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Modeling of Oil Spill and Response in Support of Decreasing Environmental Oil Effects Case Study: Blowout from Khark Subsea Pipelines (Persian Gulf)

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ABSTRACT: This paper presents results analyses of specific potential blowout scenarios for subsea oil pipelines between the coast of mainland of Iran and Khark island in the Persian Gulf. The analyses have been carried out with the SINTEF Oil Spill Contingency and Response (OSCAR) 3-Dimensional model system. Some hypothetical three-day blowout scenarios with light and heavy Iranian oil have been investigated in this study. Results related to scenarios demonstrate that wind is the major agent for advection and spreading of oil in the area. Within a few days, a large part of oil will evaporate; significant part will pollute the marine environment by depositing at subsea as sediment and hit the area beach. Also some oil spill scenarios are investigated to evaluate potential effect of oil spill operation planning for response actions in decreasing potential consequences. Mechanical recovery equipment systems decrease the environmental potential effects of spilled oil but do not eliminate it completely. Also dispersant vessels and dispersant aircrafts actions decrease potential of surface effects, but result in increasing the oil in the water column and increasing deposited oil on the seabed. This study is an objective basis for analyses of planed response actions and strategies for decreasing environmental consequences of spilled oil on Khark island area.

Key words: Oil Pollution, Pipeline, Persian Gulf, Modeling, Response Action

INTRODUCTION

Even though oil is a vital production for modern society, however this resource can destroy marine life, economy, and environment if become out of control and can be one of the most destructive pollutant substances for the environment. Many countries have a contingency plan for prevention of pollution due to oil spill in the sea environment. Numerical models are used to predict movement and distribution of oil particles concentration in the water.

The Persian Gulf has the most oil resources and oil transport activities in the world. Due to a large number of oil resources and heavy tanker traffic the potential for oil pollution is high. Elhakeem et al. (2007) presented the results of simulation of Al-Ahmadi historical oil spill crisis in the Persian Gulf using MIKE3-SA. They employed a 3-D rectilinear hydrodynamic model combined with oil spill model. Proctor et al. (1994) used a three-dimensional model to simulate fate of oil spills of Al-Ahmadi in Kuwait. Farzingohar et al. (2011) used GNOME model for simulating of oil spill in Hormozgan waters. Lehr et al. (1979) used GULFSLIKI model for simulating of oil spill trajectory in Persian Gulf, Saudi Arabia. Howlett et al. (2008) used OILMAP model to forcasting and oil spill modeling in Dubai region of Persian Gulf. Al-Rabeh et al. (1991) used both of GULFSLIK II and OILPOL models to simulating fate of oil spills of Al-Ahmadi in Kuwait. Sabbagh Yazdi (2006) represents a coupled solution of oil slick and depth averaged tidal currents near Siri island in Persian Gulf. Badri et al. (2010) represent an oil spill model based on the Kelvin wave theory and artificial wind field for Northern part of the Iranian waters of Persian Gulf.

In this research, a scenario-specific modeling has been carried out to evaluate potential effects due to oil spill from pipelines which located on the seabed between Iran mainland coast (near Genaveh port in Boushehr province) and Khark island. Khark island is the biggest oil export terminal in Iran located approximately 57 km north-west of Boushehr and 40 km south of Genaveh port (Fig. 1). Approximately 90% of crude oils of Iran is transported to Khark island from the mainland and offshore oil fields by 5 pipelines, and exported from there. The mean water depth in this

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area is approximately 20 m (KPD, 2011). This area has a high potential oil blowout from pipelines due to probable events such as earthquake and corrosion. Modeling of hypothetical oil spills have been carried out by OSCAR 3-Dimensional model in this study.

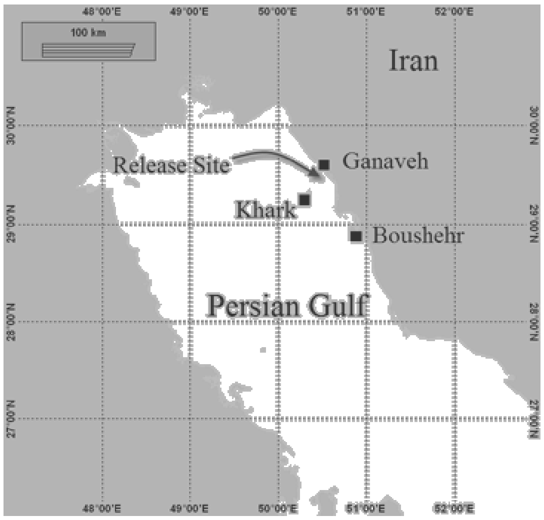

Fig. 1. Location map for application of OSCAR Khark pipelines

MATERIAL & METODS

Two Pipelines transport the heavy crudes and three Pipelines transport the light crudes. A 3-days hypothetical blowout from 2 pipelines is separately investigated for both the light and the heavy crude oil. Both pipelines have a diameter equal to 30 inches and have a length approximately equal to 46 km. One of the pipelines transports about 280,000 barrels of light oil per day with density equal to 0.852 ton/m^3 (in temperature of 21 °C), and the other pipeline transports 350,000 barrels of heavy oil per day with density equal to 0.875 ton/m^3 (in temperature of 21 °C). This transportation is between a station in vicinity of Genaveh port and a station in Khark island. Pressure at the Ganaveh port station is equal to 280 psig (19.7 kg/cm^2) and at the Khark island station is equal to 30 psig (21kg/cm^2) (KPD, 2011). Two pipelines have a 204 m fall through the path. In case of accident or corrosion at a point located at the first quarter of each pipeline, an oil blowout with initial speed of 59 m/sec will be happened (according to mass conservation and Bernoulli equation). By assuming a hole with 5 cm diameter at a point at the first quarter of pipelines, 189,000 barrels of crude oil would blowout from each pipeline. The spill analysis simulation covers the case study period from January 02, 1994 to February 01, 1994. The dominant currents in Persian Gulf are tidal currents. For simulations of tidal current in the region, hydrodynamic module of DHI-MIKE21 software has been used. The maximum velocity of tidal current between Khark island and the mainland is 0.55 m/sec. For wind input, the data from ECMWF[1] is used. The data cover the period from January 1992 to August 2002 with 6 hours time step which is produced by an atmospheric model. Main direction of wind in Khark area is blowing from north-west toward south-east with average speed of 4 m/sec in January. An Ekman model embedded in OSCAR provides subsurface wind-driven currents (Reed *et al.,* 1999). Average water column temperature in January is equal to 16 °C and averaged water column salinity is 35 gr/lit (KPD, 2011).

The OSCAR model system (Reed *et al.,* 1995a; Aamo *et al.,* 1996) has been developed to supply a tool for objective analysis of alternative spill response strategies. OSCAR is intended to help achieve a balance between the cost of preparedness in the form of available, maintained spill response capability on the one hand and potential environmental impacts on the other hand. OSCAR is a tool that directly and objectively addressed this trade-off. Key components of the OSCAR system is shown schematically in Fig. 2 which are weathering model (Aamo *et al.,* 1993; Daling *et al.,* 1990,1991), a 3-Dimensional oil trajectory and chemical fates model (Reed *et al.,* 1995b), and an oil spill combat model (Aamo *et al.,* 1995,1996).

OSCAR employs surface spreading, advection, entrainment, emulsification, and volatilization algorithms to determine transport and fate at the surface. In the water column, horizontal and vertical advection and dispersion of entrained and dissolved hydrocarbons are simulated by random walk procedures. Partitioning between particulate-absorbed and dissolved state is calculated based on the linear equilibrium theory. The contaminant fraction that is absorbed to suspended particulate matter settles with the particles. Contaminants at the bottom are mixed into the underlying sediments, and may dissolved back into the water. Degradation in water and sediments is represented as a first order decay process. The algorithms used to simulate these processes controlling physical fates of substances are described by Aamo et al. (1993) and Reed et al. (1994a, b 1995a, b).

OSCAR allows the assignment of specific operational strategies to each boom-skimmer or dispersant application system being simulated (see Table 1). It is assumed that recovery efficiency is dependent on significant wave height (Fig. 3), which in OSCAR is computed as a function of wind speed, fetch and duration. Under ideal condition a maximum of 80% of the oil entering the boom can be recovered, with the remaining leaking under the boom. Effectiveness is reduced as wave height (or wind speed) increases, and goes to zero at 2 meter wave height, or a wind speed a little over 10 m/sec (~20 knots). It is further assumed that operations cease at night (i.e. that infrared

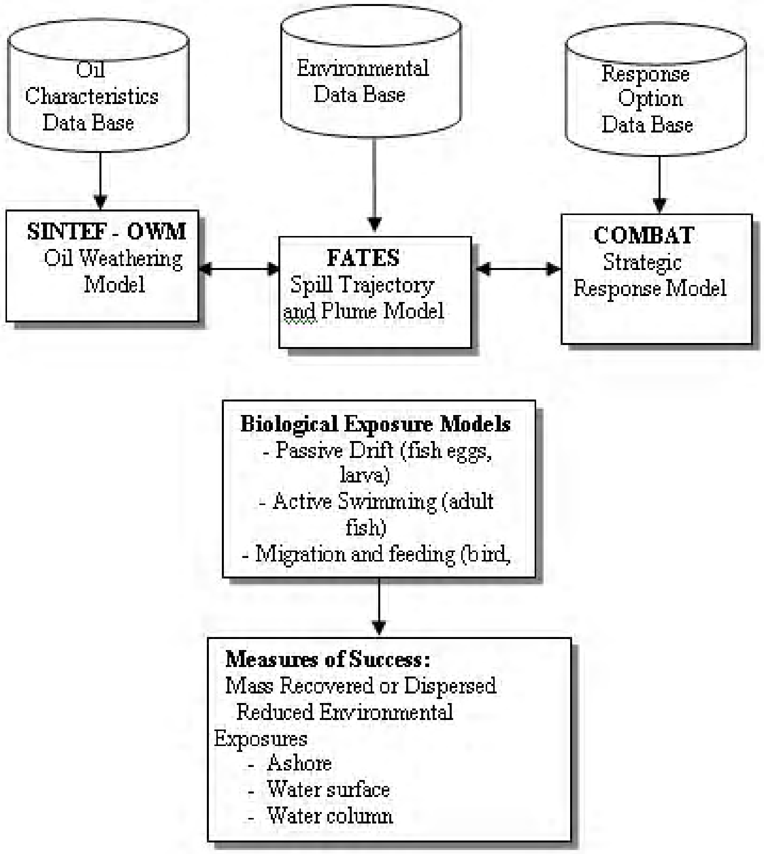

Fig. 2. Schematic overview of the OSCAR system (Reed *et al*., 1999)

monitoring equipment is not available). OSCAR computes sunrise and sunset from latitude and longitude and calendar day (Aamo *et al*., 1995, 1996). Characteristics of dispersant vessels and dispersant aircraft that used in response action are outlined in Table 2. The response action equipments that have a mobilization time equal to 2 hours are located in Khark island and the others are not.

There are three mechanical recovery equipment systems in response contingency planning. Two systems can be mobilized in 2 hours and one system can be mobilized in 48 hours after announcing the accident. Two recovery systems have a boom with 100 meters length and a skimmer with 30 m^3/hr pumping capacity, and another recovery system has a boom with 250 meter length and a skimmer with 40 m^3/hr pumping capacity are considered. In addition, there are two vessels which contain dispersant with application rate of 0.5 m^3/min and there is an aircraft which contains dispersant with application rate of 0.9 m^3/min. Mentioned systems by dispersal of oil slicks into water column particle, can significantly decrease the potential of surface oil potential. Mobilization time of vessels is 2 hours and mobilization time of aircraft is 48 hours after announce the accident. Limitation in using dispersant should be considered. Dispersant should be used when the cleaning of oil from the surface is important and oil into the water column has no bad effect on the environment. Therefore use of chemical dispersant needs an accurate investigation. Pipelines of offshore oil wells have the advantage that can be controlled after the announcement of the blowout. For example it is possible to cease pipeline oil transportation, or sometimes if there is another pipeline in the path, oil can be transmitted by that. Announcing the oil blowout from a pipeline which is located on the seabed requires a permanent mass balance between two stations, or its oil slicks need to be observed by a vessel or to be observed on the shore.

It is not appropriate to position most mechanical recovery equipment near the source because of stopping the blowout after notice of it. The oil response scenarios simulated here employ a mixed strategy (see Fig. 7), wherein two boom-skimmer systems and one dispersant aircraft work far from the source, near the coasts downwind of the source which is subjected to the most of spilled oil. Third boom-skimmer system and one dispersant vessel are located near the source. Also two other dispersant vessels are located in vicinity of Khark island oil terminal. To avoid return of boom-skimmer systems for offloading the recovered oil, some offload barges are used in the response action.

Table 1. Descriptive parameters for mechanical response activities (KPD, 2011)

System	Mobilization (h)	Cruising speed (knots)	Operational speed (knots)	Boom opening (m)	Nominal skimmer capacity (m^3/h)	Storage capacity (m^3)	Maximum operational wave height (m)
First boom-skimmer systems (1)	2	12	2	100	30	30	2
Second boom-skimmer systems (1)	48	12	2	100	30	30	2
Third boom-skimmer systems (1)	2	12	2	250	40	40	2

Table 2. Parameters governing dispersant application which is in authority with safety department of Khark island (KPD, 2011)

System	Aircraft (1)	Vessel Type 1 (2)	Vessel Type 2 (1)
Application rate (m^3/min)	0.9	0.5	0.5
Mobilization time (hr.)	48	2	2
Dispersant tankage (m^3)	5	2.7	2
Operational wind threshold (knot)	30	–	–
Cruise speed (knot)	280	10	12
Operational speed (knot)	140	2	2
Endurance (hr.)	4	–	–
Spray width (m)	25	10	10
No. of trips pr. day	5	10	10
Total available dispersant (m^3)	100	100	100
Effectiveness (%)	70	70	70
Turnaround time to refilling (hr.)	1	0.5	0.5
Dispersant type	Superdispersant-25 type 2	Superdispersant-25 type 2	Superdispersant-25 type 2

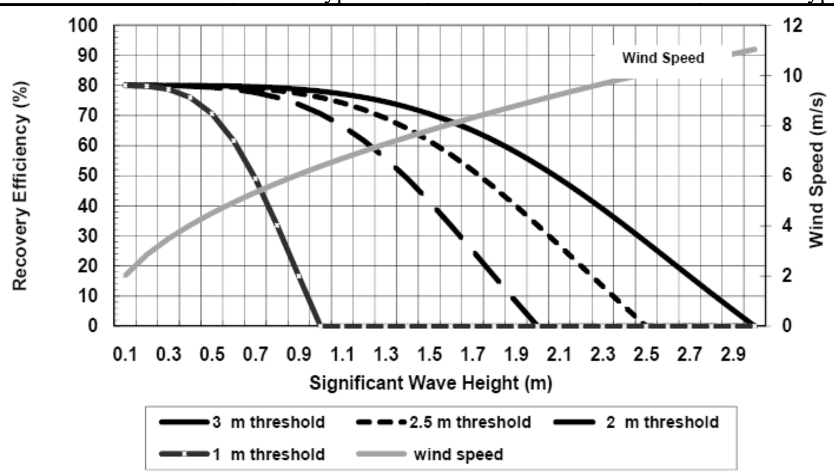

Fig. 3. Relationship of wave height to recovery efficiency of boom-skimmer systems (left axis) and wind speed (right axis), for a fully-developed sea (Reed *et al*., 2011)

The spill analysis simulation covers the case study period from January 02, 1994 to February 01, 1994 using a simulation time step of 300 second and saving the results at a time interval of 1 hour. The model runs on a rectangular grid that each cell is 1.0 km north-south, and 1.0 km east-west. Probable seabed blowout is assumed to occur between ¼ to ¾ of the pipeline path, because the water depth outside this range is very low. Also maximum diameter of probable hole is considered to be equal to 5 cm. The pipelines transfer both Iranian light and heavy crude oil. To compare the effects of light crude oil and heavy crude oil, blowout modeling of both types has been carried out separately as scenario No. 1 and No. 2. It is not possible to determine the oil release duration in Khark area, but available facilities to notice the blowout, allows approximately up to 3 days after the starting of the blowout depending on the rate of release;

Therefore both oil release duration of 1 day and 3 days was considered.

A scenario of one-month blowout from a hole with 2.5 cm diameter in any point of the pipelines will certainly hit the coast. Also, if a hole with 5 cm diameter is created any at point of the pipelines, and it continues for 1 day, spilled oil certainly reach to the coast. Purpose of the selected scenarios is a practical analysis for the evaluation of environmental consequences and determining the efficiency of contingency planning. The criteria for selecting this condition and the related scenarios are: least time for hitting the spilled oil to the coast; maximum stranded oil to the coast and longest distribution along the shoreline. Winter has the worst condition of wind history and has the least content of oil evaporation. Therefore in all the analyses date January 02, 1994 is selected as the initiate day of the blowout. Selected scenarios are outlined in Table 3. Scenario No. 6 is selected for the evaluation of the delay in the response action.

RESULT & DISCUSSION

The comparison of light and heavy oil mass balance time-series is illustrated in Fig. 4. Their mass balance time-series are almost similar. The evaporated oil in scenario No. 1 (light oil spill) is approximately 5% (9450 barrels) more than the evaporated oil in scenario No. 2 (heavy oil spill). So in the case of heavy oil released, there will be oil remaining in the water environment. On the other hand, the oil distribution in the marine environment is similar. Therefore only heavy oil blowout is considered hereafter.

Two oil release duration of 3 days and 1 day for heavy oil was considered in scenarios No. 2 and 3 respectively and their mass balance time-series are compared in Fig. 4. Their mass balance time-series and distribution of ashore and deposited oil 30 days after the beginning of the hypothetical blowout (Fig. 5 and 6) are almost similar. Because of higher amount of released oil in scenario No. 2 than 3, the ashore and deposited oil is more intense in scenario No. 2. Therefore only oil release duration of 3 days is considered hereafter.

In a simulation, scenario No. 2 was modeled without considering the potential effects of wind. In this simulation oil movement in the surface and water column is as a reciprocating motion with the currents and as a result the spilled oil remains nearby the source. Also after 30 days, less than 1% of the spilled oil hit the north-west coast which is in vicinity of the source, so major factor in the transport and spread of oil in the Khark area is wind.

Fig. 7 shows a snapshot of the surface and subsurface distribution of heavy oil in scenario No.5. For first time oil hit the coast 5 days after the hypothetical blowout. Currents are the major component in the vertical distribution and the horizontal mixing of the oil in water column and wind has the minor influence on it. In Fig. 7 the maximum oil concentration is 50 ppm and the oil concentration contours are distributed in the entire water column.

Major part of the evaporated heavy oil (15%) was observed in first 6 days of the simulation. In scenario No. 2, 8% (15,120 barrels, or 2,100 tones) of the spilled oil stranded the coast 30 days after the hypothetical blowout and resulting in occurring the maximum linear loading approximately 10 kg/m on the shoreline (Fig.

Table 3. Selected scenarios for evaluation of environmental consequences and determining effectiveness of oil spill response operations. (All scenarios assume a seabed blowout of crude oil from a point located at the first quarter of the pipeline, and starts at January 02, 1994. The response equipment specified in Table 1 and 2)

Scenario	Oil type	Released oil (Barrel)	Specification of response	Release duration (day)	Time for first oil to hit coast (day)	Maximum oil ashore (% of total)	Reason for selection
1	Light	189,000	No response	3	5	7.7	Least time to oil ashore and maximum oil stranded oil to the coast
2	Heavy	189,000	No response	3	5	8.0	
3	Heavy	63,000	No response	1	5	5.9	
4	Heavy	189,000	3 recovery system	3	5	3.5	
5	Heavy	189,000	3 recovery system, 3 dispersant	3	5	3.2	Reduce of oil the stranded by using the dispersant
6*	Heavy	189,000	vessels and one dispersant aircraft	3	5	5.0	

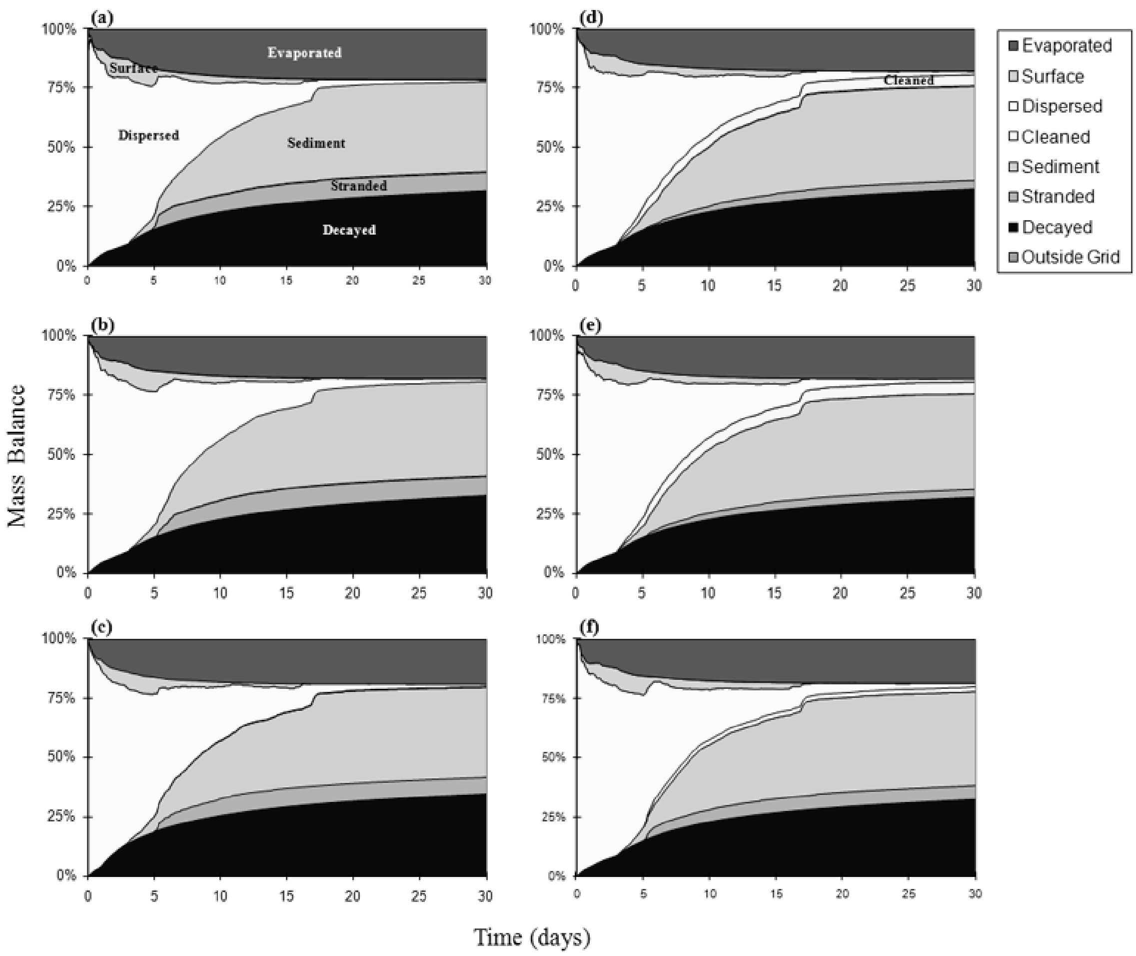

Fig. 4. Mass balance time-series for simulated blowout: (a) scenario No. 1; (b) scenario No. 2; (c) scenario No. 3; (d) scenario No. 4; (e) scenario No. 5; (f) scenario No. 6

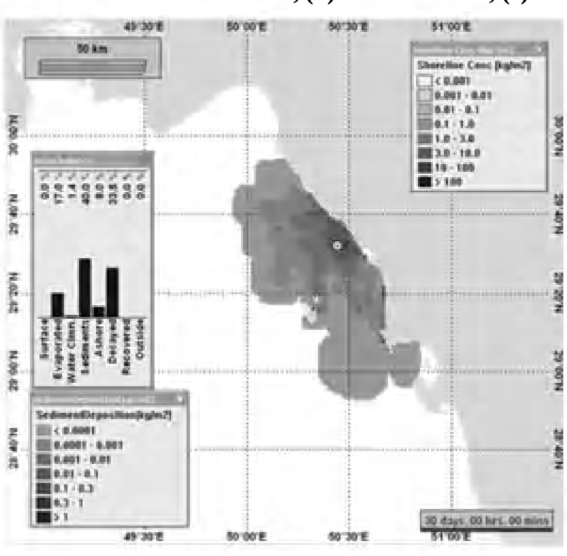

Fig. 5. Distribution of ashore and deposited oil 30 days after the beginning of the hypothetical blowout in scenario No. 2

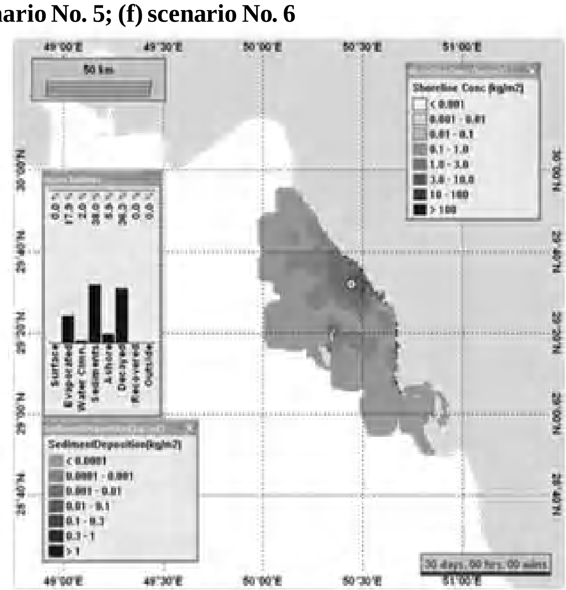

Fig. 6. Distribution of ashore and deposited oil 30 days after the beginning of the hypothetical blowout in scenario No. 3

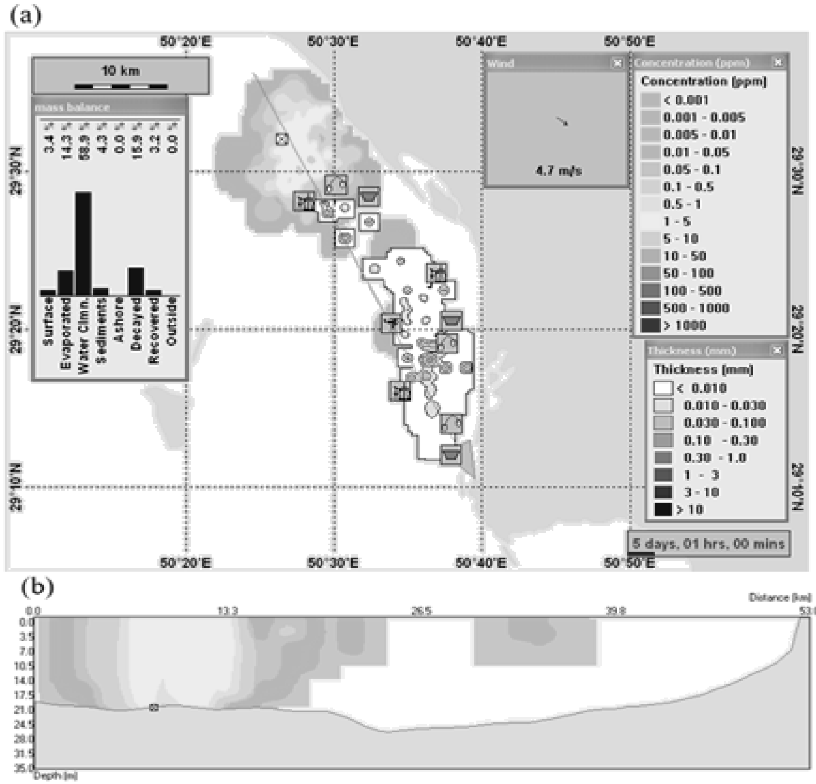

Fig. 7. Snapshot of surface and subsurface distribution of the total hydrocarbon concentrations (THC), surface oil (black) and response action equipments 5 days after the hypothetical blowout in scenario No. 5: (a) Maximum concentration at each horizontal location in the field; (b) Vertical cross section at the water column drawn from north-west to south-east

5). Major part of the spilled oil (40%) is deposited on the seabed as the sediment with maximum rate of 120 gr/m^2. This sediment threats the Khark seabed habitat (Fig. 5). Main factor in high rates of oil deposits in the region is the way out the oil on the seabed as the jet in high-speed (Ranjbar *et al*., 2011). This causes the intense entrainment and intense dispersion of the oil in the water column, so that only in the first days of simulation a small percentage of the spilled oil will be present on the water surface. As a result, in Khark area water (shallow water) this helps deposition of more oil on the seabed as the sediment.Response action cannot postpone the hitting spilled oil to the coast for first time. The mass balance time-series related to scenarios No. 2, 4, 5 and 6 are compared in Fig. 4. In scenario No. 4, approximately 5.0% of the spilled oil is recovered, and there is 4.5% reduction in the stranded oil. In the case with no response, residual oil naturally will be dispersed. In scenario No. 5 approximately 5.0% of the spilled oil is recovered and there is 4.8% reduction in stranded oil. Dispersion of some part of surface oil by chemical dispersant in scenario No. 5, do not affected the amount of recovered oil by boom-skimmer systems. One reason of low amount of cleaned oil, despite using such recovery systems is low amount of surface oil; only during the first 18 days of simulation, less than 10% of the spilled oil will present on the water surface. The boom-skimmer systems can only clean the surface oil and the oil in the upper part of water column. Therefore the low amount of recovered spilled oil is reasonable. In scenario No. 6 all response equipments mobilized in 48 hours after announcing the accident and approximately 2.5% of the spilled oil is recovered, and there is 4.0% reduction in the stranded oil. Since oil remains on the water surface for a short time, fast response action is essential. Due to wind conditions in Khark area, the Khark south east coast has the maximum oil contamination potential.

CONCLUSION

The work reported here includes analyses of specific potential for oil blowout from pipelines which located on the seabed between Iran mainland and Khark island. The analyses are carried out with the OSCAR 3-dimensional model system. Related results indicated that in Khark area the major factor in the transport and spread of oil in the area is wind and the role of tidal currents is much less than wind. Major part of evaporated heavy oil was observed in first 6 days of simulation. Significant part of the oil will pollute the environment by deposit on the seabed and hit the area beach. Also some oil spill scenarios are investigated to evaluate effects of oil spill operation planning for response actions in decreasing potential consequences. Mechanical recovery equipment systems reduce the potential surface oil effects on the environment, but it cannot eliminate all the potential consequences. The reason of the low amount of cleaned oil is the low amount of surface oil; therefore quick response in first days of spill is very important. Dispersant vessels and dispersant aircraft reduce surface potential effects, but cause to increase the oil in the water column and the deposited oil on the seabed. Generally such level of response is effective and reduces the potential environmental effects of spilled oil.

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