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Risk assessment for the benzene leakage from a sunken ship

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1. Introduction

East-north Asia (Korea, Japan, Taiwan and China) is best known for a hot economic zone all over the world. The rapidly developing China is the main source to facilitate bilateral business activities among these four countries. Moreover, with a China's increasing demand for natural resources, such as oil and gas, the traffic of marine transportation seems to be swelled in this area. This move brings the contingent maritime accident, especially the case of cargo ships loading oil or gas. In recent years, there has been a growing concern over an environmental contamination caused by oil or gas spills. Doctor Kuroda in 2006 reported that over 100 tons, 1,200 and 150,000 wrecks are around Japan and the United State of America, respectively (Fig.1.).

Among the many wrecks, the writer paid attention to the chemical tanker-Samho Brother. On the morning of 10th October 2005, the Korean chemical tanker, Samho Brother, capsized off the coast of Taoyuan after collision with another ship under the harsh weather conditions. In spite of the military actions to burn a chemical material, that is benzene, it was reported that the vessel had already sunk to the ocean floor having 3,100 tons of benzene. Sooner or later, this benzene might start to leak and it causes casualties to the marine ecosystem. This paper is designed for predicting the potential risk to the aquatic ecosystem, numerically.

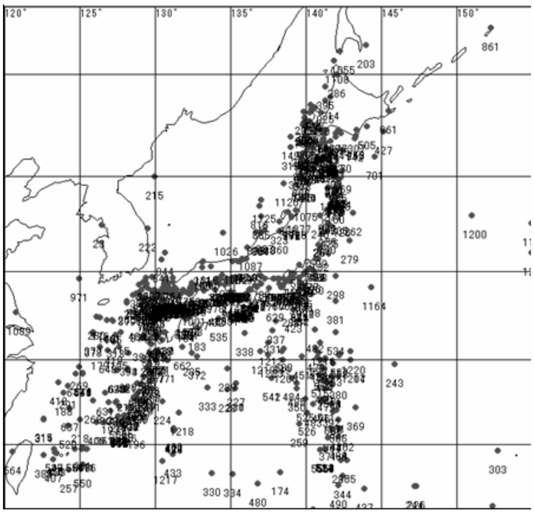

Fig.1. Hazard map of wrecks around Japan [1]

Notes: 1. Red circle: Coordinates of wreck

2. Black number: Hazard ranking

2. Numerical model

2.1. MEC Ocean Model [2]

For the numerical simulations, 3D numerical model is necessary, and the MEC Ocean Model is chosen. Ocean currents with the MEC Ocean Model are solved by using hydrostatic assumption, which approximates the NS equation with Boussinesq approximation and the continuity equation.

2.2. Benzene model

Benzene is a known carcinogen. Benzene is so toxic that the amount of dissolved benzene in water should be calculated (Fig.2.). In the present model, so as to calculate the dissolved benzene in water, the liquid and dissolved benzene are imposed in the mass transport equation

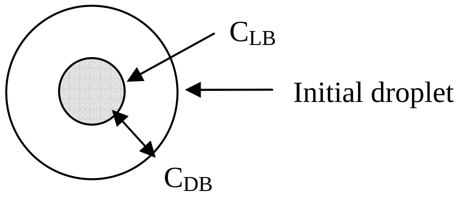

Fig.2. Model of the benzene boundary-layer around a droplet

$$\frac{\partial C_{LB\&DB}}{\partial t}+\frac{\partial (uC_{LB\&DB})}{\partial x}+\frac{\partial (vC_{LB\&DB})}{\partial y}+\frac{\partial (wC_{LB\&DB})}{\partial z}= \qquad (1)$$

$$\frac{\partial}{\partial x}\left(D_x\frac{\partial C_{LB\&DB}}{\partial x}\right)+\frac{\partial}{\partial y}\left(D_y\frac{\partial C_{LB\&DB}}{\partial y}\right)+\frac{\partial}{\partial z}\left(D_z\frac{\partial C_{LB\&DB}}{\partial z}\right)+\sum S$$

Ranz-marshall equation and buoyant velocity are imposed at Eq. 1. After the benzene reach to the surface, the dissolved benzene in water starts to evaporate.

$$\frac{1}{K_{OL}}=\frac{1}{K_L}+\frac{R\bullet T}{H\bullet K_G} \qquad (2)$$

$$N=K_{OL}\bullet\left(C_{DB}-\frac{p}{H}\right)$$

Equ. 2 is used at the surface boundary condition in Eq. 1.

2.3. Model verification

Rye et al. (1996) and Rye and Brandvik (1997) [3] and [4] reported two field experiments carried out in the North Sea to simulate the oil release from a pipeline rupture as well as an oil well blowout. These are the first and only known field experiments for oil jet/plumes. There are no observation data of subsurface benzene spills. Comparing with this result [3] is the only way to verify benzene model. By not considering dissolution rate of oil in water, time to reach water surface and position of oil jet/plume were evaluated with the benzene model. According to the observation data, it took 10 minutes for an initial droplet to impinge on the sea surface and with current velocities, twelve and half minutes after leaking was taken that oil/jet plume was placed 40-50 meters far from the origin in the southeast direction. The detailed conditions are described in Yapa [5]. For this model verification, the 10 meters of the grid size and 0.004 meters of an initial droplet size are adopted. Using the present model, 618 seconds are taken to rise to the sea surface. The results of the observations and Yapa are 10 and 10.6 minutes, respectively. The result of this present model is well-matched. Comparing with the position of oil, the high concentration of oil is placed from 40 to 70 meters. The result of field measurement is 50 meters. Therefore, the present model and observation data are in good agreement (Fig.3).

3. Simulation of benzene spill behavior

Simulation was done with some scenarios. The buoyant velocity and dissolution rate are the same manner caused by an initial droplet size. To determine the buoyant velocity, dissolution rate, and droplet size, the critical factor is an initial droplet size (Fig. 4.)

The total volume of benzene released was 864 tons at a depth of 75 m below the water surface. Fig.5. shows concentration of the dissolved benzene after 74 and 96 hours. Concentrations of the liquid and dissolved benzene in water are influenced by the total amount of the leaked benzene.

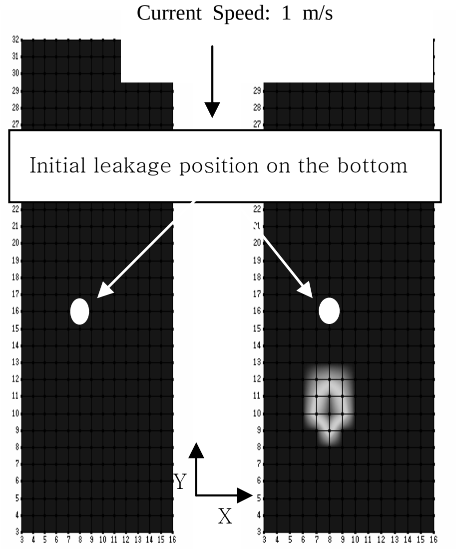

Fig.3. Horizontal distributions before and 13 minutes after the benzene spills

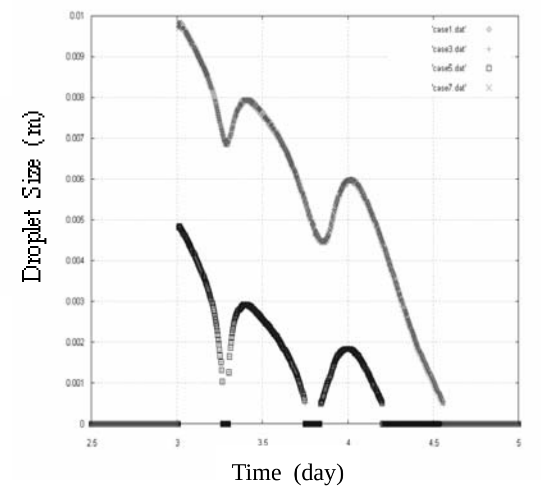

Fig.4. Time history profile of a droplet size in an accident position at 3 m depth

4. Risk assessment

Despite the diversity of approaches, in general seven steps can be identified addressing the key questions in an Ecological Risk Assessment (ERA): Problem Formulation, Hazard Identification, Release Assessment, Exposure Assessment, Consequence or Effect Assessment, Risk Characterization and Estimation and Risk Evaluation. [6]

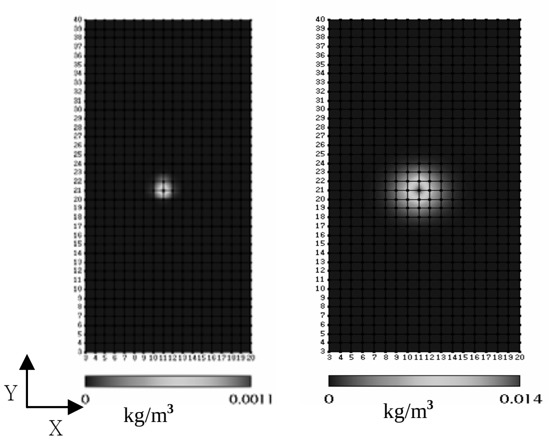

Fig. 5. Horizontal distributions of concentrations of the dissolved benzene at 3 m depth

The PEC values are evaluated by benzene model. As to the PNEC value, depending on an assessment factor of 100 or 1000, the results are changed significantly (Fig. 5. and Fig. 6). For the environment, various NOEC and LC50 values were gained from test results The lowest chronic toxicity result for daphnia [21d-NOEC (reproduction) of *Daphnia magna* (1.0 mg/l)] was used with an assessment factor of 100 to determine the PNEC. Thus, the PNEC of the benzene is 0.01 mg/l. In the case of determining the PNEC value of the acute toxicity for daphnia [24hr-EC50 of *Daphnia magna* (8.0 mg/l)] with the same process as the long-term PNEC evaluation, it is 0.08 mg/l. In the same way, different from an assessment factor of 1000 in order to perform more sensitive tests, the PNEC values of the chronic and acute toxicity for daphnia are 0.001mg/l (21d) and 0.008mg/l (24hr), respectively. It will be showed that how much effect is caused by this gap. PEC incorporates the results of the release and the exposure assessment step while PNEC incorporates the results of the consequence assessment step. Risk characterization involves the calculation of a quotient- the PEC/PNEC ratio. If the PEC/PNEC is less than 1, the substance of concern is considered to present no risk to the environment and there is no need for further testing or risk reduction measures.

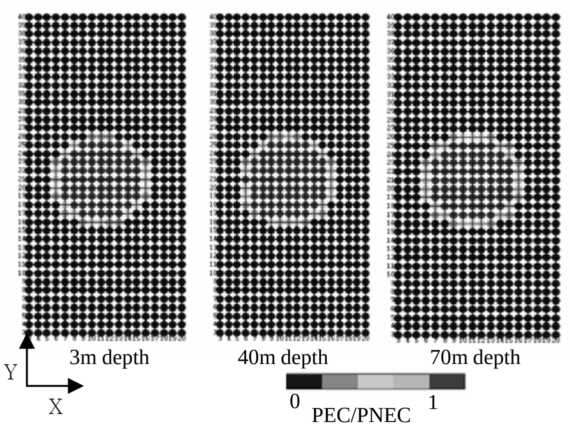

Fig. 5. Horizontal distributions of the risk value with an assessment factor of 100, 24 hours after benzene spill; Leaking rate: 10m^3/s, Droplet size: 0.01m

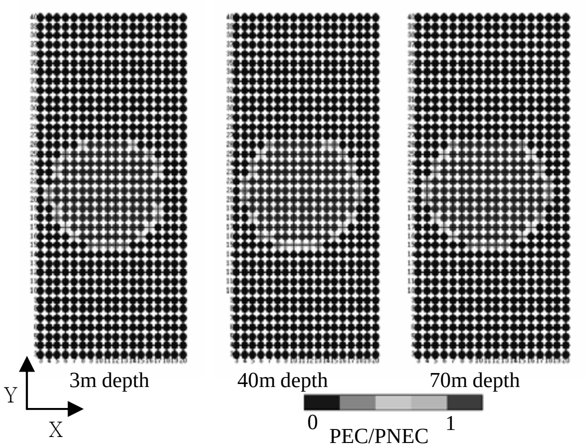

Fig. 6. Horizontal distributions of the risk value with an assessment factor of 1000, 24 hours after benzene spill; Leaking rate: 10m^3/s, Droplet size: 0.01m

If the ratio cannot be reduced to below 1 by refinement of the ration, risk reduction measures are necessary.

5. Conclusion

In conclusion, in order to evaultate risk assessment, the benzene model was developled. Comparing with observation data the subsurface oil/jet plume, model verification was in harmony. Dissoluition rate, buoyant velocity, and Reynolds number was affected by an intial droplet size. And, Concentratios of the liquid and dissolved benzene are influenced on the total amount of the leaked benzene. A risk value is dependent on the total amount of leaked benzene. Needless to say, the plenty of the leaked benzene will contaminate a wider area. On the other hand, it might be interpreted that a little amountof spilled benzene mean below the risk acceptance level. After all of the liquid benzene dissolve in water, the dissolved benezene migrates along current field. If even al little amount of benzene reaches the coastal area, the casualties would be tremendous.

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