

Numerical Analysis of a New Type of Oil Boom with Diversion

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Abstract. A new type of oil boom with diversion structure is put forward based on the analysis of oil blocking failure. Oil blocking effects of the new type oil boom are numerical simulated by using the CFD software Fluent. The results show that diversion structure improves the critical failure rate significantly, so do the oil blocking effects. Diversion structure play an important role in improving oil blocking effect.

Keywords-oil boom: diversion structure: volume of fluid(VOF) model: Fluent software

1. Introduction

The research of prevention and control methods of oil spilling becoming particularly urgent in recent years for the accidents occurred frequently. Many scholars do research in structure optimization of oil booms, because the first step after oil spilling accidents is to lay oil booms effectively^[1]. And algorithm improvements, structure optimization and three-dimensional visualization of oil blocking process have been studying. Zhang Zheng, Cheng Shiyong, Li Han etc. simulated the oil blocking process in VOF method by self-compiled program, and turbulence model would be introduced in the following study^[2]. Yu Guifeng, Wu Wanqing and Feng Xing^[3] studied the applicable conditions of single and twin booms by using of Fluent software, and finding that the twin-booms enhanced the relative rate of oil blocking ability($\Delta q\%$) to 2.66667 while the velocity of water is 0.2m/s. Cheng Hao found that the depth of the water should be considered while it is less than 30 times the height of booms^[4]. Wei Fang studied the shape of booms's effect on oil blocking in various sea conditions to optimize the shape of the booms^[5]. Liu Cheng, Shen Yongming and Liang Yan tracked oil-water interface with PLIC-VOF method, and the results showed that the pressure status in vertical direction before booms determined the stability of oil-water interface^[6].

A new type of oil booms is suggested which critical failure rate is more higher than classic structure. Besides, numercail experiments are simulated by using of CFD software Fluent.

2. Mathematical Model

2.1. Basic equations

Incompressible viscous fluid Navier-Stokes equations and continuity equation.

$$\rho \left(\frac{\partial u}{\partial x} + \frac{\partial v}{\partial y} \right) = S_m \quad (1)$$

$$\rho \left(\frac{\partial u}{\partial t} + u \frac{\partial u}{\partial x} + v \frac{\partial u}{\partial y} \right) = -\frac{\partial p}{\partial x} + \mu \left(\frac{\partial^2 u}{\partial x^2} + \frac{\partial^2 u}{\partial y^2} \right) + S_x \quad (2)$$

$$\rho \left(\frac{\partial v}{\partial t} + u \frac{\partial v}{\partial x} + v \frac{\partial v}{\partial y} \right) = -\frac{\partial p}{\partial y} - \rho g + \mu \left(\frac{\partial^2 v}{\partial x^2} + \frac{\partial^2 v}{\partial y^2} \right) + S_y \quad (3)$$

Standard k- ϵ model:

$$\rho \frac{dk}{dt} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right] + G_k + G_b - \rho \epsilon - Y_M \quad (4)$$

$$\rho \frac{d\varepsilon}{dt} = \frac{\partial}{\partial x_i} \left[\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial \varepsilon}{\partial x_i} \right] + C_{1\varepsilon} \frac{\varepsilon}{k} (G_k + C_{3\varepsilon} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} \quad (5)$$

G_k and G_b stand for turbulent kinetic energy created by average velocity and buoyancy respectively. Y_M stands for effect of compressible turbulent kinetic energy dissipation on the overall expansion rate. Turbulent viscosity coefficient is $\mu_t = \rho C_\mu \frac{k^2}{\varepsilon}$.

The VOF model:

$$\frac{\partial \alpha_q}{\partial t} + \frac{\partial (u \alpha_q)}{\partial x} + \frac{\partial (v \alpha_q)}{\partial y} = 0 \quad (6)$$

$$q = 1, 2 \quad (7)$$

$$\sum_{q=1}^2 \alpha_q = 1 \quad (8)$$

α_q is volume ratio of the q -phase to the unit.

2.2. Computational model

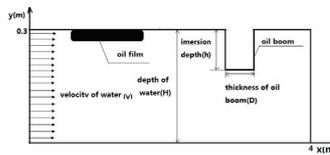


Figure 1. computational domain

The computational domain^[7] is shown in Figure 1, the numerical pool are 4 meters long, and 0.3 meter in depth. The distance from the entrance of the domain to oil boom are 2.0 meters.

h —the immersion depth, 0.07 meter. ρ_{oil} —the density of oil, 888kg/m³, ν_{oil} —the viscosity of oil, 0.7×10^{-4} m²/s, q —the quantity of oil, 0.01m³ / m. The initial distance from the oil film to the boom is 0.6 m, and the thickness of oil film is 0.1 meter. Numerical model calculations using k - ε model does not consider wind and wave factors. Velocity boundary condition for import. Pressure boundary for export. Friction-free for the free surface. Smooth and fixed for bottom wall. Set the acceleration of gravity as -9.81 m/s² in y direction.

TABLE I. COMPARISON OF NUMERICAL RESULTS IN THIS PAPER AND RELATIVE LITERATURES

Results	Critical failure rate/(m·s ⁻¹)
This paper	0.23
literature[2]	0.28
literature[3]	0.24
literature[7]	0.24
literature[8]	0.24

Comparison of numerical results in this paper and others([2],[3],[7],[8]) are shown in Table 1. The numerical simulation method taken in this paper is reasonable, effective and reliable. For the result in this paper is in good agreement with the experimental result which shown in table 1.

The differences of flow field before and after the failure of oil blocking following. And $h=0.7$ m, $D=0.1$ m, $q=0.6$ m³/m. The thickness of oil film is 0.3m initially, 1.0m away from the boom.

2.3. 1.3 Analysis of flow field

The oil film becoming thinner in downlinking, and oil blocking failure prone to take place while the film reach the bottom of boom. That is found during the numerical experiment shown in figure 2. Oil blocking failure occurred at 4.428s.

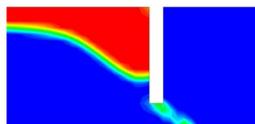


Figure 2. Profile of oil-water interface ($v=0.3$ m/s, $t=4.428$ s)

The upstream along the oil boom appeared after oil blocking failure. And vertex formed during the process. So the upstream inhibited the downlinking of the oil film, and improving oil blocking effect.

2.4. New oil boom

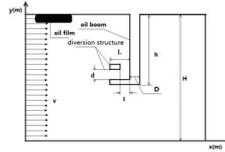


Figure 3. computational domain of new oil boom

New oil boom with diversion structure is put up based on the analysis above, and it is shown in figure 3.

3. Numerical Experiments on New Oil Boom

Parameters of numerical model are follows: $h = 0.7\text{m}$, $H = 2 \times 22\text{m}$, $L = 0.1 \& 0.2\text{m}$, $l = 0.05 \& 0.1\text{m}$, $d = 0.1\text{m}$.

Quality of oil spilling $q = 0.6\text{m}^3$. The oil film is 1.0m away from the boom initially, and the thickness is 0.3m .

Low viscosity oil parameters^[3]: $\rho_{\text{oil}} = 888\text{kg/m}^3$, $\nu_{\text{oil}} = 0.7 \times 10^{-4}\text{m}^2/\text{s}$; high-viscosity oil parameters^[4]: $\rho_{\text{oil}} = 915\text{kg/m}^3$, $\nu_{\text{oil}} = 3.6 \times 10^{-3}\text{m}^2/\text{s}$. In order to consider the effect of the depth of pool^[4], creating two value pools now (length(m) \times depth(m)): NO.1 (8×2) and NO.2 (24×22). $q = 0.6\text{m}^3/\text{m}$. The film's thickness is 0.3m , 1.0m away from the boom initially.

3.1. low-viscosity oil

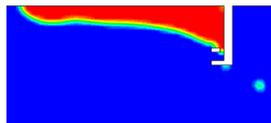


Figure 4. Profile of oil-water interface in NO.1 pool ($v = 0.51\text{m/s}$, $L = 0.1\text{m}$, $d = 0.05\text{m}$, $t = 4.72\text{s}$)

Oil blocking failure is found at 4.72s while $L = 0.1\text{m}$, $v = 0.51\text{m/s}$ which shown in figure 4. To increase L to 0.2m , and experiment results show that the downlinking of the oil is inhibited while $v = 0.61\text{m/s}$. That's the effect of the upstream from diversion, and improved the critical failure rate.

Results of NO.2 numerical pool are the same to NO.1 except the critical rate improved a lot. So the effect of the depth of the pool on oil blocking should not be ignored.

3.2. high-viscosity oil

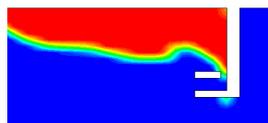


Figure 5. Profile of oil-water interface in NO.2 pool ($v = 0.58\text{m/s}$, $L = 0.2\text{m}$, $l = 0.05\text{m}$, $t = 5.6\text{s}$)

The failure occurred at 5.6s while $v = 0.6\text{m/s}$ which shown in figure 5. It can be seen that oil blocking effect is decreased due to the increasing of oil viscosity.

Results of NO.1 pool are the same to NO.2 except the critical rate decreased a bit.

It is noteworthy that the diversion has a significant impact on the shape of oil film. And the increasing of velocity of water may lead to oil blocking failure, while the film becoming more thicker on the increasing of the distance from the boom.

4. Conclusions

The conclusions based on numerical experiments of new oil booms are follows:

(1) Oil blocking failure caused by downlink of oil should be inhibited by proper diversion.

(2)Critical failure rate getting improved due to the exist of diversion structure for both low and high viscosity oil.

(3)When the depth of water is lower, the depth of the booms stopped the oil effect is not negligible.

(4)Those parameters like the diversion length(L), thickness(d), gap(l), and the boom's height(h) need further research to confirm its effects on oil blocking effect.

5. References

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