International Journal of Engineering Science Invention
ISSN (Online): 2319 – 6734, ISSN (Print): 2319 – 6726
www.ijesi.org ||Volume 4 Issue 4 || April 2015 || PP.68-74

Research on the Trajectory of Oil Spill in Near-shore Area

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Abstract: The diffusion trajectory of three common oil-spills was numerical simulated in the dock area and open water in this paper. Vortexes appeared in simulated diffusion trajectory of oil-spills in the dock area, which was attributed to the effect of water flow and shoreline. Whereas a ribbon diffusion trajectory was observed when the diffusion trajectory was simulated in open water, and the diffusion direction of oil-spill is along the direction of water flow.

Keywords: Oil Spill; Nearshore; Proliferation; Trajectory

I. INTRODUCTION

For exploring oil spill trajectory, theoretical researches and numerical simulation has been studied by scientists, and the most of theoretical basis is Fay's "Three Equilibrium Equations"[1, 2]. Many oil spill simulation systems are using oil particle model [3, 4], by integrating numerical simulation and GIS technology, a range of marine oil spill simulation systems have been developed, such as the OILMAP system that can be simulated oil spill fate and behavior and traceable back to the push, which was developed by ASA (Applied Science Associates, Inc.) in the 1980s; The company also launched the SIMAP (Spill impact model analysis package) system consists of a biological effects module. Norwegian Industrial Technology Research Institute has developed the OSCAR (oil spill contingency and response) system that can simulate the degree of pollution of the coastline caused. Australia OSTM system based on OILMAP completed, and includes a hydrodynamic model HYDROMAP. The simulation results this system obtained show that the effects of the geostrophic flow in oil spill trajectory simulation are very important. As can be seen from the above description, the international oil spill simulation systems developed earlier and more mature, with higher forecast accuracy of oil spill trajectories. But they are mainly used in large-scale simulation of oil spills at sea, and a large range of the analog waters, but the accuracy of these systems used in a small amount of oil spill and near-shore oil spill simulations needs to be verified. The domestic use of oil spill simulation systems are generally based on the post-secondary development of OILMAP [5-7]. These systems are widely used in fixed open waters. Some researchers have studied the oil spill trajectory in rivers and lakes [8, 9]. But research on the oil spill trajectories above does not consider the impact of shoreline adsorption and bottom friction [10] on the oil spill trajectory. Through the analysis of the relevant literature, the current oil spill trajectory simulation systems used widely in open waters, while they are used in large marine oil spill trajectory simulations, they have a high degree of accuracy and extremely reliable. However, the oil spill occurred in the near-shore terminals generally have a small amount, complex factors and other characteristics. Therefore, the study of the oil spill trajectory simulation in marina area becomes necessary.

1 The oil spill dispersion model under the near-shore hydrological conditions

The main content of oil spill dispersion modeling under the near-shore hydrological conditions is simulated oil spill occurred in the dock area. By establishing a simplified near-shore (extended from the shore to 50m) model of environmental conditions to simulate and analyze the diffusion of oil spill trajectory.

1.1 Modeling

Taking a depot located in Zhoushan Port as the background to create a simplified model of near-shore environmental conditions. Crude oil, fuel oil and diesel were used as the diffusion to build the model. The nature of the oil required for the experiment shown in Table 1.

Tab1 the main properties of the test oil [11]

Parameter / Oil species	Density [kg/m³]	Dynamic viscosity [Pa·s]
Crude Oil	810	0.08
10#Diesel Oil	850	0.003825
180# Fuel Oil	985	0.1773

Establish a simplified model based on the following principles:

1) Ignoring the local variations of the quay and considered it is approximately flat. In the marina there has a 2000t's berth; its length is 125m, so only take the spilled oil near the shoreline as research subjects;

2) The model area is mainly controlled waters surrounded booms within the near-shore hydrological conditions (the sea water flowing is onshore flow, the tide is irregular semidiurnal, the water temperature is 15 ℃, constant wind field model), ignoring the effects of wave residual current;

3) Assuming the leak width of 1m, oil leakage rate of 1m / s, steady oil leak;

4) Embankment perpendicular to the sea. Influence on the movement of the spilled oil caused by the adsorption of shoreline is considered;

5) The material used in the construction of the dock is cement. There is no shear stress and the roughness height is 1.5mm, roughness constant is 0.5.

1.2 Numerical simulation

The theoretical analysis and the establishment of computational models are included in this section. Theoretical analysis based primarily on near-shore tidal wave nonlinear equations, combined with the impact of spilled oil caused by wind field transformation matrix. Numerical simulation with a depot located in Zhoushan Port as the background, using software for modeling and post-processing.

1.2.1 Theoretical model

Stratification of Seawater density in the coastal region was not significant, Two-dimensional flow mathematical model can be used for simulating the flow field. The continuity and momentum equations are as follows:

The continuity equation: $\frac{\partial x}{\partial t}+\frac{\partial H\bar{u}}{\partial x}+\frac{\partial H\bar{v}}{\partial y}=0$ (1)

The momentum equations: $\frac{\partial H\bar{u}}{\partial t}+\bar{u}\frac{\partial H\bar{u}}{\partial x}+\bar{v}\frac{\partial H\bar{u}}{\partial y}=f\bar{v}H-gH\frac{\partial z}{\partial x}+\frac{\tau_{xw}}{\rho}-\frac{\tau_{xb}}{\rho}+\frac{\partial}{\partial x}(Hv_t\frac{\partial\bar{u}}{\partial x})+\frac{\partial}{\partial y}(Hv_t\frac{\partial\bar{u}}{\partial x})$ (2)

$$\frac{\partial H\bar{v}}{\partial t}+\bar{u}\frac{\partial H\bar{v}}{\partial x}+\bar{v}\frac{\partial H\bar{v}}{\partial y}=f\bar{v}H-gH\frac{\partial z}{\partial y}+\frac{\tau_{yw}}{\rho}-\frac{\tau_{yb}}{\rho}+\frac{\partial}{\partial x}(Hv_t\frac{\partial\bar{v}}{\partial x})+\frac{\partial}{\partial y}(Hv_t\frac{\partial\bar{v}}{\partial x}) \quad (3)$$

Considering the impact of wind field on the sea surface, then:

The wind stress equation: $U=\alpha\left(\begin{bmatrix}\cos\theta & \sin\theta\\ -\sin\theta & \cos\theta\end{bmatrix}\right)W$ (4)

In the equations: $\bar{u}$, $\bar{v}$ - The average flow velocity along the perpendicular direction of the x and y， m/s;

τ_{xw} , τ_{yw} - Wind stress in the x direction and the y direction;

τ_{xb} , τ_{yb} - The bottom floor stress in the x and y directions of the seabed;

v_t - Turbulent viscosity coefficient;

f - Coriolis force coefficient;

U - The oil film drifts velocity under the action of wind, m / s;

W- Wind speed of 10m on the sea, m / s;

α - Wind factor, generally take 3% -4%;

$\left(\begin{bmatrix} \cos\theta & \sin\theta \\ -\sin\theta & \cos\theta \end{bmatrix}\right)$ - Wind field transformation matrix;

The initial conditions: $h(x, y, 0) = h_0(x, y)$; (5)

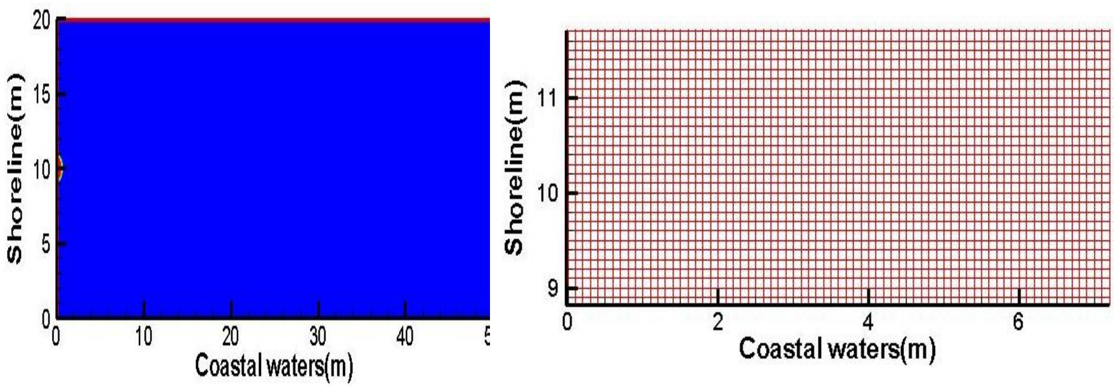
$U(x, y, 0) = V(x, y, 0) = 0$. (6)

The boundary conditions: The fixed boundary normal vector $U_n = 0$, $V_n = 0$; (7)

Open borders $\begin{cases} u(x, y, t) = u_A(x, y, t) \\ v(x, y, t) = v_A(x, y, t) \end{cases}$. (8)

1.2.2 Calculation model

Using Gambit to modeling and meshing, and set the boundary conditions. Where the boundary condition of water boundary (water-inlet) and spill boundary (oil-inlet) types are velocity-inlet, 50m from the shoreline will be set at the distal (far), outputting a two-dimensional model (Export 2-D (XY) Mesh). The simplified model used is shown in Fig1.



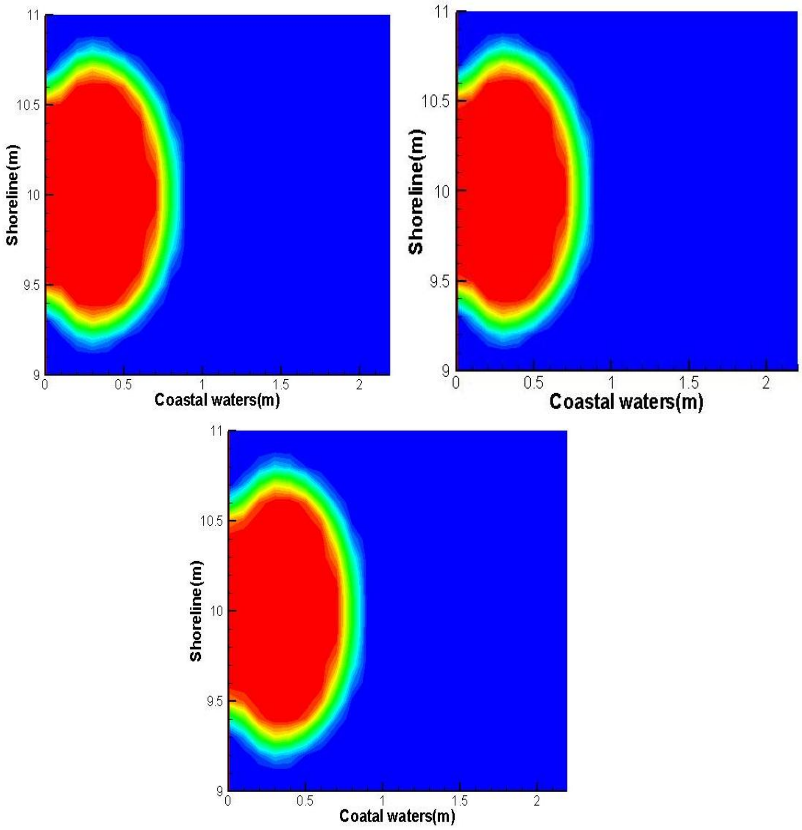
1-a 1-b

Fig1 a partial simplified schematic diagram of calculation model

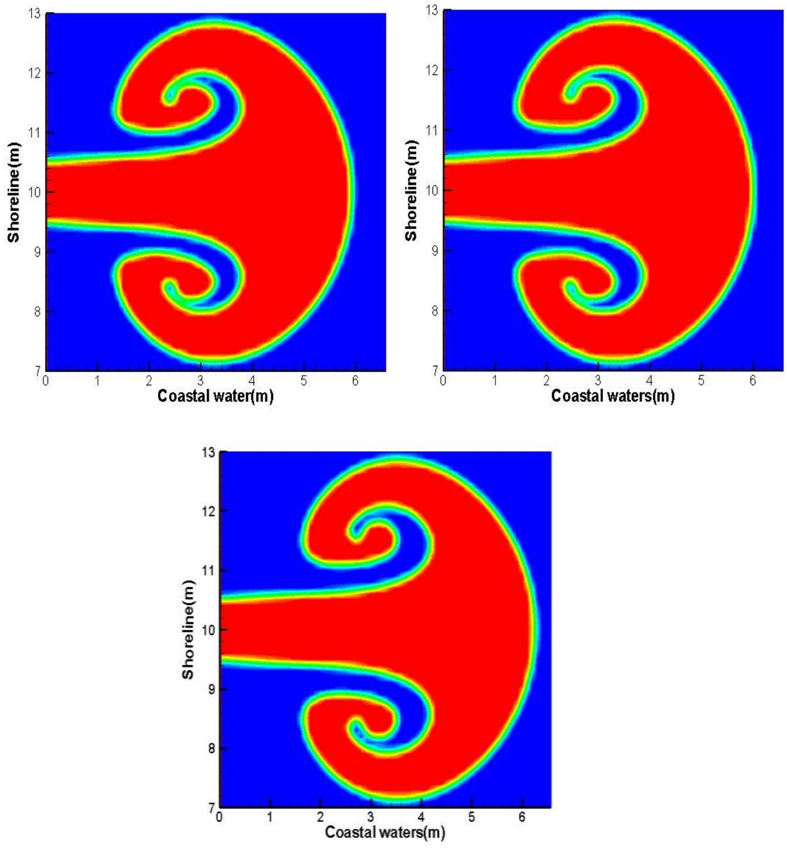
(a- the schematic diagram of initial flow field; b- the partial schematic diagram of the grid)

1.3 Analysis

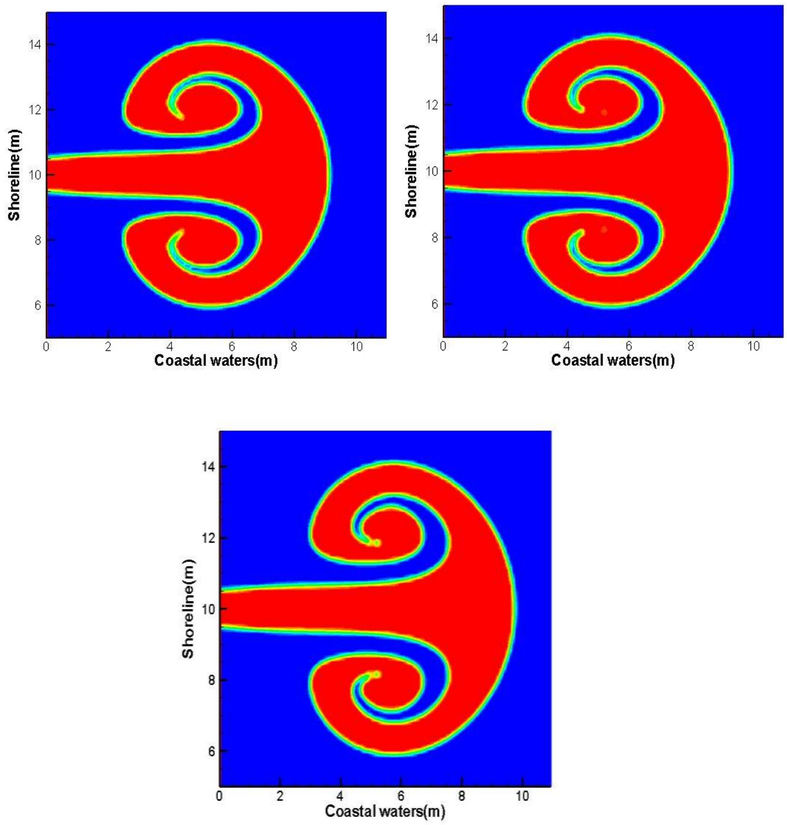
Adopt ANSYS for the post-processing of the model. Select k-epsilon model and the VOF method to simulate the running track after the oil spill.


Shoreline(m)
Coastal waters(m)
Shoreline(m)
Coastal waters(m)
Shoreline(m)
Coatal waters(m)

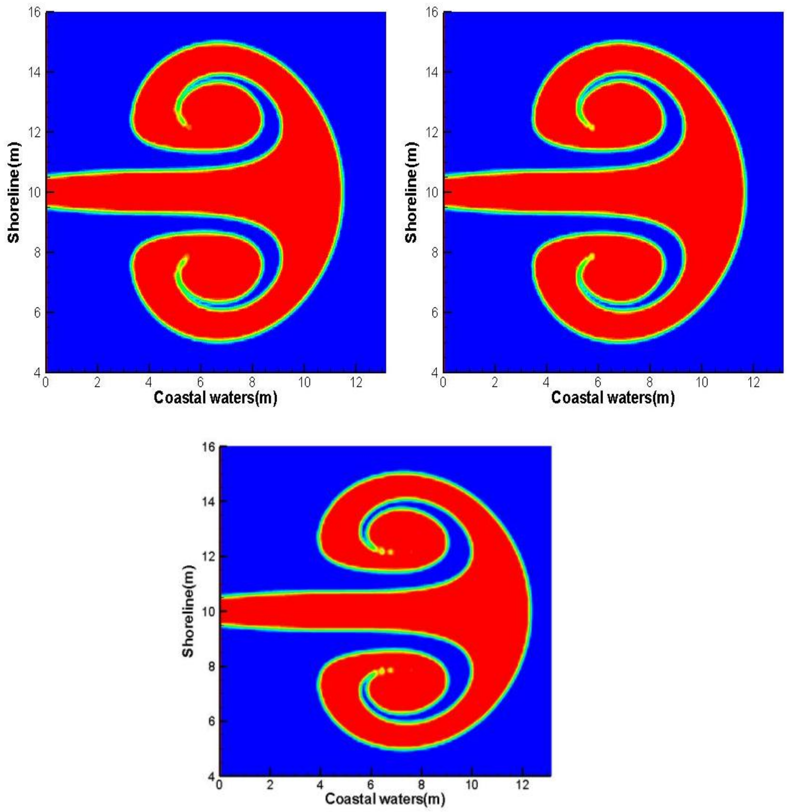
2-a


Shoreline(m)
Coastal water(m)
Shoreline(m)
Coastal waters(m)
Shoreline(m)
Coastal waters(m)

2-b



2-c



2-d

Fig 2 the range of the spill schematic

(a- the schematic of the range after 1s; b- the schematic of the range after 20s;c- the schematic of the range after 40s; d- the schematic of the range after 1min. From left to right: crude oil, 10# diesel oil, 180#fuel oil)

For the same oil, spill oil is mainly concentrated in the vicinity of the exit as a group throughout the process of spill. In the beginning 20s, the scope of the spill is rapidly expanding according to this shape.

For different kinds of oil，the basic shape of the oil spill centralized area is similar, but there still exists differences. During diffusion process, two symmetrical vortexes are forming near the axis of the outlet. The formation of vortex is mainly due to the impact of water flow to the oil and the wall, in which the affect of the water flow plays a major role. With the proliferation continues, Center of the vortex moves along the exponential curve. The density of fuel oil is greater than crude oil and diesel oil, the shape of the vortex is clearer, the same as diffusion range.

II. COMPARISONS

The main content is to compare the simulation results and which under the open water environmental conditions, including two aspects such as the diffusion region and the trajectories of oil particles (As shown in Figure 3, 4).

2.1 The differences in diffusion areas of spill

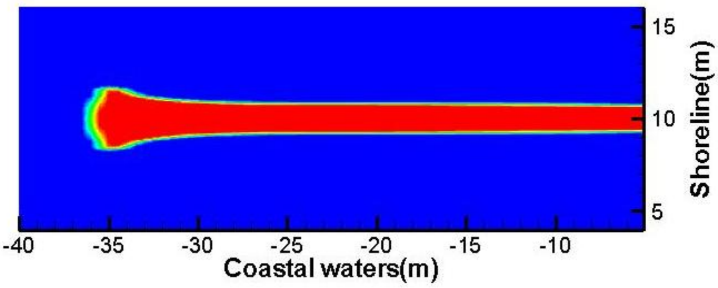
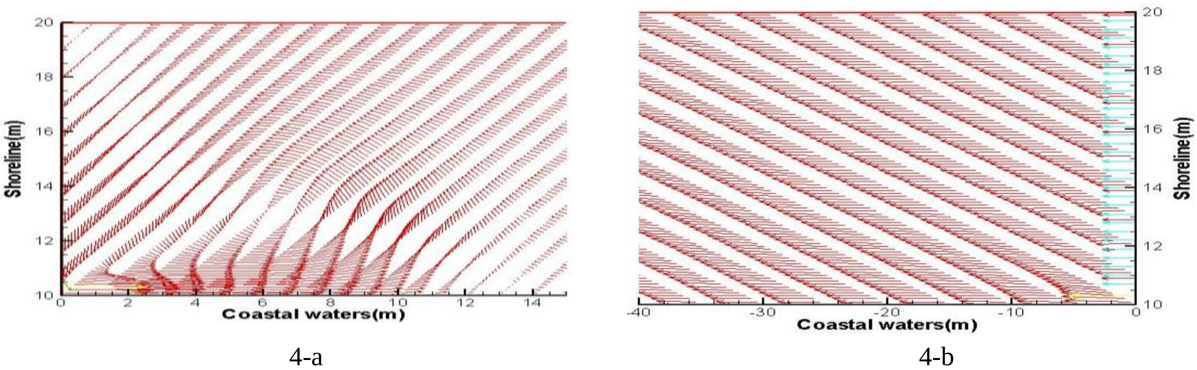


Fig 3 the oil spill extended area under two environmental conditions

As can be seen in Fig 2-d and Fig 3, oil spill occurred in open water, distributed like tape along the flow direction, only small amount of the oil accumulate in the front of the export. With the increase of oil spills time, the regional of oil distributed increases gradually and began to disperse. But the oil spill occurred near the marina waters is relatively concentrated. This is mainly affected by shoreward flow and the wall. Thus, the recycling method will be different.

2.2The differences in oil particles trace



4-a 4-b

Fig 4 the traces of oil particles under two environmental conditions

(a- the traces of oil particles under the near-shore hydrological conditions,

b- the traces of oil particles under the open water environmental conditions)

Through the analysis of Fig 4 can be known, the oil spill occurred in the area near the pier affected by the vortex. The existence of vortex makes the oil spill was reunited and limits the proliferation of regional of oil. Center of the vortex changing as time increases. But for oil spills occurred in open waters, by the impact of water, the trajectory of spill is changed, its direction tends to follow the movement of water, and gradually spread radically.

III. CONCLUSIONS

1) Compared with the oil spill occurred in open sea, the diffusion range of the oil spill occurred in the dock area is relatively small, mainly concentrated in the vicinity of the oil spill exit. The oil spill occurred in the open water has farther distance, which is determined by the speed of the water flow and oil spill. The reason for this phenomenon is the different movement state of oil spills.

2) On the motion state of oil spills, for the oil spill occurred in the dock area, vortexes will form in the diffusion process, which makes the oil to be diffused like groups. But for the oil spill occurred in the open water, it spread like ribbon along the flow direction, the range of its influence is larger. This also makes the recovery process in two cases is different.

3) In selecting recovery methods, large recycling equipments can be used in open water, such as oil spill recovery vessels. During recovery, it is possible to achieve better results recovered against the direction of flow. When recycling the oil spill occurred in the dock areas, as the complex topography, it is not appropriate to use large-scale recycling equipments. Using oil fence to control the area of the accident and recycling flexibility by a small recovery unit will be more appropriate.

4) When simulated the trajectories of spilled oil in near-shore, the bottom friction is not taken into account. Therefore, bottom friction effects on the oil spill trajectory needs further study.

Acknowledgements : The study was supported by the Welfare Technology Research Project of Zhejiang Province (No. 2011C31009), the Science and Technology Project of Zhoushan (special) (No. 2013C41012) and the Science and Technology Project of Zhoushan (No. 2012C21025).

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