International Journal of Modern Manufacturing Technologies
ISSN 2067–3604, Vol. XIV, No. 3 / 2022
https://doi.org/ 10.54684/ijmmt.2022.14.3.291

SIMULATION OF RISK MINIMIZATION IN CASE OF POLLUTION ON MARINE AREAS

Florentina-Aurelia Vasilica[1] , Fanel-Viorel Panaitescu[1], Mariana Panaitescu[2], Ionut Voicu[2], Daniela-Elena Juganaru[2], Valeriu Nicolae Panaitescu[1]

[1]POLITEHNICA Doctoral School of Energy Engineering, Bucharest-Romania, Blvd. Spl. Independentei, nr. 313, sector 6, 06004, Bucharest, Romania
[2]Constanta Maritime University, Doctoral School of Mechanical and Mechatronics Engineering, 104 Mircea cel Batran Street, PC 900663, Constanta, Romania

Corresponding author: Panaitescu Mariana, panaitescumariana1@gmail.com

Abstract. In this paper are presented the results obtained from a simulation of a pollution situation with crude oil products and the efficiency of the use of hydrocarbon recovery systems. In the event of major pollution accidents, in which the oil moves and touches the sandy drum, the only way of disposing is to load the polluted sand and to bring another in place, very costly and difficult operation. So, recovering a large amount of oil offshore is highly recommended.
The phenomenon that governess the dynamics of pollution has been simulated using CFD (Computer Fluid Dynamics) and involves as follows:
-In the first phase, the oil stain extends as the surface and thinning as thickness (thickness);
-In the second phase, the mixing of hydrocarbon with water occurs, and the mixture becomes more and more difficult and no longer floats but moves immerse, but not less dangerous for the marine flora/fauna. This second phenomenon is favored by the state of the sea (the excitement of the water due to the waves). At the same time part of the hydrocarbon is volatile in the air, proportional with the temperature of water and air. Results of simulation are: a) the evolution of the quantity of petroleum product discharged during the simulation; b) the evolution of the quantity of evaporated petroleum product; c) the variation of the maximum thickness of the oil product film; d the variation of polluted surface; e) the variation of the quantity of petroleum product recovered; f) minimizing the risks of pollution by simulating scenarios with PISCES II software. The simulations on the movement and evolution of the oil film on the water surface are necessary for assessing the environmental impact, assessing the response time of the authorities in emergencies, assessing the situation, establishing The most sustainable strategies for limiting the scattering and isolation of petroleum products and the use of the most appropriate methods of response for the removal of petroleum products from the surface of the sea water or the shoreline.
Key words: risk management, marine, computer fluid dynamics

1. INTRODUCTION

The case study presented in the paper consists in interpreting the results obtained following a simulation of a pollution situation with petroleum products, incident occurred as a result of the cracking of a pipeline transporting oil product in Midia Port, where the oil storage tank is located.
“Oil spills at sea are one of the most dangerous maritime disasters. Oil pollution has a serious hazard to the marine ecological environment and marine biological resources. Oil spill pollution accidents can cause vast stretches of ocean to become hypoxic, leading to the smothering of sedentary species, such as seaweeds and shellfish [1, 2]. The fishing and marine culture industries will also be seriously affected by oil spills. If the spilled oil is not cleaned up in time, it may also cause explosions and fires, causing more serious economic losses and casualties. Oil spills include releases of crude oil from tankers, offshore platforms, and drilling rigs [1, 2]”.
“When an oil spill occurs, if the competent authority and ship’s officers can respond effectively and successfully, the damage caused by oil spill will be significantly reduced. However, effective and successful emergency response capability is usually obtained from a lot of practical experience or simulation training. It is unrealistic to accumulate practical experience from actual oil spills because it will often bring huge losses and even dangers, and no mistakes are allowed. The advantage of marine simulator is that it can build virtual oil spill scenes and can simulate oil spill scenes under different weather and sea conditions according to user’s requirements. There is no risk during the training process, and the emergency response capability of competent authority and officers can be trained through a large number of repeated simulation training. The marine simulator can play a more

important role in the oil spill emergency response training [3]. During the early stages of a spill, spreading, drift, evaporation, dispersion, emulsification, and dissolution are most important [4], [5].

2. MATERIALS AND METHODS

The PISCES II (Potential Incident Simulator Control and Evaluation System) program was used to simulate the pollution situation, which is a software for simulating potential incidents, control system and evaluation of the response to oil spills, produced by the British company TRANSAS, world leader on the market for software developers for aviation and shipping simulators [6].
This program is used to train teachers, students and licensed individuals working in this field, to respond to major spill incidents and to minimize the impact of spills on the local environment and economy.
A variant of the development of the emergency event is called a scenario. A scenario includes all objects and events related to a single incident. During a PISCES II work session, several users participate in the same exercise. An exercise can contain several scenarios depending on the objectives and objectives of the exercise [7].

2.1. Scenario of simulation

The program is based on a mathematical model, namely the modelling of the physical phenomenon of the biphasic water-oil system in the non-permanent motion of waves and sea currents. This model also calculates the methods of action (Response resources) on the films spilled on the surfaces of the seas and oceans [8].
Software can also be used with Crisis Management Module, which is a great help in case of pollution with oil products, dangerous goods, rescue operations or search in case of shipping accidents.
At the end of the simulation, the effectiveness of the pollution response can be assessed, by assessing the consequences of pollution on the shore, flora and fauna, but also by accounting for the total costs of the equipment and techniques used in the pollution response action. This is possible because the simulator has a database of various types of equipment, means of intervention, marine and terrestrial plant and animal species.
The processes that take place on the hydrocarbon and that can be tracked with the help of this simulator are: viscosity variation, dispersion, emulsification, interaction with skimmers, barriers and transport of the film due to wind and sea currents [9].
Scenario: The accident occurred on April 15, 2021. The oil product was discharged into the Black Sea due to the alleged breach of the submarine pipeline transporting oil to the shore (figure 1), [10].
The point where the rift occurred was near the platform, because here the pressure is higher. At the referral of the damage, the operator closed the pipeline, and the oil leak took place with increasingly low flow, to the equalize of the pressure in the pipeline with that of the sea water.

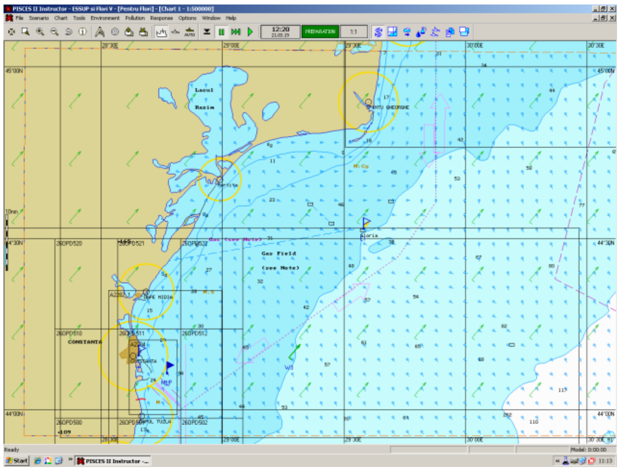


Fig.1. Image of the port of Constanta and the Central Platform [10].

The initial shortened quantity is 700 tones, with a flow rate present in the table below (table 1). After this period, the fixed centre of production stops pumping the oil product.

Table 1. Oil flow rate for 6 hours and 30 minutes.

No.crt.	Flow time (minutes)	Quantity (tones)
1	The first few minutes	350
2	30 min	300
3	1 hour	250
4	1 hour 30 min	150
5	2 hours	100
6	2 hours 30 min	80
7	3 hours	75
8	3hours 30 min	60
9	4 hours	50
10	4 hours 30 min	45
11	5 hours	40
12	5 hours 30 min	35
13	6 hours	30
14	6 hours 30 min	25

Authorities are notified 30 minutes after the start of the flow on this incident. These are the Port Authority, which then announces the ARSVOM (Romanian Agency for the Rescue of Human Life at Sea). There are created 3 divisions, each with its component a tug, 1 barrier and 3 exchange apples. The first two divisions depart from the port of Constanta after about a 30-40 minutes after the accident was announced, after they were prepared to intervene on the polluting. According to Open CPN, which is software for planning the voyage, the two trailers arrive in about 5 hours-5 hours and a half, near the area where the central production platform is located. Another division is ready and waiting in Dana for departure, in case the pollution is too high, and the two divisions do not cope with large amounts of pollutant. The change in the form of oil is due to the fact that the direction of wind, the marine currents and the water temperature vary over time. In these circumstances, the full recovery of the oil product is impossible.

The efficiency of the titanium recovery barriers depends heavily on their location. The location closer to the site of the leak is ineffective, because the installation of a large barrier requires a lot of time. From this point of view, it is more convenient to place the barriers further from the location of the marine incident.

2.2. Materials

For the first simulation, we used the physico-chemical characteristics of the crude oil extracted from the Black Sea, which we obtained from the Grigore Antipa National Institute for Marine Research and Development.

Physical characteristics of oil extracted from the Black Sea are input data for simulation:

- Name: Kirkuk
- Oil density: 850 kg/m3
- Superficial Tension: 1.68 N/m2
- Kinematic viscosity: 41.6 mm2/s
- Maximum water content: 70%
- Freezing point: -23, 33 ° C

Other parameters that are important in running this simulation:

- Distance from Midia Terminal, 26 km;
- Distance to shore, 17.6 km;
- Inner diameter of the pipe, 291.95 mm;
- Water density, 1 015 kg/m3;
- Average movement speed of the petroleum product by pipeline, 0.32 m/s.

In the event of major pollution accidents, in which the oil moves and touches the sandy drum, the only way of disposing is to load the polluted sand and to bring another in place, very costly and difficult operation. So, recovering a large amount of oil offshore is highly recommended.

2.3. Methods

The main point of calculation of the method is the extension of the Lagrangian approach by introducing interactions between oil product particles. The adjustment of the interaction between particles is done through successive stages of parameter optimization and includes verification with known semi-empirical solutions, but also various logic tests. The model takes into account the main physicochemical processes that take place in the Black Sea (evaporation, dispersion, emulsification and variation of viscosity), as well as environmental factors (shore, currents, weather conditions, sea state and ecologically sensitive areas). In addition, the model of response and recovery of the oil product from the surface of the water has been developed [10].

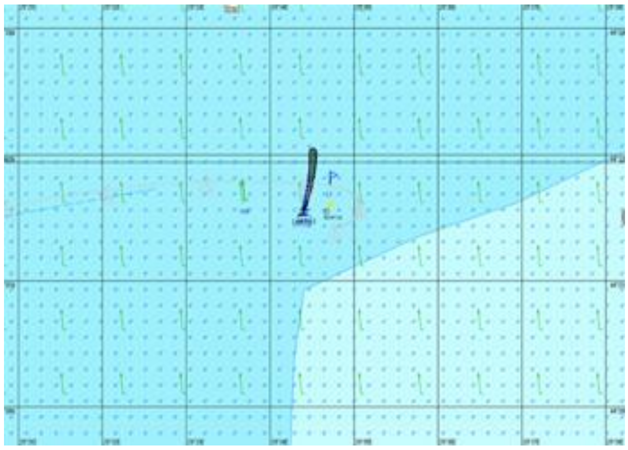
The phenomenon that governess the dynamics of pollution has been simulated using CFD (Computer Fluid Dynamics) and Evolutes as follows [11]:

-In the first phase, the oil stain extends as the surface and thinning as thickness (thickness);

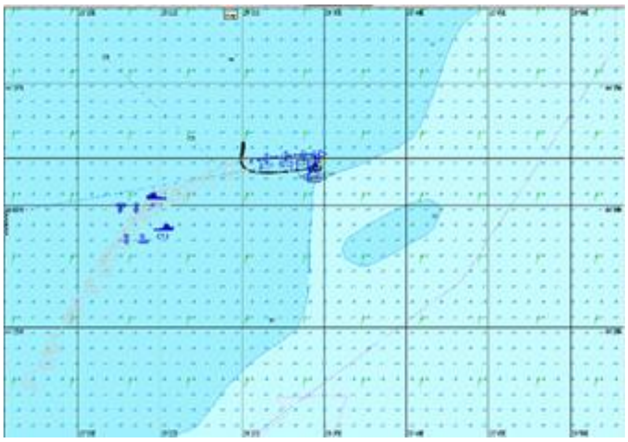
-In the second phase, the mixing of hydrocarbon with water occurs, and the mixture becomes more and more difficult and no longer floats but moves immerse, but not less dangerous for the marine flora/fauna [12]. This second phenomenon is favored by the state of the sea (the excitement of the water due to the waves), [13].

At the same time part of the hydrocarbon is volatile in the air, proportional with the temperature of water and air.

The scenarios of these accidents take place on March 7, 2019 in conditions of wind, temperature and real sea currents. These data were taken using the marine. Copernicus website and the zyGrib program. It runs for 48 hours. The shape of the spot is shown in figure 2 (a, b), figure 3 (a,b),figure 4 (a, b) and is due to the fact that the wind direction changed during the runoff, according to table 2. Under these conditions, full oil recovery is virtually impossible, due to the fact that the shape of the oil slick would require huge ship resources and barriers / skimmers.

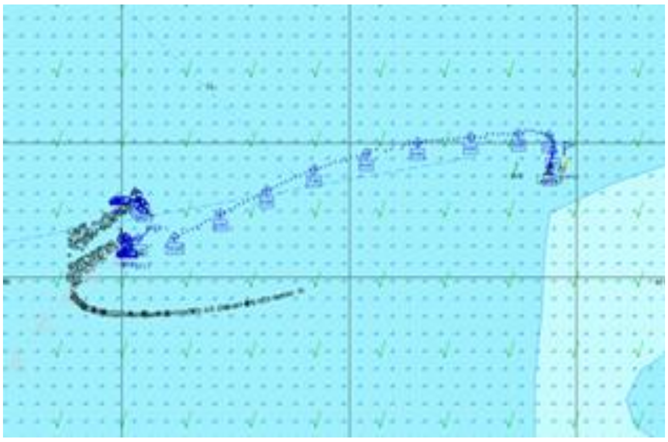


a

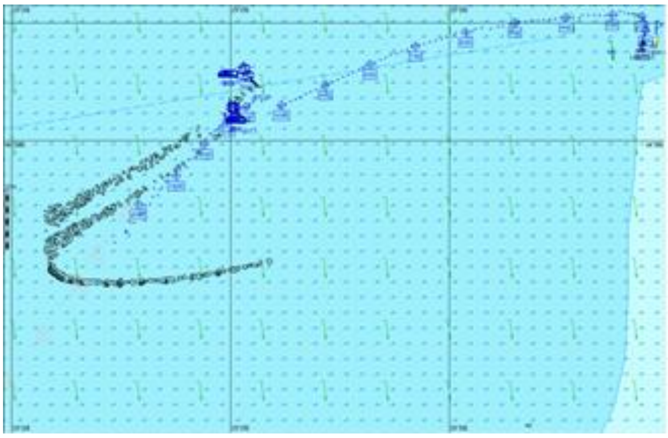


b

Fig. 2. KIRKUK hydrocarbon simulation. at 3 hours; b) at 6 hours

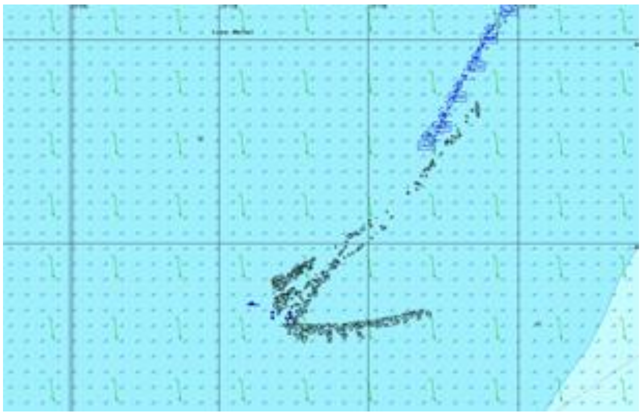


a

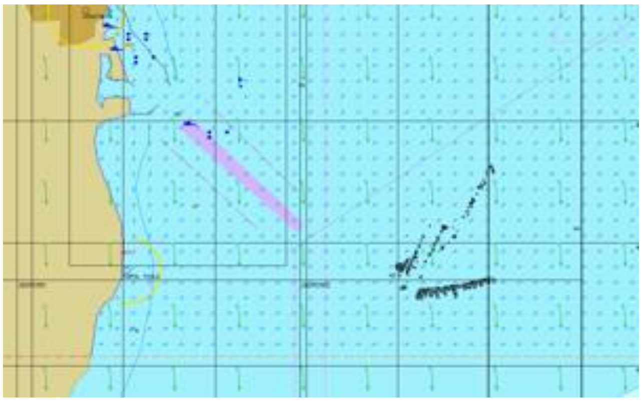


b

Fig. 3. KIRKUK hydrocarbon simulation.
a) at 12 hours; b) at 15 hours



a



b

Fig. 4. KIRKUK hydrocarbon simulation.
a) at 30 hours; b) at 53 hours, finish of simulations.

Table 2. Hydrometeorological observations.

Date	Time	Wind speed [m/s]	Wind direction [^{0}]	Water temperatur e [^{0}C]	Current speed [m/s]	Current direction [^{0}]
7.03.19	00:00	7.3	351	7.7	0.01	78
7.03.19	03:00	4.3	357	7.5	0.26	267
7.03.19	06:00	1.7	17	7.5	0.29	258
7.03.19	09:00	1.1	195	7.9	0.23	246
7.03.19	12:00	3.3	204	8.7	0.18	260
7.03.19	15:00	5.6	176	8.7	0.16	256
7.03.19	18:00	7.1	170	8.4	0.19	246
7.03.19	21:00	8.6	170	8.6	0.16	241
8.03.19	00:00	9.5	174	8.8	0.20	266
8.03.19	03:00	8.8	173	8.8	0.18	268
8.03.19	06:00	8.2	173	9.1	0.23	247
8.03.19	09:00	7.8	174	9.5	0.27	243
8.03.19	12.00	7.7	177	9.8	0.24	260
8.03.19	15.00	7.4	172	9.8	0.28	245
8.03.19	18.00	8.3	168	9.7	0.26	243
8.03.19	21.00	8.6	170	9.8	0.25	259

3. RESULTS AND DISCUSSION

As can be seen in the table 3, the quantity of petroleum product discharged into the Black Sea, increases for 6h and 30 minutes, then its discharge stops, in total is reached a quantity of 811 m3 of the titanium, equivalent to 701 tones.

Table 3. Evolution of the quantity of petroleum product discharged during the simulation.

Time [h]	Quantity of petroleum product dispersed [tones]
00:00	0
05:00	2.6
10:00	2.7
15:00	3.9
20:00	9.9
25:00	27.3
30:00	41.9
35:00	50.7
40:00	57.6
45:00	67.6
50:00	78
53:00	82.4

Due to the properties of the titanium, some of it, in contact with the air evaporate. In the table 4 is presented the evolution of the quantity of petroleum product evaporated in 53 hours of running of simulations.

Table 4. Evolution of the quantity of evaporated petroleum product.

Time[h]	Evaporated product quantity [tones]
00:00	0
05:00	2.3
10:00	7.5
15:00	16.8
20:00	34.9
25:00	56.3
30:00	73.9
35:00	88.5
40:00	101
45:00	112
50:00	122
53:00	126

The thickness of the oil product film differs due to currents, wind and temperature. This increases in the area where the barriers are applied, as can be seen from table 5, and then decreases (table 6).

Table 5. Variation of the maximum thickness of the oil product film.

Time [h]	Maximum film thickness of petroleum product [tones]
00:00	0
05:00	6.7
10:00	9.1
15:00	71.5
20:00	13.1
25:00	27.5
30:00	1.3
35:00	1.2
40:00	1
45:00	1
50:00	27
53:00	6.4

Table 6. Variation of polluted surface.

Time [h]	Polluted surface [m^2]
00:00	0
05:00	619 668
10:00	993 523
15:00	2 341 910
20:00	3 273 628
25:00	3 695 806
30:00	4 007 212
35:00	4 334 579
40:00	4 447 768
45:00	4 616 689
50:00	3 242 805
53:00	3 257 172

Were used for the recovery of the titanium discharged a number 3 "*open sea*" tug-type ships, which operate 3 barriers and 9 skimmers. In this situation, through multiple run of the scenario, it was managed to optimize the location of the barriers and skimmers so that the quantity recovered to be maximum.

After were used tugs, barriers and skimmers, there were collected a total of 355 m^3 oil product from 811 m^3 of the titanium discharged into the Black Sea. 43.77% of total quantity recovered (Table 7).

Table 7. Variation of the quantity of petroleum product recovered.

Time [h]	Amount of mixture recovered [tones]
00:00	0
05:00	0
10:00	0
15:00	523
20:00	744
25:00	855
30:00	956
35:00	956
40:00	956
45:00	956
50:00	963
53:00	1015

When placing barriers, it is advantageous to mount them as far forward as possible because the surface is small and the thickness is advantageous, but this involves deploying a small length of barrier due to the limited time (deployment of a 950 mm barrier, for example, takes about 3h 40min). From this point of view, it would be more convenient to place the barriers further "behind".

As can be seen in the figure 5, the amount of oil product discharged into the Black Sea increases for 6 hours and 30 minutes, then its discharge stops, in total it reaches a quantity of 811 m^3 of crude oil, the equivalent to 701 tones.

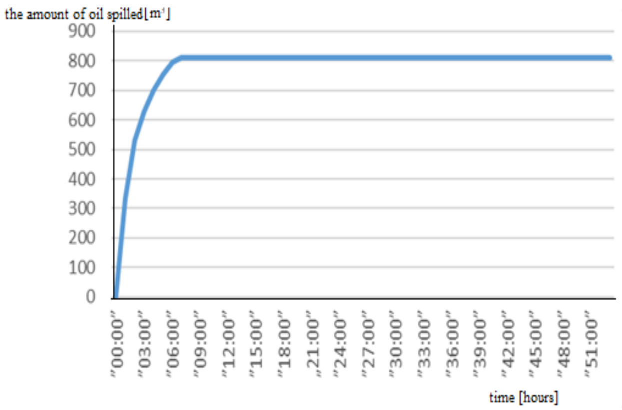


Fig. 5. The evolution of the amount of oil product discharged during the simulation.

The evolution of the desperate quantity of petroleum product is presented in figure 6.

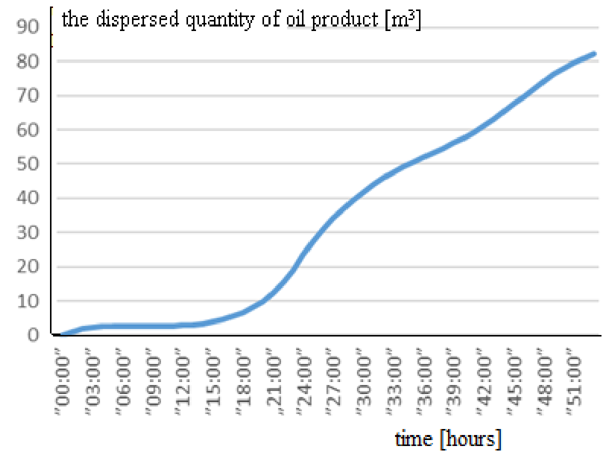


Fig. 6. The evolution of the desperate quantity of petroleum product.

Due to the properties of crude oil, some of it evaporates on contact with air. The figure below shows the evolution of the amount of oil product evaporated in 53 hours of running the simulation (figure 7).

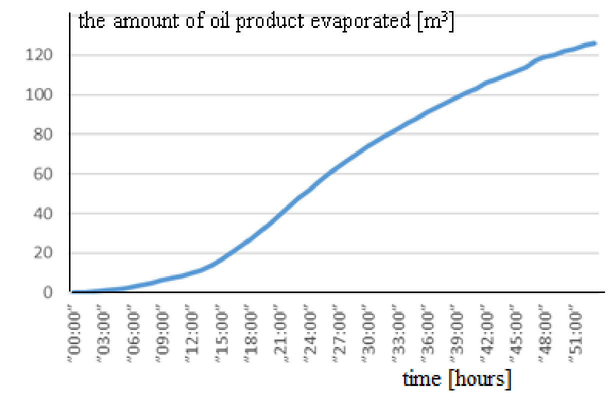


Fig. 7. The evolution of the evaporated amount of petroleum product.

The thickness of the oil product film differs due to currents, wind and temperature. This increases in the area where the barriers are applied, as can be seen in the graph below, and then decreases (figure 8).

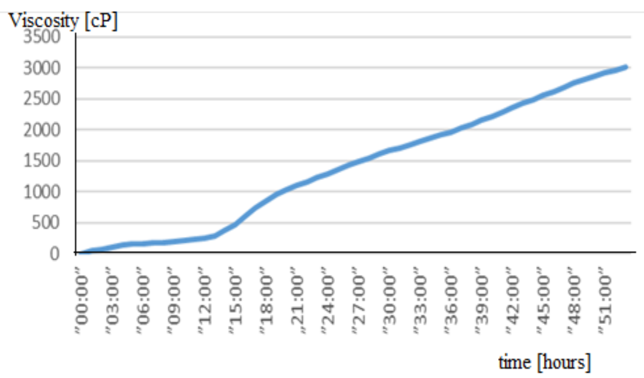


Fig. 8. The variation of the maximum thickness of the oil product film.

Instead, the surface of the film decreases when it reaches the barriers, then increases. Due to this situation, the process of total recovery becomes increasingly difficult, almost impossible.

The viscosity of the drained oil varies over time, it increases, following the mixture with water (figure 9).

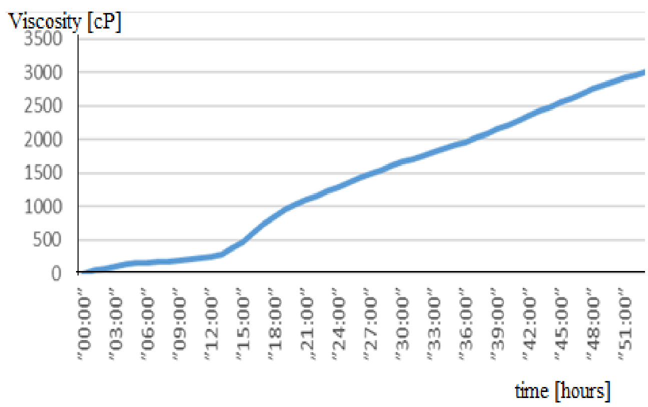


Fig. 9. Variation in the viscosity of the oil product.

In this situation, through multiple runs of the scenario, it was possible to optimize the location of barriers and skimmers so that the amount recovered is maximum. The results of the recovery of oil spilled in the Black Sea are shown in the figure 10.

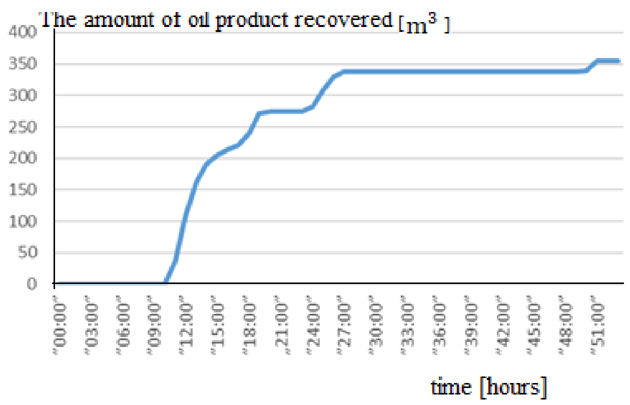


Fig. 10. Variation on in the amount of oil product recovered.

4. MINIMIZING THE RISKS OF POLLUTION BY SIMULATING SCENARIOS

In order to minimize the risks of pollution, the simulation with the help of the PISCES II software helps to predict some intervention operations, such as:

1. stages of the intervention;
2. surveillance of pollutant discharges;
3. requesting assistance within the plan;
4. joint intervention operations;
5. use of dispersing agents;
6. requests for additional assistance from other bodies;
7. concluding the joint intervention operations and deactivating the plan.

It also helps the administration, logistics and financing with:

1. logistics;
2. financial procedures;
3. cross-border movement of personnel, equipment, products and autonomous intervention units:
   3.1. immigration and customs formalities;

3.2. cross-border flight procedures;
3.3. navigation procedures;
4. insurance and medical assistance;
5. liability for damages
6. documentation of intervention operations and associated costs.

In addition to meteorological factors, marine hydrocarbon pollution and its consequences on the environment are also influenced by the physicochemical properties of hydrocarbons [12].

The pollution caused by this incident is a major one, with a quantity of 701 tons dumped in the Black Sea. After the decontamination process used, i.e. the action of barriers and skimmers, it was possible to recover 43.77% of the amount of oil product spilled.

The total costs for the technological process of pollution reduction, recovery, shore transport and its neutralization, in case of major pollution is very high. In this simulation, the real rental prices of the tugs, barriers and skimmers used in the Port of Constanta were used, in case of such an incident.

The first two divisions leave about an hour after the accident was announced. They arrive after 5 hours and 5 and a half hours of walking, respectively, at the point where the barriers and skimmers will be located. respectively 23 and a half hours, during which time the barriers and skimmers on the two divisions will be installed. The time required to inflate a barrier is 3 hours and 20 minutes, which is 950 meters long. A skimmer has a clamping flow of 11 m^3 / hour. In one division there was a barrier and 3 recovery pumps.

Due to the large amount of oil product spilled, the two divisions that operate for about 20 hours, fail to collect all the spilled oil. Therefore, 36 hours after the accident, the third division intervenes. It only takes 4 hours to reach the indicated location, working another 12 hours.

The three divisions act quickly and accordingly, managing to recover 43.77% of the total amount of crude oil spilled. The rest floats offshore, but the trajectory of this spot can change at any time, taking into account sea currents, wind direction and water and air temperatures.

A barrier takes an hour and 40 minutes to be closed, and the first divisions arrive in the port after 5 hours, at the berth. The third one arrives after 4 hours. The total running time of this simulation is 53 hours.

For the rental prices and operation of the decontamination equipment, the values from the official website of the Romanian Agency for the Salvation of Human Life at Sea - ARSVOM were used [14].

The total amount for marine decontamination is 51,984 euro. But that amount is only 43.77% of the total amount of oil spilled in the Black Sea. If the oil film reaches the seashore, the amounts can be much higher, because the decontamination process is different from the shore than from the sea.

4.CONCLUSIONS

The results of the simulations show that pollution of the shoreline and the Black Sea is dependent on environmental factors (wind and current direction/speed, air temperature, water and wave height), the distance from the place of pollution to the shore, as well as the operability of the deputation teams.

The major impact on the environment of the accidental discharge of petroleum products on the surface of the Black Sea water has led to the need for better monitoring of pollution and thus to reduce the intervention time for the organization and conduct of decontamination operations. For this, the mathematical modelling of the pollution phenomenon becomes a very important and useful necessary operation for all the institutions involved in the decontamination operations.

Simulations on the movement and evolution of the oil product on the surface of the water are needed to assess the impact on the environment, assess the response time of the authorities in emergencies, assess the situation, establish the most appropriate strategies to limit the spread and isolation of petroleum products such as and the use of the most appropriate response methods to remove petroleum products from the surface of the sea or shore.

The Emergency Situations Simulator of the Maritime University of Constanta, PISCES II, was used to study an accident in which 750 m^3 of KIRKUK type oil spilled into the Black Sea due to the cracking of the transport pipeline of the crude oil product from Central Fixed Production Platform, at the tank fleet for storage of petroleum products. The point where the crack occurred is near the platform, because there the pressure is higher.

The shape of the oil slick floating on the surface of the sea is due to hydro-meteorological factors, such as wind speed and direction, temperature, direction and speed of sea currents.

The amount discharged is high, which indicates a major pollution. In this case, we are trying to recover as much oil as possible, because a full assembly is practically impossible, due to the fact that the shape of the oil slick requires very high human, financial and technological resources.

At first, the oil stain expands in area and thins in thickness. Then, in the second phase, the mixing of the hydrocarbon with the sea water appears, and the mixture becomes more and more difficult and no longer floats but moves immersed. This phenomenon is due to the state of the sea. At the same time, some of the oil product volatilizes in the air due to the temperature of the air and water.

To recover the spilled oil, it is operated with three divisions, each consisting of a tug, a barrier with a length of 950 meters and 3 skimmers.

Placing barriers as close as possible to the accident is more advantageous because the surface area of the oil product is smaller and the thickness is greater. Through multiple runs of the scenario, it was possible to optimize the location of barriers and skimmers, so that the amount recovered is as high as possible, i.e. about 43.77% of the total 750 m^3 of hydrocarbon.
The major impact that this spill can have on the environment, leads to the idea of re-engineering the extractive industry in Romania, the need for pollution monitoring and reducing the time of organization and intervention in case of a real accident.

5. REFERENCES

1. Li, K., Yu, H., Yan, J., Liao, J., (2020). *Analysis of offshore oil spill pollution treatment technology*, IOP Conference Series: Earth and Environmental Science, 510, 042011.
2. Do, V., Ren, H., (2019). *Using Poisson disk sampling to render oil particles at sea*, Journal of Computing and Information Technology, 27(4), 31–46.
3. Qiu, S., Ren, H., Li, H., Tao, R., Zhou, Y., (2021). *Model Using Implicit Viscosity in Marine Simulator*, Journal of mathematical problems in engineering, 2020, 5545051.
4. Li, H., (2020). *Physical model-based ocean scene modelling in marine simulator*, PhD Thesis, Dalian Maritime University, Dalian, China.
5. Fay, J.A., (2005). *Physical processes in the spread of oil on A water surface*, Proceedings of the International Oil Spill Conference, Global Engineering Documents, Miami Beach, FL, USA, 463–467.
6. Pratt, T.W., (1987). *PISCES 2 User manual*, Technical Report 19870017141, USA, 44p.
7. Panaitescu, M., Panaitescu, F.V., (2019). *Smart System to Coordination of the Available Response Resources* In A Oil Spill Leakage, *TRANSNAV Journal*, 13, 205-212.
8. Panaitescu, F.V., Panaitescu, M., (2009). *Training pentru evaluarea, controlul si simularea unor situatii de criza pe simulatorul PISCES II, ACVADEPOL*, 2066 – 5962.
9. Panaitescu, F.V., Panaitescu, M., Voicu, I., Panaitescu, I.I., (2014). *Training for environmental risks in the Black Sea Basin*, TransNav Journal, 8-2, 205-209.
10. Voicu, I., (2014). *Gestionarea unor situatii de urgenta ca rezultat al deversarii accidentale de produse petroliere in Marea Neagra*, PHD thesys, Bucharest, Politehnica Press, Romania.
11. Dumitrescu, G.L., Voicu, I., Panaitescu, F.-V., Panaitescu, M., (2015). *The evolution of an accidental release of oil, near BURGAS*, Journal of Marine Technology and Environment, 2.
12. What's new in PISCES II-2.90, (2007), TRANSAS LIMITED, IRELAND, Poland.
13. Panaitescu, F.V., Panaitescu M., Ciucur, V., Padineanu, E.,Tudor A.(2006). *Applications on Constantza Maritime University Emergency Simulator*, Nautica Publishing, Constantza, Romania.
14. https://www.arsvom.ro/index.php/informatii-financiare/achizitii-publice.html, accesed 19.04.2022.

Received: April 17, 2022 / Accepted: December 15, 2022 / Paper available online: December 20, 2022