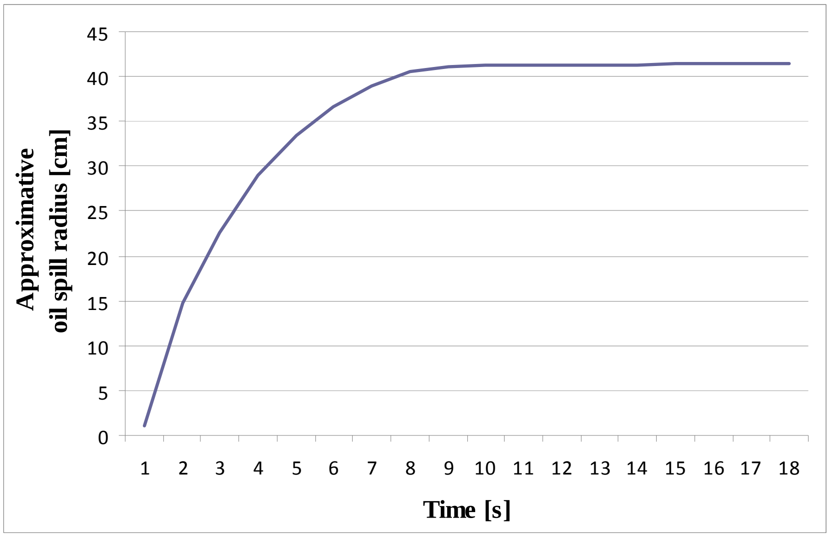

Fig. 7. Variation of the approximate oil spill radius

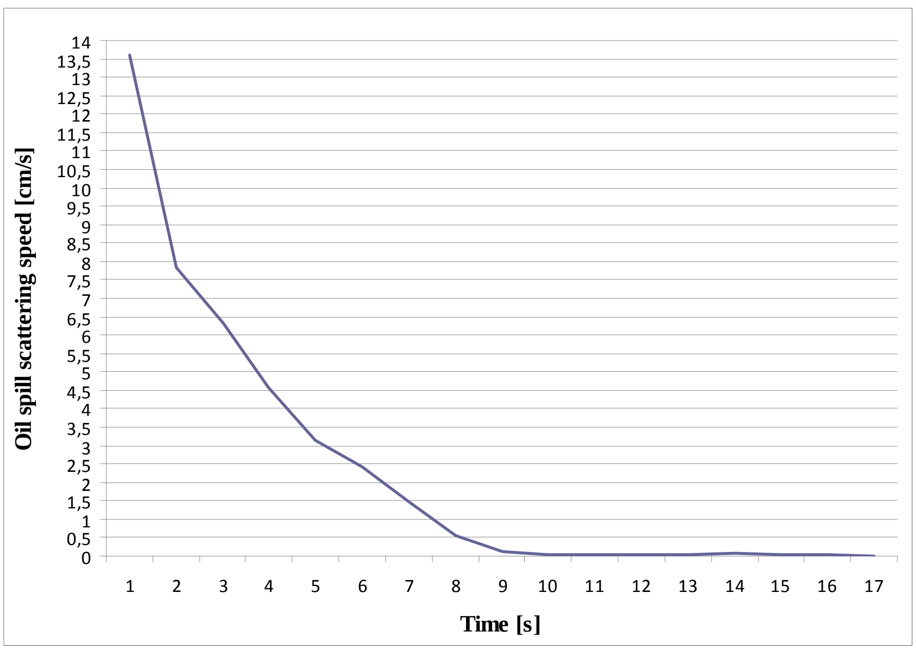

Fig. 8. Variation of the oil spill scattering speed

The results show that the oil film thickness is directly proportional to the scattering speed and inversely proportional to the spill area and radius.

For a more accurate determination of the scattering stages authors derived the relations describing the range of oil film in the three modes of the Fay scattering model [1, 4, 5].

Thus, one obtained the scattering rate *dl/dt*:

- for the inertial regime, by using the relationship

$$l \sim (g\Delta V)^{1/4} t^{1/2} \Rightarrow \frac{dl}{dt} \sim \frac{1}{2}(g\Delta V)^{1/4} t^{-1/2}, \tag{5}$$

where $\Delta = \frac{\rho_a - \rho_p}{\rho_a}$ is the fraction of oil that floats above the water level; ρ_a and ρ_p are the water respectively the oil densities;

- for the viscous regime, by using the relationship

$$l \sim \nu_p^{-1/12} (g\Delta)^{1/6} V^{1/3} t^{1/4} \Rightarrow \frac{dl}{dt} \sim \frac{1}{4}\nu_p^{-1/12} (g\Delta)^{1/6} V^{1/3} t^{-3/4}, \tag{6}$$

where ν_p is the kinematic viscosity of the oil product, g is the gravitational acceleration, V is the volume of oil spilled, t is time;

- for the regime produced by the surface tension of oil-water interface, by using the relationship

$$l \sim \sigma^{1/2} \frac{t^{3/4}}{\rho_p^{1/8} \eta_p^{1/4}} \Rightarrow \frac{dl}{dt} \sim \frac{3}{4}\sigma^{1/2} \frac{t^{-1/4}}{\rho_p^{1/8} \eta_p^{1/4}}, \tag{7}$$

where σ net scattering coefficient, η_p is dynamic viscosity of the oil product, ρ_p is the petroleum product density.

4. Measurements obtained with Pisces Simulator II

To check the results of laboratory measurements authors have simulated instantaneous discharge of a volume of 524 m^3 of oil. The properties and environmental conditions in the simulation were considered similar to the laboratory ones.

The simulation was performed with the Simulator for Emergencies Pisces II (Potential Incident Simulation Control and Evaluation System), situated inside the Environmental Engineering Department at the Constanta Maritime University [6, 7]. The results are presented in table 2 below, [8].

Table 2

Computer simulation results for an oil discharge of 524 m^3

Time [s]	Spill area [m^2]	Average spill thickness [mm]	Radius of the spill [m]	The spreading speed [m/s]
0	10 445	50.16754	57.67524	0.929962
6	101 333	5.17107	179.6431	0.161252
12	158 605	3.303805	224.7468	0.092811
18	202 286	2.590392	253.8155	0.06471
24	238 335	2.198586	275.5047	0.051098
30	269 649	1.943267	293.0452	0.04458
36	297 539	1.761114	307.8273	0.038352
42	323 244	1.621066	320.8488	0.032935
48	347 111	1.509604	332.4829	0.029106
54	368 413	1.422317	342.5332	0.027031
60	389 208	1.346324	352.0676	0.024065
66	408 409	1.283028	360.6474	0.021992
72	426 503	1.228596	368.5498	0.020726
78	443 675	1.181045	375.896	0.019618
84	459 338	1.140772	382.4735	0.017061
90	474 344	1.104684	388.6708	0.016333
96	488 432	1.072821	394.4003	-

The following figures (from 9 to 12) present graphic results of the simulation [8].

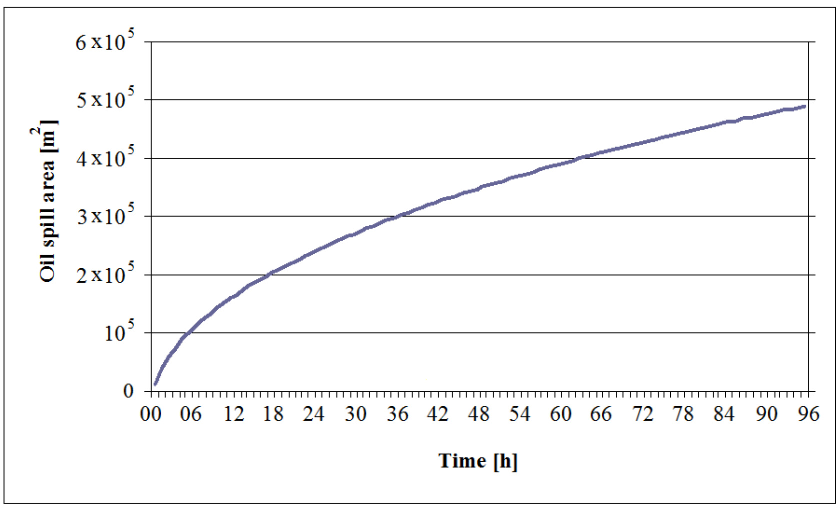

Fig. 9. Variation of the oil spill area

To find out the thickness of the oil spill, authors used $h = \frac{V}{A}$ relation, where V is the oil spill volume and A is the area of the oil spill.

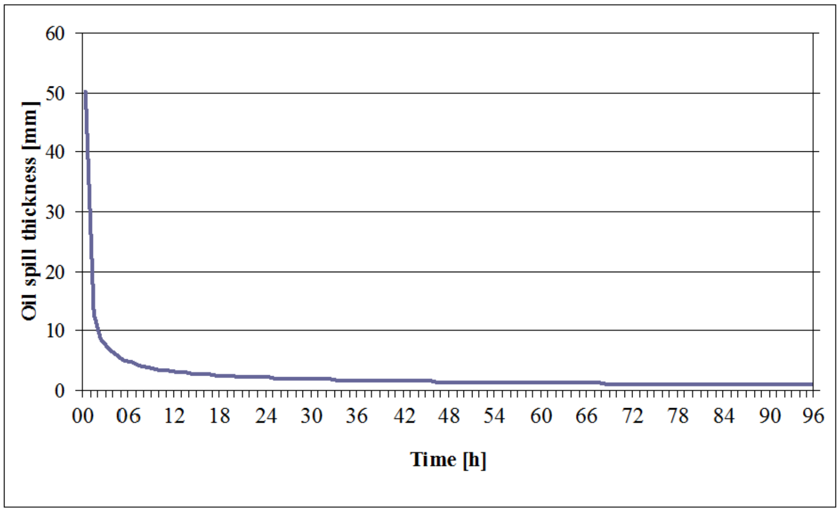

Fig. 10. Variation of the oil spill thickness in time

To find out the radius, authors used the relation $l = \sqrt{\dfrac{V}{\pi \cdot h}}$, where V the oil volume and h is the medium thickness of the oil spill.

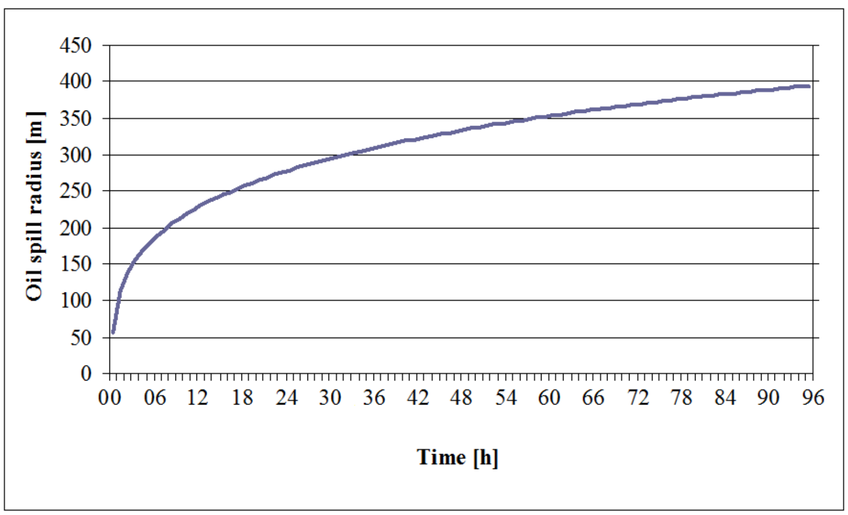

Fig. 11. Variation of the oil spill radius in time

The scattering speed was calculated by using $v(t) = \dfrac{dl}{dt}$ relation, where l is the radius of the spill and t is the time.

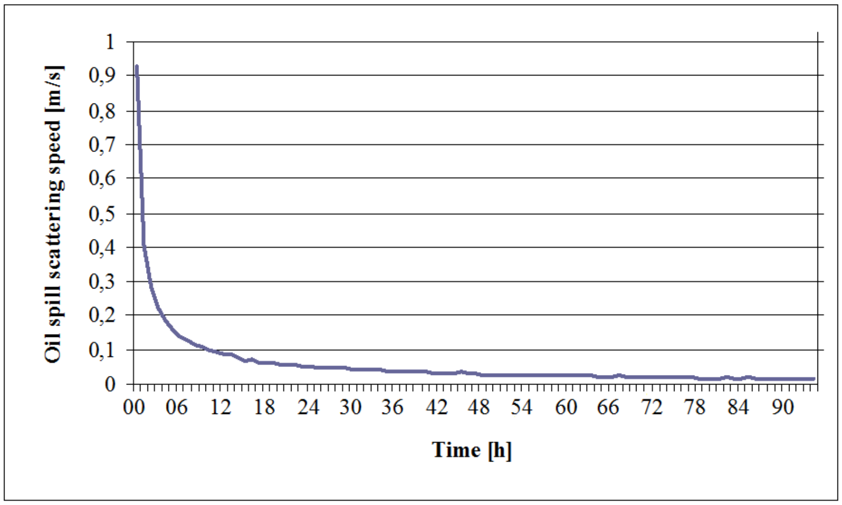

Fig. 12 Variation of the oil spill scattering speed in time

Following the interpretation of the results, authors noticed similarities between the curves *A=f(t)*, *h=f(t)*, *l=f(t)*, *v=f(t)* for laboratory and computer determination. This means that measurements made with Pisces Simulator II confirms the results obtained in the laboratory and vice versa.

5. Conclusions

As shown in the laboratory research at small scale, the scattering phenomenon is qualitatively similar to that which occurs on a large scale (actual discharges) with large amounts of oil.

As shown by Fay model [5], in the surface tension regime, the scattering rate of the spill becomes independent of the volume of pollutant discharged. Therefore, in the last phase of pollution the scattering speed is very low and the initial quantity of oil discharged is not of importance.

By analyzing the graphs obtained from both laboratory and computer measurements the authors can say that the predictive model largely reflects the situation simulated in the laboratory. Under these circumstances one can say with certainty that the Pisces II simulator can be successfully used for rapid intervention in emergency oil sea water surface pollution. Also it can be used to prevent environmental accidents by simulating a large number of scenarios to establish different possible consequences. These consequences are influenced by the quantity of oil spilled, by the distance to the shore and many others. Using computer simulation, the authorities having jurisdiction can make quick and thorough assessments, avoiding this way, real environmental disasters.

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