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Numerical Simulation of Oil Spill in the North West of the Persian Gulf

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ABSTRACT

This paper presents the results of oil spill simulation in the northwest of the Persian Gulf, next to Al-Ahmadi oil wells. A two-dimensional depth averaged flow and oil pollution model is developed for coastal water simulation. To increase accuracy advective terms in transport equation were discretized by applying third-order upwind scheme and modified by using GH limiter. The oil spill is considered in two different layers: surface smudge layer and depth emulsion part. The model takes into account the major physiochemical phenomena of oil spill including wind and current speed, oil evaporation, dissolution and coastline deposition. Average monthly wind speed has been used for long-term prediction in the Persian Gulf. Comparing the model result with the actual measured data in the incident sight revealed good agreement for predicting oil spill behavior and model accuracy.

KEYWORDS

Marine Oil Spill, Persian Gulf, GH Limiter, Spread of Oil Slick.

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1- INTRODUCTION

The life of organisms depends on water. About 71% of earth's surface is covered by water with an average depth of 8.3 Km. The total volume of water in the oceans, marines and rivers is about 3.1 billion cubic kilometers, which is 24% of the Earth's mass [1].

Today marines are subjected to human abuse for various reasons, more than ever. Relatively, complete statistics of all accidents and oil contamination with volume more than 10 million gallons (37,854 cubic meters) have been reported by the National Academy of Sciences of the US Navy, recently [2].

Fay (1969, 1971) and Stolzenbach et al. (1977) derived oil spreading formulas for constant volume slicks with idealized configurations in calm water [3]. Youssef and Spaulding (1993) have recently extended a basic approach to account for wind generated wave induced turbulence at the sea surface [3].

Spill models are normally developed by linking mathematical formulations to represent oil transport and fate processes (Stolzenbach et al. 1977; Huang and Monastero 1982; Spaulding 1988; Lee et al. 1990; Spaulding 1995) [3].

Increasing number of accidental oil spills in aquatic environments presents a growing concern about oil pollution of seas leading to more research in this area, recently. Mariano et al. (2011) suggested to improve the accuracy of oil spill transport modeling using two oil particle trajectory forecasting systems to weaken the influence of current modeling error [4].

The present paper contains additional improvements on Tkalich and Xiaobo approach [5]. To this end, the oil slick dynamics are described within the kinetically coupled two-layer approach. The oil slick thickness is computed using the layer-averaged Navier-Stokes model for the upper layer. While the oil droplet mixture in the wave-mixing layer of the water column is calculated for the lower layer.

2- METHODOLOGY

Mechanisms that govern the fate of oil slick in marine area are spreading, evaporation, dispersion, emulsification, sedimentation and biodegradation. In this paper, these mechanisms are described shortly by mathematical formulations that are based partially on empirical results.

In this research, flow modelling is done for hydrodynamic solution, using a finite volume based numerical model. Continuity and momentum equations are solved to estimate the flow surface level and velocity components in each computational step. To reduce the numerical oscillation, staggered mesh is applied.

Advection-diffusion equation is discretized and solved to simulate oil droplets vertical motion in a water column. Two-dimensional advection diffusion equation is discretized by applying the finite volume method in the Cartesian coordinate system. The ADI scheme is used to solve the equation for horizontal variation of oil slick during the time. The solution scheme is second order accurate in space and time.

To reduce dispersion errors and avoid spurious oscillations due to shocks, discontinuities or sharp changes in advection-diffusion simulation, the Ghiassi-Heydariha (GH) flux limiter is introduced as follows:

$$q(i)=\begin{cases} q(i-1)+a\Delta x & if\ |a|<|b|\ and\ ab>0 \\ q(i+1)+b\Delta x & if\ |b|<|a|\ and\ ab>0 \\ q(i-1) & if\ |a|<|b|\ and\ ab<0 \\ q(i+1) & if\ |b|<|a|\ and\ ab<0 \\ q(i-1) & if\ ab=0 \end{cases} \quad (1)$$

Where q is the calculating parameter. To compute flux limited value of q parameter, a and b are also defined as follows:

$$a=\frac{(\bar{q}_i^n-\bar{q}_{i-1}^n)}{\Delta x} \quad , \quad b=\frac{(\bar{q}_{i+1}^n-\bar{q}_i^n)}{\Delta x} \quad (2)$$

Proposed flux limiter is applied in the model to prohibit oil concentration oscillation during oil spill simulation. This limiter uses data of 3 grids to reduce distortion around one grid.

For accurate oil spill modeling, the daily wind velocity need to be applied that, unfortunately, was not available for simulating Al-Ahmadi spill event. Al-Rabehet al. (1992) used average effective monthly wind velocities and directions in the Persian Gulf. In the current simulation, as suggested by Al-Rabeh, optimal values for wind deflection angle (γ= 26.03° to the right of the wind direction) and wind drag coefficient (ß=0.031) were used.

3- NUMERICAL MODEL

A new oil slick simulation module is developed and added to existing CECAD-MAR hydrodynamic model. The new oil slick module inputs: water velocity, flow depth and specification, wind velocity and direction, temperature, wave information and oil specification. The module takes into account: wind, water flow, wave, evaporation, emulsification, spreading and dispersion, dissolution, coastal absorption and aggregation. The mentioned parameters contain about 95% of parameters affect the oil spill fate.

4- VALIDATION

Three different research results are compared in this paper: (A) Investigation notes provided by researchers who have described and simulated the occasion and applied a trajectory model, namely GULFSLIK II, applied in King Fahd University of Petroleum and Minerals (Al-Rabehet al., 1992). They provided reasonably accurate predictions and have extensively documented the actual trajectory of the spill. (B) Results of MIKE3-SA module that solves the so-called Fokker-Planck equation for suspended oil substances by the Lagrangian Discrete Parcel Method (LDPM). (C) Results of the current simulation study, based on the numerical modeling of tidal flow and oil slick fate, by applying CECAD-MAR hydrodynamic model and newly developed oil-pollution module.

To evaluate the slick trajectory, the slick leading edge advancement with time was derived from simulation results as reported in Table 1 along with the times recovered from the actual oil spill sighting and from the simulated KFUPM GULFSLIK II model at five stations along the Saudi Arabia coast.

Simulation results show that the model is accurate enough to predict the slick center of gravity movement and it can be applied for investigating the oil slick trajectory on marine waters.

TABLE 1. ACTUAL AND PREDICTED TRAJECTORY COMPARISON OF AL-AHMADI OIL SPILL

Location	Date of Actual Oil Sighting	Predicted date of impact using GULFSLICK II
Al-Ahmadi (Start)	January 19, 1991	January 19, 1991
Khafji	January 25, 1991	January 26, 1991
Safaniya	January 29, 1991	January 30, 1991
Ras Al Ghar	February 08, 1991	February 09, 1991
Abu Ali	February 14, 1991	February 13, 1991
Location	**Predicted date of impact using MIKE3**	**Predicted date of impact using OILSLICK**
Al-Ahmadi (Start)	January 19, 1991	January 19, 1991
Khafji	January 26, 1991	January 25, 1991
Safaniya	January 30, 1991	January 29, 1991
Ras Al Ghar	February 07, 1991	February 08, 1991
Abu Ali	February 09, 1991	February 14, 1991

5- CONCLUSION

The simulation results show that after the first week of February, a non-prevailing south-eastern wind front took place. This caused lowering the velocity magnitude of the north-western wind in the region and the trajectory of the oil spill was reversed and delayed during the rest of February and March, when the net wind blow was in favour of the north-western wind that again caused the spill to move slowly in the southeast direction. Relatively, a simulated trajectory similar to the actual trajectory plot is produced. The simulation results reveal that horizontal spreading took place during the holding conditions in the February was much more than that of typically noticed by Spaulding et al. (1993). The MIKE3-SA and current study results showed that the impacted region along the Saudi Arabia coast was almost similar to the actual condition. The extent of shoreline impact was less in the simulation than it was in real life. This is probably due to the difference in the wind data combination of magnitude, direction, and duration from the real data.

Reviewing measured data and simulation results, one can note that the oil slick thickness decreases rapidly during the first 5 to 6 hours. This means that the first stage of spreading occurs within a short time. After the initial phase involving gravity, inertia, and viscous forces, the surface tension phase of spreading takes over and lasts for a longer time until the oil slick becomes unstable and breaks up.

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