OIL FATE AND SLICK TRAJRCTORY PREDICTION FOR MARINE OIL POLLUTION CONTROL STRATEGIES

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Dedicated to father, mother, wife, siblings, children and dear friends and lecturers

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IN THE NAME OF ALLAH S.W.T, THE MOST GRACIOUS THE MOST MERCIFUL

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ABSTRACT

The impact of oil pollution is significant and its effects can be seen in different marine related aspects including fisheries, tourism and costal industries. Hence, the choice of the most effective oil pollution combating strategy is very important to minimize the effect of oil spills on the environmental and socio-economic activities. An efficient strategy includes the prediction of oil fate and slick trajectory to determine which shoreline will be affected and which combating technique is most suitable. In this research, a model describing the selection of oil pollution combating strategy has been developed. Software simulations and mathematical relationships were used to predict the oil fate and slick trajectory. For oil fate, ADIOS2 program was used to predict evaporation, dispersion and change in viscosity processes and mathematical relationships were used to predict spreading and emulsification processes respectively. Slick trajectory calculator program was used to predict the movement of oil. A case study has been performed on a simulated oil pollution scenario off the South West coast of Johor, Malaysia. The type of oil was Arabian Heavy, Amoco with API 28 spilled at 103^{o} 28’ 50 E and 1^{o} 07’ 12 N. The model predicted that nine hours after the time of spill, the weathering processes such as spreading, evaporation, dispersion, emulsification and viscosity were 637748 m^2, 104 m^3, 3.7 m^3, 470 m^3 and 60 cSt respectively and the trajectory with over all bearing of 26.3^{o} towards a sensitive shoreline with Tanjung Pelepas Port, Tanjung Bin Power Plant and mangrove areas. The model proposed the use of the combination of oil pollution combating equipment including booms, skimmers, pumps, manual and motorized equipment, in addition to chemical dispersant and placement of such equipment. Using the selected strategy model predicted that the pollutant would be effectively controlled.

ABSTRAK

Impak pencemaran tumpahan minyak memberi kesan yang sangat besar kepada industri berkaitan maritim termasuk perikanan, pelancongan dan industri persisiran pantai. Dengan itu pilihan strategi yang berkesan bagi mengatasi masalah pencemaran tumpahan minyak adalah penting untuk meminimumkan kesannya terhadap alam sekitar dan aktiviti sosio-ekonomi. Strategi yang cekap termasuklah menentukan ciri-ciri tumpahan dan unjuran arah aliran pencemaran bagi mengetahui kawasan persisiran yang akan terjejas dan kaedah penyelesaian yang bersesuaian. Di dalam penyelidikan ini, sebuah model yang menerangkan cara pemilihan strategi mengatasi tumpahan minyak telah dibangunkan. Simulasi menggunakan perisian komputer dan secara persamaan matematik telah digunakan untuk meramalkan ciri-ciri dan arah aliran tumpahan minyak. Perisian ADIOS2 digunakan untuk meramal proses-proses pengewapan, penyebaran dan perubahan kelikatan dan persamaan matematik digunakan untuk meramal penyerakan dan proses emulsifikasi. Sebuah program pengiraan unjuran pergerakan tumpahan minyak digunakan untuk menentukan pergerakan minyak. Kajian kes telah dijalankan dengan melakukan simulasi tumpahan minyak di kawasan pantai Barat Daya Johor dengan menggunakan jenis minyak Arabian Heavy, Amoco (API 28) pada koordinat 103^o 28’ 50 T and 1^o 07’ 12 U. Model meramalkan bahawa selepas sembilan jam kondisi penyerakan, pengewapan, penyebaran, emulsifikasi dan kelikatan tumpahan minyak adalah masing-masing 637748 m^2, 104 m^3, 3.7 m^3, 470 m^3 dan 60 cSt dengan unjuran kedudukan 26.3^o menuju persisiran di mana terdapat Pelabuhan Tanjung Pelepas, Janakuasa Tanjung Bin kawasan hutan bakau. Model mencadangkan penggunaan kaedah kombinasi peralatan untuk mengatasi masalah tumpahan minyak seperti boom, penapis minyak, pam, peralatan manual dan peralatan yang menggunakan kuasa sebagai tambahan kepada tambahan bahan kimia penyebaran yang berkenaan dan penempatan peralatan-peralatan tersebut. Dengan strategi yang dipilih model meramalkan tumpahan minyak akan dapat dikawal dengan berkesan.

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LIST OF ABBREVIATION

AASTMT - Arab Academy for Science, Technology and Maritime Transportation
ACP - Australia Contingency Plan
ITOPF - International Tankers Owners Pollution Federation
NEEB - Net Environmental and Economical Benefit
IPIECA - International Petroleum
NRC - National Research Council
TAP - Trajectory Analysis Planner
API - American Petroleum Institute
MARPOL- Marine Pollution
MEPC - Marine Environment Protection Convention
OPRC - Oil Pollution Response and preparedness Cooperation
DOE - Department of Environment
SPCC - Spill Pollution Contingency Convention
IOPC - International Oil Pollution Compensation
NOAA - National Oceanic and Atmospheric Administration
ADIOS - Automated Data Inquiry Oil Spil
PERSGA- Protection of Environment at Red Sea and Gulf of Aden
OSTC - Oil Spill Training Company
EARL - East Asia Response Limited
ICS - Incident Command System
IC - Incident Commander
SSW - South South West
NNE - North North East

LIST OF SYMBOLS

A	-	constatnts derived from distilation data
A_S	-	silver/sheen color area
A_R	-	rainbow color area
$A_{B/b}$	-	black/brown color area
$A_{B/O}$	-	brown/orange color area
B	-	constatnts derived from distilation data
C_3	-	the constant viscosity equal to 0.7 for heavy fuel oil and 0.25 for light oil
C_{dis}	-	an experimentally determined parameter
D_a	-	the fraction of sea surface dispersed per hour
D_b	-	the fraction of the dispersed oil not returning to the slick
D_e	-	dispersion of wave energy per unit surface area
dmax	-	maximum droplet size 70 microns
dmin	-	minimum droplet size 5 microns
F_{bw}	-	fraction of breaking waves per wave period per unit area
F_E	-	volume fraction evaporated
g	-	gravitational acceleration
h	-	average thickness of oil
H_{rms}	-	root-mean wave height in meters, assumed to be related to the spectrally based significant wave height
$H(t)$	-	the thickness of slick as a function of time
K_2	-	mass transfer coefficient for evaporation
K^o	-	reference mass transport coefficient defined at 1 m/s
L_{max}	-	the length of the major axes of ellipse
L_{min}	-	the length of the minor axes of ellipse
N	-	speed of boat or aircraft
$N(\delta)$	-	the number of oil droplets per unit volume of water per droplet diameter

P_1 - vapor pressure of the ith Pseudo component

Q_{dis} - application rate of dispersant

R_{dis} - desired dispersant-to-oil volume ratio

R - gas constant = 8.3144 j/k, mole

S - swath widh on the water surface

s_t - oil- water interfacial tension (dyne/m)

T - ambient temperature

t - time

T_0 - initial boiling point at F_E of zero K

T_G - gradient of boiling point, T_B and F_E line (K)

U_w - the wind speed

V_e - water content of the emulsion

V_{dis} - application rate of dispersant

$V_{o/w}$ - volume of oil entrained per unit volume of water

V_{oil} - the total volume of an oil spill

V_1 - molar volume of the ith Pseudo component (m^3/ mole)

$\vec{V}_c$ - depth-averaged current velocity

V_0 - initial volume of spilled oil

$\vec{V}_w$ - wind velocity at 10 m above the mean seawater surface

$X_1(t)$ - downwind dimension

Y(t) - fraction of water in emulsion as a function of time

θ - jet angle with respect to x - axis

μ - viscosity (cp)

ρ_0 - the density of oil

ρ_w - the density of water

α_c - current drift factor (~1.1)

α_w - wind drift factor (~0.3)

If the above illustration of any symbol conflicts with the illustration of that symbol given in the following text then preference should be given to the illustration, which is provided in the following chapters.

CHAPTER 1

INTRODUCTION

1.1 Research background

Marine oil pollutions have negative impact on the marine environment and have significantly adverse effects on fisheries, tourism, and costal industries and sometimes are used as weapon such as made by Israel against Lebanon in 1982 and the second Arab Gulf War between Iraq and the allied forces led by the U.S (Muhanna, 2006). The direct impact of oil spills can cause damage to fishing and aquaculture resources by physical contamination and toxic effects. Also, it disrupts the maritime and coastal business activities. The nature and extent of the impact of oil spill on seafood production depends on the characteristics of the spilled oil, the circumstances of the incident and the type of fishing activity or businesses in the affected (IOTPF, statistic, 2009). Also shoreline industries are directly affected because of extension of heavy oil along the coastline such as the 1978 *Amoco Cadiz* spill, the loss of 220 thousand metric tons of crude oil and bunker fuel polluted some 240 miles of the Brittany coast (Grigalunas, *et al*, 1986). In addition, the coastal population communities may affected be as described by White and Molly (2003) in the first 1.5 years after 1986 spill, and contrast their findings with earlier works regarding the effects of oil on tropical community.

Usually, oil pollution is caused by ships, offshore units, seaports, pipelines and oil handling facilities. There are Information gathered from published sources such as shipping press, vessel owners and their insurers and other specialized publications which says that the large spills are often resulting from collisions, groundings, structural damage, fires and explosions, whereas the majority of individual reports relate only to small operational spillages (ITOPF, 2004). In the event of oil pollution incident, predicting the oil slick trajectory and oil fate will lead to prompt an effective oil pollution control strategies to mitigate or minimize the damages resulting from such incidences on environment and socio-economic activities.

The prediction of oil slick trajectory depends upon the seawater current and wind directions and speeds with assistance of transmission technology to confirm the trace of predicted trajectory. Whereas the oil behavior is affected by a number of physical and chemical characteristics, climate and the sea conditions which lead to spreading, dispersion, evaporation and emulsification. The prediction should be verified by air and/or sea reconnaissance to deploy and control the operation at sea, for timely protection of sites along threatened coastlines and the preparation of resources for shoreline clean-up.

Employing the contingency plan to combat the oil pollution and choosing the suitable strategy for each place requires good background information about the sensitivity of attacked shoreline environmentally and economically. After that, employing the righteous equipments and techniques, which are available for recovery, dispersion and clean-up should be properly implemented to reach the net of environmental and economical benefit (NEEB).

1.2 Problem statement

Marine oil pollution has negative impact on the environment and socio-economic activities for short and long terms, and the major spill is considered as a disaster because of its destructive effects. The effects of an oil spill on the environment and socio-economic activities and the effectiveness of cleanup and control vary significantly with the type of oil spilled. As happened in 1978, the incident of Amco Cadiz oil spill where 220 thousand metric tonnes of crude oil and bunker fuel extend along 240 miles of the Brittany coast. Resulted a negative impact on the environment and the coastal population communities at least in the first 1.5 year (White and Molly, 2003).

The severity of the effects of an oil spill on the natural resources and socio-economic depends on many factors. These factors include the type and amount of oil and its behavior once spilled into seawater, the physical characteristics of the affected area, weather conditions and seasonal time of year, which affect on the oil fate and slick trajectory, the type and effectiveness of response operations and the biological characteristics of the area (Fingas, M., 2000). Oil pollution control strategies need to be developed for each oil fate and slick trajectory scenario. Since each scenario is unique and independent, simulation method is preferred.

The simulation of oil pollution incident in the south west of Johor state in Malaysia is used. Software simulations and mathematical relationships are used to predict the oil fate and slick trajectory. Based on the predictions, the combating strategies are chosen according to the sensitivity of the shorelines which may be affected and the capability of in-hand combating equipment. The suitable response operations lead to minimizing the long and short-term impacts on the environment and economical activities in this area.

1.3 Objectives

Study all of the circumstances of oil pollution response operations. The right way to make combating operation effective, it must be based on a scientific background to reach the optimum response level. The scientific background consists of knowing how the oil spill affects the environmental and economical resources. To avoid or mitigate the harshness of oil spill incident, there are some technical procedures that should be followed. The procedures include to where the oil slick is moving because of the forces of wind and sea current, what is happening to the physical and chemical characteristics of the spilled oil, what is the nature of coast lines and how the in-hand equipments could be employed effectively. The objectives of this research are as:

i. Predict the oil pollutants fate

ii. Predict the oil slick trajectory

iii. Identify the types of shorelines which may be affected and their characteristics

iv. Establish a matrix of equipments and the useful techniques

1.4 Scope of Project

This project covers the following:

i. Variables for the research have been strategically limited to common variables used to define oil fate and oil trajectory. These are spreading, evaporation, dispersion, viscosity and emulsification. Variables not commonly used in the real world such as dissolution, photo-oxidation, biodegradation and sedimentation here are not included.

ii. For data analysis and simulation of trajectory, currently available mathematical formulas and software have been used. For example, software by OSTC for calculation of slick trajectory has been used and ADIOS2 has been used to predict the weathering processes.

iii. The model has been designed to be applicable for the development of the oil pollution combating strategies of typical weather conditions.

1.5 Organization of the research

This research is organized into six chapters:

i. Chapter one gives introduction, shows the importance of this research and discusses a general overview of research activities

ii. Chapter two reviews the main areas of oil pollution control which are related to this research

iii. Chapter three explains the methods which will be used to achieve the objectives of this research

iv. Chapter four consists of the results which are gotten from this research

v. Chapter five contains the discussion on the results

vi. Chapter six includes the conclusion of this research and the suggested future works