Numerical Study on the Far Field Diffusion of Ocean Dumping for Liquid Waste

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ABSTRACT

The far field phase diffusion of discharging liquid waste into the sea water was investigated in the present study. The diffusion in the far field phase can basically be simulated by the three dimensional turbulent diffusion equations. The moment method is used to integrate the governing equation. A numerical model is developed to solve these moment diffusion equations. The numerical model prediction result is shown in good agreement with the field measurement of Ball and Reynolds. The effects of the current speed and ocean diffusive characteristics on the diffusion of liquid waste concentration are calculated numerically. The calculated results indicate that ocean diffusivity has a strong effect on the diffusion and spread of the liquid waste cloud. A large current speed is favorable to the transport and spread of the liquid waste cloud. The maximum concentration of the liquid waste cloud significantly decays in a few hours after discharging, and the decay rate approaches a constant value after a few decades of hours.

KEY WORDS: Ocean dumping, liquid waste, far field diffusion

INTRODUCTION

Taiwan is surrounded by the sea. Ocean dumping is considered as one of the feasible and economic ways for disposal of industrial liquid waste. The pollution problems of ocean dumping of liquid waste become important since the environmental protection consciousness arises. After dumping the liquid waste in the ocean, it is mixed with the entrained ambient sea water. The mixing process in the ship wake is generally divided into three time stages: (1) the initial dilution phase, (2) the near field phase, and (3) the far field phase. When liquid waste is discharged into the sea water, the initial dilution phase occurs immediately. The liquid waste mixing with the sea water is due to the turbulent wake of ship. A short time (order of minutes) later, the far field phase succeeds. The mixed liquid waste begins to disperse by the ambient currents and sea water diffusion. The diffusion phenomenon in the far field phase can basically be simulated by the three dimensional turbulent diffusion equation.

There are some studies on the mixing and diffusion of ocean dumping in the ship wake. For the near field phase, Tromp (1976) employed the dimensional analysis method to analyze the model and full scale results. The results become the formula basis of IMO (International Maritime Organization) which was used to predict the dilution of liquid wastes for ocean dumping in a few minutes. Lewis (1983) derived a theoretical relation for the short term dilution of liquid waste in the wake of ships. For the far field phase, Ball and Reynolds (1976) made in-situ measurement of the dispersion of liquid waste from a moving barge. In fact, it is necessary to have a simple and quick method to predict the mixing and diffusion of the liquid waste in the far field phase. To achieve this aim, a simple numerical model is developed in the present study which is able to predict the diffusion of the liquid waste for the far field phase in the ocean. The model prediction can offer diffusion information for the environmental evaluation of the ocean pollution.

MATHEMATICAL MODEL FORMULATION

The diffusion of the liquid waste in the ocean basically is a three dimensional phenomenon. The governing equation is derived by employing the mass conservation law and Fick’s law.

\[ \frac{\partial C}{\partial t} + U \frac{\partial C}{\partial x} + V \frac{\partial C}{\partial y} = K_x \frac{\partial^2 C}{\partial x^2} + K_y \frac{\partial^2 C}{\partial y^2} + K_z \frac{\partial^2 C}{\partial z^2} \]  (1)

Here \( C \) is the liquid waste concentration; \( U, V \) are longitudinal and lateral velocities in \( x \) and \( y \) directions, respectively. We neglect the vertical velocity, \( W \) in \( z \) direction, since it is usually very small as compared with the horizontal velocities, \( U \) and \( V \). \( K_x, K_y \) and \( K_z \) are turbulent diffusion coefficients in \( x \), \( y \), and \( z \) directions, respectively.

We apply the moment method to solve this equation. Some assumptions are made as follows: (1) the sea water depth is constant, (2) the flow field is homogeneous, (3) the flow rate flux of liquid waste is zero on the water surface and at the sea bottom, (4) the sea water surface area is very large. The moment operation on the concentration is defined as:

\[ C_a(z,t) = \int_{-\infty}^{\infty} \int_{-\infty}^{\infty} C(x,y,z,t) x' y' dx dy \]  (2)