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Oil Spill Spreading of Continuous Spills

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INTRODUCTION

Since oil spills discharged by offshore oil production platforms, ship accidents etc., cause many environmental problems, forecasts of drift and spreading of the spilled oil are requested as a basis for oil spill combat management. The numerical approach has been thought as the most effective methods of such forecast. In general, the oil spill model takes into account the trajectory and fate of oil, including drifting, spreading, evaporation, dispersion, emulsification, shoreline stranding, and so on. Among those processes, the spreading process is concerned in this study, in particular for dealing of time interval dependancy of the spreading in continuous spills.

There exist various models describing this spreading, but Fay's three regime spreading theory given as a function of the physical properties of the oil, its volume, and the elapsed time, is by far the most widely used:

- the gravity-inertial stage $$R(t) = K_i(g\delta V t^2)^{1/4} \quad (1)$$
- the gravity-viscous stage $$R(t) = K_v(g\delta V^2 t^{3/2} \nu_w^{-1/2})^{1/6} \quad (2)$$
- the surface tension-viscous force stage $$R(t) = K_t[\sigma^2 t^3/(\rho^2 \nu_w)]^{1/4} \quad (3)$$

where,

- R : radius of the oil slick
- V : total volume of oil
- g : gravity acceleration
- ρ : density of water
- ν_w : kinematic viscosity of water
- σ : interfacial tension
- δ : ratio of density difference between water and oil to density of water

The non-dimensional constants, K_i, K_v and K_t are usually given 1.14, 1.45 and 2.30, respectively. The slick radius is supposed to be defined as shown in Fig. 1 so as to yield the total oil volume, V when the area surrounded by radius, R is multiplied with the height at a slick center, h_c as follows.

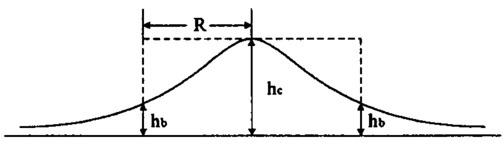

Fig 1. Definition sketch of oil slick radius.

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$$V = \pi R^2 h_c \tag{4}$$

The slick height may be expressed to satisfy the volume conservation decreasing with the distance from a slick center as

$$h = h_c \exp\left(-\frac{r^2}{R^2}\right) \tag{5}$$

BASIC CONCEPT

In most oil drift models, the spreading of an instantaneous spill is simulated by using Eqs. (1-3) and continuous spills are represented by subsequent instantaneous spills, each with a volume ΔV corresponding to the product of the spill rate and the chosen model time interval. However, the resulting radius of oil slick spreading is sensitive to the chosen model time interval. From this reason, the other schemes has been proposed by Motora(1967), Arai et al.(1994), Yoon et al.(1997) etc.. In this study, we propose a new approach under hypothesis that the spreading process of oil spill may be explained as the function of slick height predetermined at each point rather than the volume amount. The diffusion coefficient, K is assumed to be determined as

$$K = \alpha h^{\beta} \tag{6}$$

The empirical parameters, α and β are tuned so that the computed radius follows the consequent formulae for the radius given in Eqs. (1-3) no matter what volume is given for numerical simulation. As the best tuned, the values of α and β determined are 8.0 and 0.15, respectively.

NUMERICAL APPROACH

A random-walk concept is used to estimate the spreading of oil droplets, so that changes occurring in individual oil droplets are followed. Provided that the droplet's size is sufficiently small, we can treat oil droplets as point particles. In this approach, new positions of point particles are approximated by

$$x_k(t+\Delta t) = x_k(t) + \eta_x \tag{7}$$

$$y_k(t+\Delta t) = y_k(t) + \eta_y \tag{8}$$

where, η_x and η_y is for the random walk in the x, y-direction. The diffusion operator with an impulse as initial condition has a solution which is the probability density function of a Gaussian distribution with zero mean and a variance $2K\Delta t$. Therefore, the diffusive transport of droplet elements is simulated by the random walk displacement drawn from a Gaussian distribution. To apply random walk in numerical model means that the total mass of spilled oil is broken down into a number of tracer elements whose trajectories describe the transport phenomenon. In the present model, the computed slick radius are determined as follows:

$$R_c = \sqrt{\frac{a}{\pi}\sum_{i=1}^{n} H_i} \qquad \text{where} \quad \begin{array}{ll} H_i = 1 & \text{for } h_i > h_b \\ H_i = 0 & \text{for } h_i < h_b \end{array} \tag{9}$$

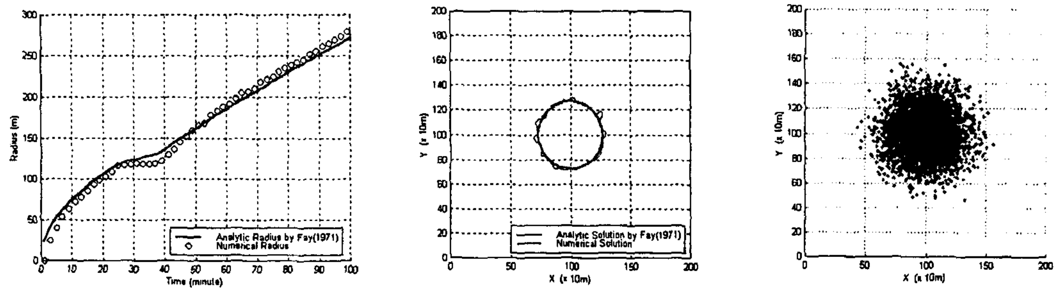
where a is the grid cell area, n the total number of grid cells and h_b the height at $r=R$ given as h_c/e from Eq. (5) where $e \approx 2.71828$.

RESULTS

This model was simulated for the open sea slick. Density of oil, surface tension, and time interval are 0.95 t/m^3, 30 dyne/cm, 60 sec, respectively. Figure 2 shows results for the volume of 100tons. In that case, the grid spacing and run time are 10m and 100minutes, respectively. Figure 2a represents the temporal variation of radii by the present model compared with those by Fay(1971)'s consequent three stages. The region for $h \geq h_b$ after 100minutes is illustrated in Fig. 2b and compared with Fay's radius circle. The positions of oil particles by random walking are illustrated in Fig. 2c. Figs. 3 and 4 show the results of volume 1000 and 10000tons, respectively. For the case of 1000tons, the grid spacing and run time are 10m and 300minutes, respectively and for the case of 10000tons, grid spacing of 50m was used and the computing was run for 250 minutes. The model results appears to be very close to Fay's radii for the volume less than about 5000tons, but for the more than 5000tons, the results become deviated from the Fay's. In the Lagrangian random-walk model, the droplet elements of 10000 were used for all cases.

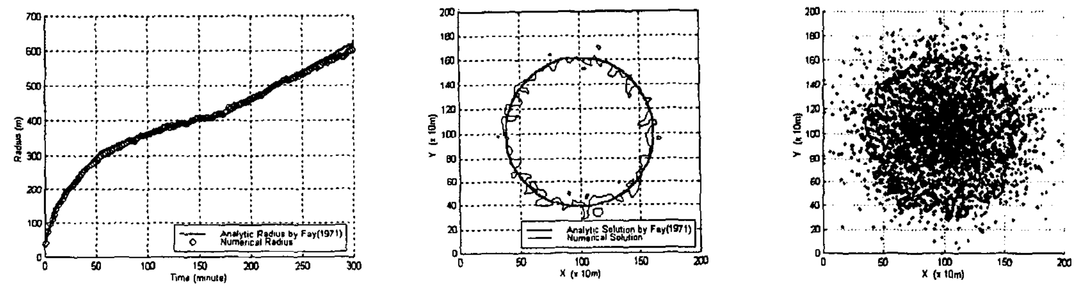
CONCLUSION

A new treatment of the oil spill spreading has been made and the numerical solutions has showed to accord with Fay's solutions without alteration of time interval. In the present approach, the diffusion coefficient has been assumed to have something to do with oil slick height instead of the volume spilled so that the resulting radius of the spreading of continuous spills does not vary according to the time interval. For comparison with Fay's spreadings, the model has been accomplished here only for instantaneous spills and appeared to be applicable to a range of 100~5000tons. Further work is needed to more precisely define the limits of validity.



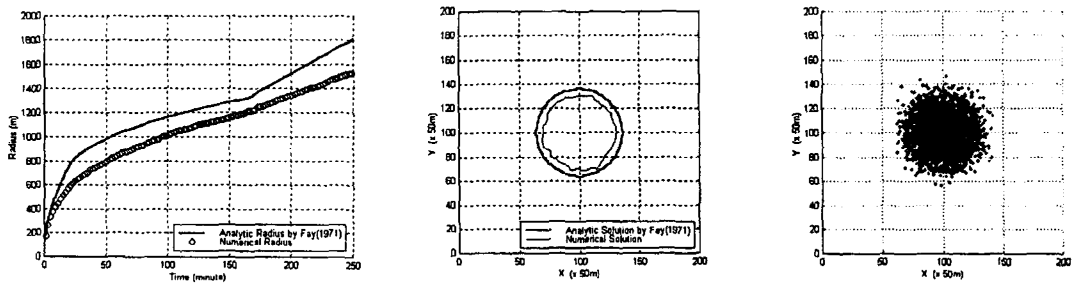
(a) (b) (c)

Fig. 2 For volume 100ton, (a) temporal variation of radii by the present model and Fay's formulae (b) comparison between radius by the present model and Fay's radius circle and (c) positions of oil particles with the region for $h \geq h_b$.



(a) (b) (c)

Fig. 3 For volume 1000ton, (a) temporal variation of radii by the present model and Fay's formulae (b) comparison between radius by the present model and Fay's radius circle and (c) positions of oil particles with the region for $h \geq h_b$.



(a) (b) (c)

Fig. 4 For volume 10000ton, (a) temporal variation of radii by the present model and Fay's formulae (b) comparison between radius by the present model and Fay's radius circle and (c) positions of oil particles with the region for $h \geq h_b$.

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