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Simulation of hypothetical oil spill from platforms of Khark oilfield in the Persian Gulf using MIKE21 Spill Model

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Abstract

The Persian Gulf has extensive oil and gas resources and oil transport activities in the world. Because of this, it is exposed to high potential of oil spill. A progressive increase in traffics of the vessels in the Persian Gulf led to pay more attention to prepare practical contingency plans. This paper presents the results analyses of particular hypothetical oil spill scenario in Khark offshore oilfield which is one of the oldest discovered oil fields in Persian Gulf. Simulation of oil spill was carried out using MIKE21 model. After completion of simulation, it is safe to say that wind will play a vital role in advection and spreading of the oil slick in the sea. Tidal currents in the Persian Gulf have a Reciprocating motion which causes oil slick does not go far away. So, currents have negligible effect on advection and spreading of oil. The vast majority of spilled oil was evaporated in the first few days following a spill. The oil will pollute the marine environment by dispersing it in the water column and sedimentation on the sea floor. At last, the results of MIKE21 model lend support to the fact that they are in good agreement with field observation and it would be a golden key to prepare a practical contingency planning to combat against destructive effects of oil pollution on marine environment.

Keywords: Oil Spill Modeling, Hydrodynamic, Persian Gulf, Khark.

1. Introduction

Although oil is the life-blood of human societies, when this vital resource gets out of control, it can be threatening for the marine life, economy and the environment. Oil enters marine environment around the world daily which caused by natural leaks and accidental oil spills. Many countries have contingency plans for prevention of pollution due to oil spill in the marine environment. The

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Table 1. Largest oil spills throughout the World (www.mnn.com/earth-matters/wilderness-resources/)

Oil Spill	Location	Year	Amount of Oil Spilled (Million Gallons)
Gulf War	Persian Gulf	1991	380-520
Gulf of Mexico	Gulf of Mexico	2010	206
Ixtoc I Oil Well	Gulf of Mexico	1979	140
Atlantic Empress	Trinidad and Tobago	1979	90
Fergana Valley	Uzbekistan	1992	87
ABT Summer	3900 km from Angola	1991	51-81
Nowruz Field Platform	Persian Gulf	1983	80
Castillo de Bellver	Saldanha Bay, South Africa	1983	79
Amoco Cadiz	Brittany, France	1978	69
MT Haven	Mediterranean Sea near Italy	1991	45
Odyssey	3900 km from Nova Scotia, Canada	1988	40.7

most important oil spills throughout the globe are listed in the Table 1.

Table 1 clearly suggests that the Persian Gulf countries must pay more careful attention to destructive effects of oil spills on the Persian Gulf's environment. The Persian Gulf has extensive oil and gas resources and oil transport activities in comparison to the rest of the world and as a results, the potential for oil pollution is high.

Nowadays, numerical models are widely used to predict trajectory and distribution of oil particles concentration in the water. The effectiveness of these models heavily depends on the quality of the input data of the incident and the model calibration effort. The processes through which oil weathers action concurrently, and the rate and importance of the weathering processes on the final fate of the oil are rely on the oil type, the location of oil spill and the weather conditions when oil spilled. In a marked contrast, there are numerous inaccuracies in the environmental condition such as wind speed and direction, sea state, magnitude and direction of the currents, temperature and salinity of seawater. The degree of reliability can be increased by decreasing these inaccuracies in the input data (Rezvandoost and Shafieefar, 2013).

Ranjbar *et al* (2011) presented the results of oil spill simulation using OSCAR in the region of Khark. Farzingohar *et al*. (2011) used GNOME model to simulate oil spill incidence in the region of Hormozgan. Badri and Azimian (2010) represented an oil spill model based on the Kelvin wave theory and artificial wind field for Northern part of the Persian Gulf. Howlett *et al*. (2008) utilized the OILMAP model to forecast and to simulate an oil spill incidence in the Dubai region of the Persian Gulf. Elhakeem *et al*. (2007) presented the results of Al-Ahmadi historical oil spill crisis simulation in the Persian Gulf using MIKE3-SA. They employed a 3-D rectilinear hydrodynamic model combined with an oil spill model. Sabbagh Yazdi (2006) signified a coupled solution of oil slick and depth averaged tidal currents near Siri Island, in the Persian Gulf. Proctor *et al*. (1994) used a 3-Dimensional model to simulate fate of spilled oil of Al-Ahmadi oilfield. Al-Rabeh *et al*. (1992) operated both of GULFSLIK II and OILPOL models to simulate fate of spilled oil of Al-Ahmadi in Kuwait. Lehr *et al*. (1984)

applied a GULFSLIK I model for simulating of oil spill trajectory in the Persian Gulf.

Badri and Faghihifard (2017) simulated the oil pollution in Assaluyeh port in 2008 and the spreading and diffusion of oil pollution due to wind forces and tide effects as well. They used MIKE3 model, as a three dimensional model founded on the finite volume method which was suitable for oil spill fate include of spreading, diffusion advection, and determining the evaporation rate, oil dissolution, emulsification in water and residual oil spill depth. The outcomes showed that wind velocity could have the maximum effect on oil fate. The oil spill moved toward the shore lines and scratched beaches near the Assaluyeh port typically in Bandar-e Siraf and Bandar-e Kangan.

2. Materials and methods

Considering such prodigious potential of oil spill, in this research, the results of oil spill modeling is presented. To this end, a hypothetical oil spill in the region of Khark was simulated using MIKE21 model. At first, the aforementioned model is verified by result corresponding to oil spill modeling of Mina Al-Ahmadi oil field incident, then after simulation of a hypothetical oil spill scenario was carried out in the Khark region.

As it is mentioned earlier, the purpose of this study is to be an applicable reference for analyses of planed response actions and strategies to mitigate environmental effects of oil spill in the Khark oilfield which is one of the oldest discovered oilfields in the Persian Gulf, (As is shown in Figure 1 and Figure 2). On top of that, Khark offshore oil fields are located approximately 57 kilometers away from the shoreline in the northwest part of the Boushehr province between Genaveh and Rig seaports (30 and 35 Kilometers away from Genaveh and Rig port, respectively). Technically, crude oil is classified as light, medium or heavy, according to its measured API gravity. An API value greater than 30^{o} means oils are considered light, API values between 30^{o} and 22^{o} mean an oil is considered to be of medium weight, while a value of below 22^{o} implies the hydrocarbons are heavy crudes. As a result, aforementioned oilfield, Khark, bears oil with an API gravity of 29 degrees that can be considered as medium oils (FGO Co., 2012). A scenario-specific modeling has been done to assess potential effects due to oil spill from well-head platforms which are located in Khark area.

Figure 1. Location map for application of MIKE21 model in Khark oilfield

Figure 2. Khark Offshore Well-Head Platform

In this study, simulation of hypothetical oil spills have been carried out by MIKE 21 Spill Model and there are just two types of oil including light and heavy, in the model's oil database. Therefore, in this scenario Khark's oil is considered as heavy crude oil, during the model setup. In the determined scenarios the oil spill simulation covers the case study period from January 01, 2012 to February 01, 1994. In order to verify the applied model, its simulation results of Mina Al-Ahmadi oil spill in the Persian Gulf during Persian Gulf War is compared with the actual data of oil slick movement and also GULFSLIK II model simulation results (Al-Rabeh *et al*., 1992).

2.1. The Oil Spill Phenomenon

Oil spilled in the water surface immediately spreads over a slick of few millimeters. The spreading is especially promoted by gravity and surface tension, however many spills of varying size quickly reach a similar average thickness of about 0.1 mm. Advection of currents and wind affects both surface oil and droplets dispersed in the water body.

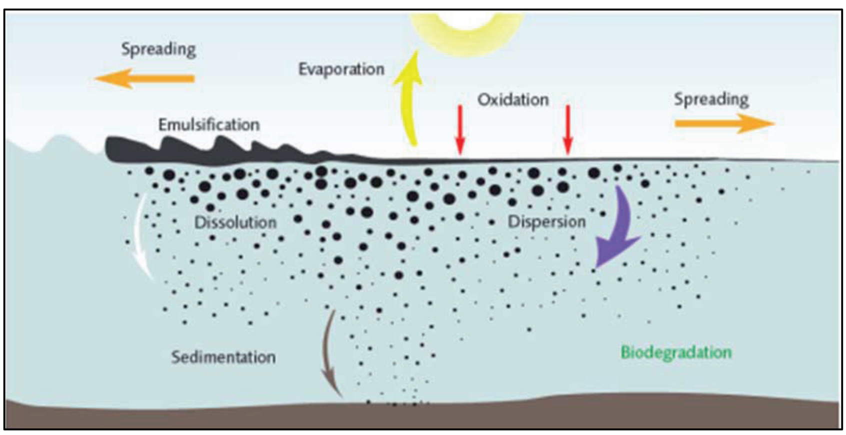

Figure 3. Processes acting on spilled oil (from Fate of Marine Oil Spills, 2002)

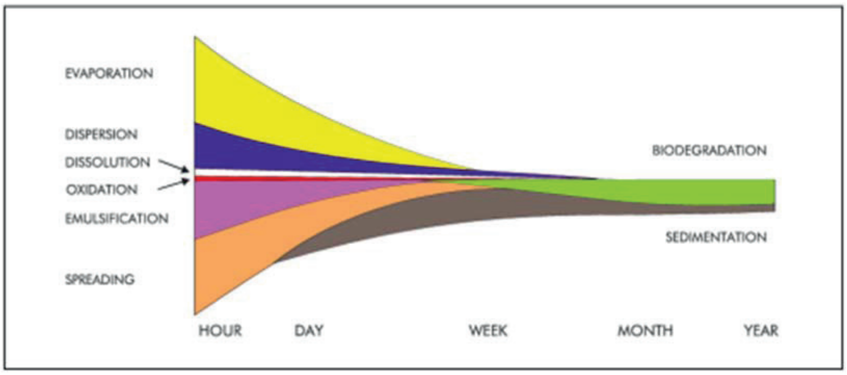

Figure 4. A schematic of the fate of a crude oil spill with time - the width of each band (from Fate of Marine Oil Spills, 2002)

Due to evaporation, emulsification, dispersion, dissolution, photo-oxidation, sedimentation and biodegradation the oil changes its physical and chemical properties and may disappear from the sea surface. All mentioned processes are dependent on each other and are referred to as oil weathering (Figure 3).

Spreading, evaporation, dispersion and dissolution can be defined as short-term weathering processes, whereas emulsification, biodegradation and photochemical oxidation are recognized as long-term weathering processes (Figure 4).

2.2. Spill Model description

In this study, as it is mentioned earlier, MIKE 21 Spill Analysis (SA) was used to simulate trajectories. DHI's Oil Spill Model is a tool for predicting fate of marine oil spills, covering both the transport and the changes in chemical composition. The model is a Lagrangian model that runs decoupled from hydrodynamics. The pre-run hydrodynamic results from the hydrodynamic model that can be applied in the model are contained in 2D or 3D result files. The changes in chemical composition of oil residues over time is a result of physical and biological processes and is often referred to as "weathering" of the oil. The more closely the chemical composition of a residue resembles that of the un-spilled oil, the fresher it is. The weathering process included in the model depends on the user's choice. Most simulated weathering process can be separately enabled or disabled. In the model; the oil is divided into two oil fractions; a light volatile fraction and a heavier fraction. In general the model describes the total amount of spilled oil as an assemblage of smaller oil amounts represented by individual oil track particles. These oil track particles are subject to weathering and drift process, working solely on the represented oil.

In MIKE21 Spill Model, there are 8 internal state variables for each oil track particle. Each state variable has an ordinary differential equation describing its rate of change. The first five describe the oil loading, whereas the last three represent physical properties:

- Volatile oil mass [kg]
- Heavy oil mass [kg]
- Amount of asphaltenes [kg]
- Amount of wax [kg]
- Water fraction of oil [kg/kg]
- Droplet diameter [m]
- Area of oil [m^2]
- Immersed state [logical (0/1)]

The droplet diameter can be significantly altered by wave action. The diameter change is only computed when wave dissipation is enabled. The change is described as (DHI, 2017):

$$\frac{dDropletDiameter}{dt} = DiameterChange \quad (1)$$

The change rate is set to match the mean droplet diameter d as calculated according to French-McCay (2004):

$$d = 1.818E^{-0.5} N^{0.34} \quad (2)$$

where:

E= Energy dissipation rate for breaking wave ($J/m^3/s$) set equal to $10e^3$

N= kinematic viscosity (10^{-6} centistokes)

Area of oil is defined as the area of contact with the sea surface. It represents the equivalent area of a circular slick for the oil loading of an individual oil track particle. This area does not describe the total, by all particles covered area. Also this total covered area is not equivalent to the sum of all particle track areas as single particle track areas can overlap. However, the sum of all particle track areas gives an upper bound for the total covered area. The change in this area with time is expressed by Mackay *et al*. in1980 (DHI, 2017):

$$\frac{dA}{dt} = K_{Spread} \cdot A^{\frac{1}{3}} \cdot \left[\frac{V}{A}\right]^{\frac{4}{3}} \quad (3)$$

where:

K_{spread}= is a rate constant [s^{-1}]

V= volume of oil [m^3]

A= area of the oil particle [m^2]

2.3. Model Setup for Validation

The dominant currents in the Persian Gulf are the tidal currents. Simulation of the tidal current in

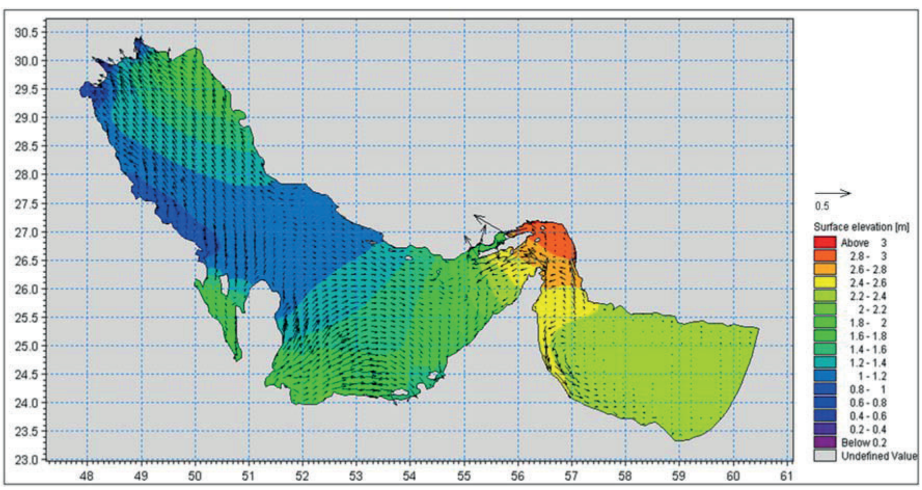

Figure 5. Tidal current field (including depth-averaged velocity and direction) and surface elevation at the beginning of specified scenarios (10 a.m., January 02, 1994)

Table 2. Wind data on Al-Ahmadi oil spill (Al-Rabeh *et al*., 1992)

Month	Speed	Direction
January	5.32	295.7
February	5.49	285.7
March	5.01	286.5

the Persian Gulf is carried out by hydrodynamic module of MIKE21 model which is based on the numerical solution of the two-dimensional incompressible Reynolds averaged Navier-Stokes equations invoking the assumptions of Boussinesq and of hydrostatic pressure (DHI, 2017). The hydrodynamic model of Persian Gulf is forced with water level boundary. Measured water level recording as the open model boundary from a station near Chabahar port (in the Gulf of Oman) is available. The variation along the boundary is same as the measured water level recording near the Chabahar port. The model runs on a triangular mesh from January 02, 1994 to February 01, 1994 using a simulation time step of 5 minutes and saving the results at a time interval of 60 minutes. The analysis results including both tidal current field (including depth-averaged velocity and direction) and surface elevation at the beginning of specified scenarios are demonstrated in Figure 5. The maximum depth-averaged velocity of tidal current in Khark area is 0.55 m/sec.

To validate the MIKE 21 Spill Model, the Modeling has been carried out for the major oil spill of Mina-Al-Ahmadi oil field with the related wind data (Table 2), in which the spill rate was 12,500 barrels per hour for 10 days. Oil type was determined as Venezuelan medium. Average water column temperature during case study period, January, was 16 °C and average water column salinity of the region was 35 gr/lit, (Al-Rabeh *et al*., 1992).

2.4. Model setup for simulation of oil spill

Wind data used to simulate Khark oil spill obtained from Islamic Republic of Iran Meteorological Organization (IRIMO) that is illustrated in Figure 4 (IMO, 2014). Main direction of wind in the area is 270 degrees which blowing from North-West toward South-East direction. The wind intensity is equal to 4.5 m/sec (IMO, 2014). The Modeling has been carried out in which the spill rate is assumed to be 100 thousands of oil barrels released in 24 hours (NIOC. 2011). Oil type was determined as Iranian heavy (FGO Co., 2012). Average water column temperature during case study period, January, was 25 °C and average water column salinity of the region was 35 gr/lit (Elhakeem *et al*., 2007). The spill simulation for the case study covers the period from January 01, 2014 to February 01, 2014 using a simulation time step of 60 minutes. The hydrodynamic model of Persian Gulf is forced with water level boundary and is simulated using MIKE21 Model.

3. Results and Discussion

Results of the oil spill modeling in Kuwait

Table 3. Comparison of real oil trajectory with modeling results on Kuwait, Mina Al-Ahmadi, by GULFSLIK II and MIKE21 models (Al-Rabeh *et al*., 1992)

Location	Date of Observation	Estimated date (MIKE21 model)	Estimated date (GULFSLIK II)
Al-Ahmadi	January 19, 1991	January 19, 1991	January 19, 1991
Khafji	January 25, 1991	January 25, 1991	January 26, 1991
Safania	January 29, 1991	January 28, 1991	January 30, 1991
Ras Al-Ghar	February 08, 1991	February 07, 1991	February 09, 1991
Abu-Ali	February 14, 1991	February 08, 1991	February 13, 1991
Ras Tanura	March 18, 1991	--------------	March 18, 1991

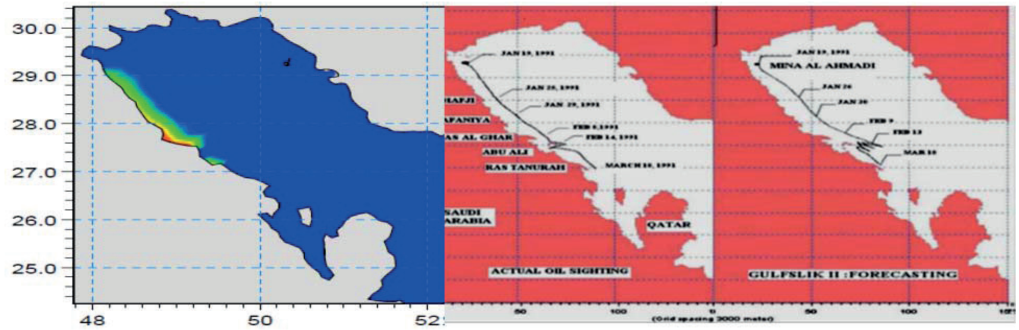

Figure 6. Oil trajectory modeled by GULFSLIK II, Real oil trajectory and Oil trajectory modeled by MIKE21 during January 19, 1991 to March 18, 1991, (Right to Left, respectively)

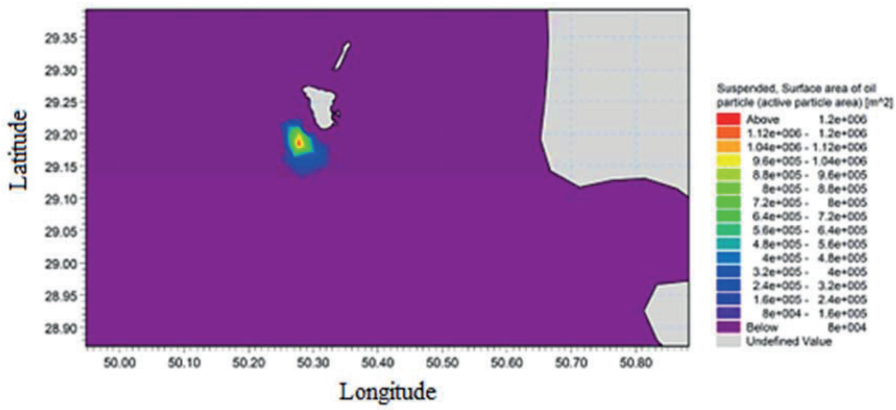

Figure 7. Distribution of Surface oil (m^2), predicted by MIKE21 model, a day after oil spill incidence, Khark

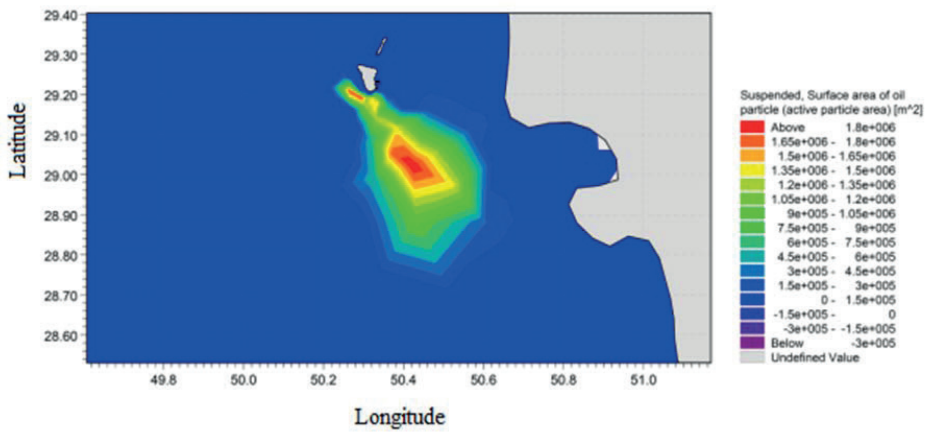

Figure 8. Distribution of Surface oil (m^2), predicted by MIKE21 model, 16 days after oil spill incidence, Khark

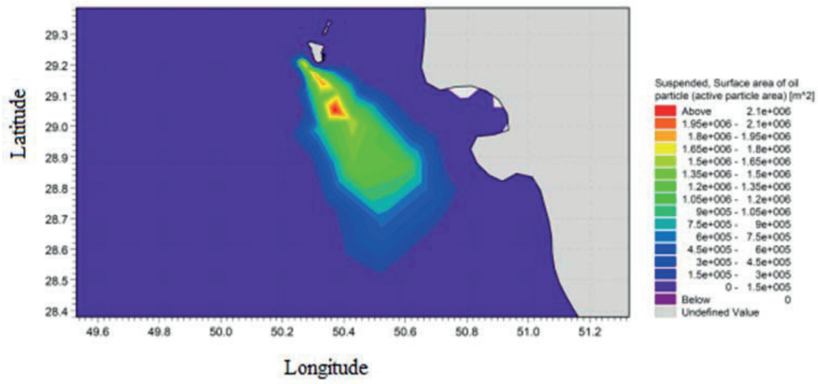

Figure 9. Distribution of Surface oil (m^2), predicted by MIKE21 model, 20 days after oil spill incidence, Khark

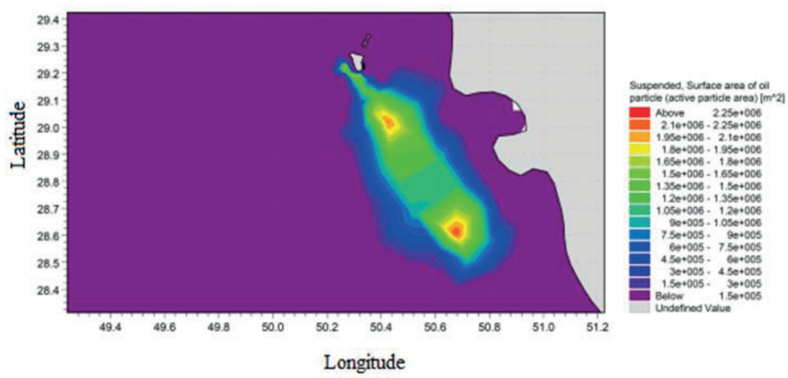

Figure 10. Distribution of Surface oil (m^2), predicted by MIKE21 model, 30 days after oil spill incidence, Khark

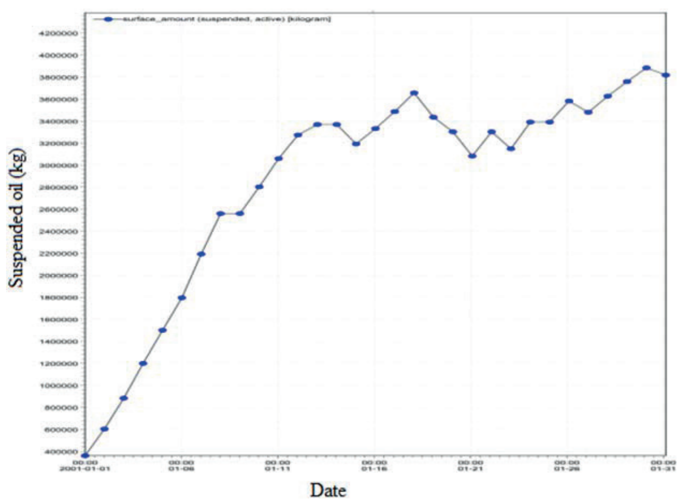

Figure 11. The amount of Released oil in the Water Surface, predicted by MIKE21 model

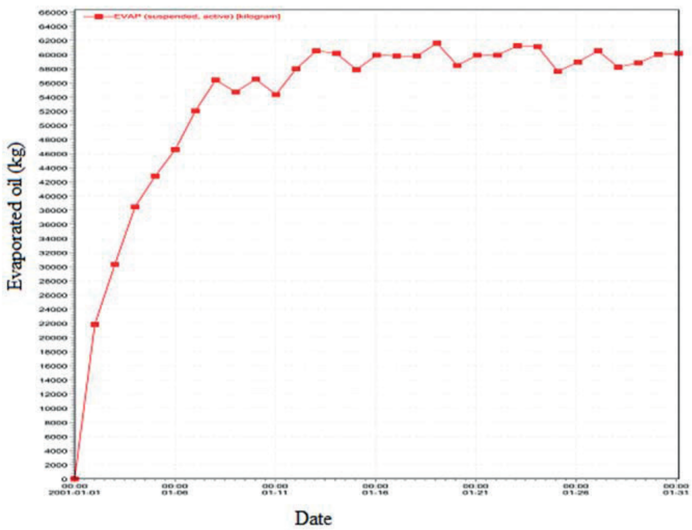

Figure 12. The amount of evaporated oil (2001), predicted by MIKE21 model

oil fields have been presented in Table 3. The results obtained by MIKE21 model have good agreement with both real observations and results obtained by GULFSLIK II model, Figure 6. According to Al-Rabeh *et al*, major part of oil slicks trapped in the North East of the Abu-Ali Island, and the situation continued for several days until February 14, when the slick started moving towards Ras-Tanura (DHI, 2017). Given that the MIKE21 model has not the capability for modeling very thin oil slicks on surface water, and because the modeling would be terminated when the thickness of oil slicks reached a negligible limit, it was impossible to simulate oil slicks movement after reaching Ras Abu-Ali. Obviously, difference in magnitude, direction and duration of applied (Table 2) and real wind data and also inability of MIKE21 model to simulate oil sedimentation causes some differences in the simulated results compared to the real observations (Al-Rabeh *et al*., 1992).

Results for simulation of trajectory of surface oil slicks have been shown in Figure 7 to 10. Furthermore, results for the amount of released oil are shown in Figure 11, and the amount of evaporated oil is shown in Figure 12. As can be seen, the MIKE21 model possesses a good capability for predicting surface oil slick trajectory in the Persian Gulf. This result clearly is in good agreement with above-mentioned statement.

Conclusion

A hypothetic scenario of leaking 100,000 oil barrels over one day from subsea oil well in Khark region, predicated on the potential of oil slicks to reach regional shore, was investigated in this study. Simulations were carried out by MIKE21 model. Results of spill scenario points to wind as the major factor in oil slick movement and expansion in the region, with a mild wind having the potential to rapidly spread the slick across the region, and tidal currents play a significantly minor role compared to wind. Also the results suggest that a major portion of oil evaporates during the first days of spill. Therefore, it is safe to say that oil slicks do not hit the coastline in its vicinity. Although, MIKE21 is a 2-Dimension oil spill model but the results are suggestive of satisfactory accuracy of the model in simulation of oil spill in the Persian Gulf.

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