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Simulation of oil pollution in the Persian Gulf near Assaluyeh oil terminal

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ABSTRACT

Numerical simulation of oil slick movement with respect to tidal factors and wind effects was performed in order to counteract oil pollution in the Persian Gulf. First, a flow model was invoked with respect to water level fluctuations. The main tidal constituents were applied to the model using the initial conditions of water level variations in the Hormuz Strait near the Hangam Island. The movement of oil pollution was determined due to wind, tide and temperature effects and confirmed by applying a verified field results. Simulations were focused near an important terminal in the Persian Gulf, Assaluyeh Port. The results were led to preparing a risk-taking map in a parallel research for the Persian Gulf.

1. Introduction

In two recent decades, researches have been conducted to study transfer and fate of oil slick; therefore, different spreading models and some types of software have been developed (Reed et al., 1999). Based on oil spreading models, many of them have focused on the advection of oil slicks. In Elshorbagy researches, the oil spill hazard contour maps were developed for the prediction of oil spill travel times and critical wind directions in association with major strategic desalination plants (Elshorbagy and Elhakeem, 2008). Spreading processes (Elshorbagy et al., 2006), horizontal and vertical diffusion (Sebastiao and Soares, 1995; ASCE, 1996), the amount of emulsification, evaporation and dispersion of oil into water column and the total remaining oil volume have been considered as well. Theoretical and experimental studies addressing spreading and depreciation of oil pollution have already been conducted by Milgram (1983), followed by amendments made by Swan and Moros (1993), Rye and Brandvik (1997) and Zheng and Yapa (2000). Chao developed a two & three-dimensional oil trajectory and fate model for coastal waters. A three dimensional oil fate model was developed based on mass transport equation by Chao et al. (2001). Also Al-rabeh (Lardner et al., 1993) run a model in two dimensional mode over all or part of the gulf to compute the flows by density gradient and also found the Gulf Spill package. The disadvantage was that the package is tied to the one geographical location (Al-Rabeh et al., 2000). Fingas and Fieldhouse (2004) proposed a new numerical modeling scheme. The model was based on empirical data and the corresponding physical knowledge of emulsion formation. Wang et al. (2008) considered the processes of hydrolysis, photo oxidation and biodegradation for the simulation of oil spill transport Considering the spread of a thin film of a viscous substance on the sea surface. Arkhipov and Kketerov (2007) discussed the simulation of pollutant due to advection and diffusion in a turbulent flow. Guo et al. (2009) used fractional Brownian motion to model oil spill trajectory.

Hydrodynamic model of MIKE's software was considered in this study based on a validation performed and calibrated by the authors (Badri and Azimian, 2010; Badri et al., 2010). As an applied sample, determination of the direction of oil slick in Assaluyeh Port located in the Persian Gulf was analyzed and the results were offered (Fig. 1). In this numerical simulation, tidal currents were noted by applying water fluctuations for the Persian Gulf region. The fluctuations of water average level in the open boundary, namely, Hormuz Strait, for a 19-day period were applied to the software from august 22nd to September 9th, 2008 in Hangam Island. In Sections 2.1 and 2.2, some explanation regarding modeling of the fate of oil in the Persian Gulf by MIKE software was presented. In Section 2.3, the effects of oil depreciation processes including important factors of evaporation and emulsification are considered. In Section 2.4, spreading process of oil slick and in Sections 3 and 4 simulation results and conclusion are presented, respectively.

2. Materials and methods

2.1. Simulating the fate of oil with respect to spreading and depreciation

In the performed simulation, Hormuz Strait was considered as an open boundary in the Persian Gulf. Meanwhile, Hangam Island and the tidal fluctuations of water level in this island were selected as one of the regions near Hormuz Strait (near open boundary). An unstructured grid was used to cover the model with a multi-layer system

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Fig. 1. Assaluyeh local map in Persian Gulf.

(5-layer) and the Persian Gulf was converted into different grid points (5000 m grid points in the horizontal plan) including land regions.

Bathymetry data was selected from Mitchell research vessel (Elshorbagy et al., 2006). In addition, measured depth of the Persian Gulf with specified longitude and latitude was applied on corresponding points for simulation aims. Tidal raising forces constituents were included in a pair of semi-diurnal constituents, M_2 for moon and S_2 for sun and a pair of diurnal constituents, K_1 and O_1 for moon. These four main constituents were considered by using Admiralty Method of Tidal Prediction NP 159. Initial salinity 39 [psu] (practical salinity unit) and temperature (20 °C) were used. Air temperature was considered constant equal to 50 °C over the entire region and bottom roughness was considered as 0.1 m (Elshorbagy et al., 2006). The Smagorinsky formulation turbulence model was used as a turbulence model in the hydrodynamic simulation. Empirical values of the used coefficients were employed by the original model. Eddy viscosity limits were considered in the horizontal plane i.e. 5×10^6 [cm^2/s] and in vertical plane of 0.1×10^6 [cm^2/s]. To verify the hydrodynamic model, calculations for water surface level and surface layer currents near Kish Island were used and compared to the measured data. The computed water surface level and water surface velocity at Kish Island were compared with the measured values to calibrate the software (Badri and Azimian, 2010). The spilled oil on the water and its fate are influenced by the physical, chemical and ecological processes. Advection of oil on water surface is a physical process dominated by wind, water currents and waves. It is caused by surface current and wind drag, while the advection of suspended oil is the movement of oil droplets entrained into the water column due to water current. Accurate environmental information is essential for the reliable prediction of the transport and fate of oil pollution. Therefore, forecasting dynamic factors accurately is the base of the oil spill model. The fate of oil at sea is determined by the environmental conditions as well as the physiochemical properties. The latter are relatively settled if the spilled oil is certain, while the former is space and time dependent, of which the most important three factors are surface wind tension, water currents and waves. These results were exemplified and offered for 2008.

2.2. Hydrodynamic and oil spill analysis model

Hydrodynamic modeling of the Persian Gulf was first conducted to provide the flow field needed for oil spill modeling. This was accomplished by the hydrodynamic module MIKE3-HD, a rectilinear model simulating unsteady flow with Z layer system. Bathymetry and external forcing such as meteorology, tidal elevations, currents and other hydrographic conditions were taken into account. The classical Navier–Stokes equations for mass and momentum conservation in three dimensions were applied. The hydrodynamic basis for computations performed in successive modules was provided; namely, spill analysis module (SA). Natural dispersion, evaporation and emulsification were taken into consideration as the encountered weathering processes in the oil spill analysis. They were dynamically coupled with the temperature and salinity modules and resolved by advection–dispersion processes. The heat exchange was calculated on basis of four physical processes, sensible heat flux (or the heat flux due to convection), latent heat flux (or the heat loss due to Vaporization), net Short Wave Radiation, and net Long Wave Radiation. The turbulent fluctuations were modeled by employing the Boussinesq eddy viscosity concept. The Smagorinsky turbulence closure was adopted in the study. In the present study, the 3D non-hydrostatic *z*-layer version of the MIKE3-HD software was used in combination with Smagorinsky closure. These developments were in line with Elhakeem et al. (2007), but included more extended physical model, taking salinity and temperature effects into account. At Hormuz

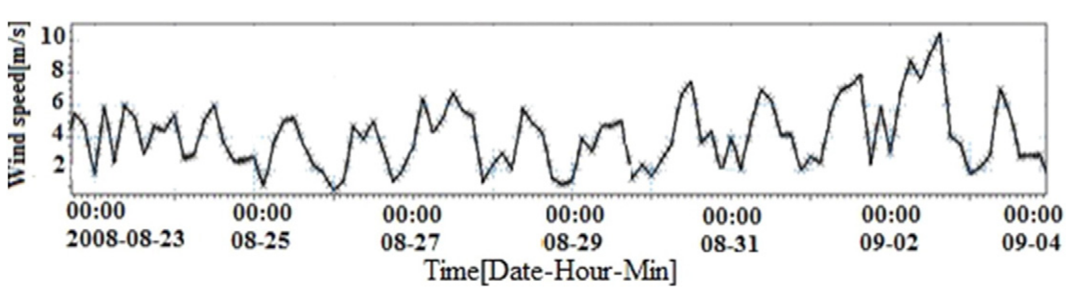

Fig. 2. Assaluyeh port, Wind speed, (August & September, 2008).