RESEARCH ARTICLES

J. Sci. Soc. Thailand, 7 (1981) 136-146

WASTE DISPERSION IN THE UPPER GULF OF THAILAND

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(Received 2 November 1981)

Abstract

Recent increases in the industrial development around the periphery of the Upper Gulf of Thailand have created considerable concern about the capability of its coastal waters to act as intermediate zones for receiving waste effluents and subsequent dispersion of material in offshore waters. The dynamics of the dispersion and diffusion mechanisms in the upper gulf are complex, and very few field studies of these processes have been carried out.

In view of the importance of coastal environmental control of the Upper Gulf, this paper presents theoretical analysis of waste dispersion there. Throughout use is made of physical properties of wastewater and flow parameters in the gulf derived from various coastal studies. These analytical results provide a background for useful recommendations regarding dumping processes in the Upper Gulf

Introduction

Maintenance and improvement of environmental quality are today of major concern to the public. Water quality, particularly in estuaries and coastal seas, has received a great deal of attention. Discharges of industrial wastes and domestic sewage into river, estuarine and coastal waters will affect water quality, depending on discharge loading and waste characteristics, diffusion and dispersion processes, etc. In order to understand the effect of waste disposal, it is indispensable to understand the distribution patterns as well as the interaction processes of various constituents in the discharged wastes.

The constituents in discharged wastes can be classified as conservative and non-conservative substances. Conservative substances are those which preserve their properties during transportation or for which the rates of decay are very low, e.g., some forms of heavy metals. On the other hand, non-conservative substances are those which change their forms during transportation, e.g., organic materials, some forms of nitrogen, etc. Since discharged wastes from various sources contain different constituents with different characteristics, it is necessary to use some indicators for an assessment of their strength and harmfulness. Among these indicators one has the biological oxygen demand (BOD) and chemical oxygen demand (COD), which indicate the amount of oxygen required to stabilize biologically and chemically organic material in the wastes.

Diffusion and dispersion are important processes which govern transportation of the discharged wastes. Diffusion has been defined as the transport associated with molecular and turbulent actions while dispersion has been defined as the transport associated with the variation of velocity across flow sections (Tamai[1]). Factors affecting diffusion and dispersion processes include differences in substance concentrations and water density, flow current and wave action, variation in shear velocities, turbulence, etc.

For a channel with a small cross-sectional area, the flow component and the lateral variation in the substance concentration are small and can be neglected. In this case the dispersion process can be considered to be one-dimensional. For large water bodies such as a coastal sea, the flow components as well as the substance dispersion vary in all directions, and cause more rapid decline of the substance concentration at the discharge point. Thus a coastal sea has been found to have greater capability for receiving waste effluents.

Recent increases in the industrial development around the periphery of the Upper Gulf of Thailand have created considerable concern about the capability of its coastal waters to act as intermediate zones for receiving waste effluents and subsequent dispersion of material in offshore waters. This paper presents theoretical analysis of waste dispersion in the Upper Gulf Throughout use is made of physical properties of wastewater and flow parameters in the gulf derived from various coastal studies.

Theoretical Considerations :

Two-Dimensional Dispersion from a Line Source

The governing equation for two-dimensional dispersion in an area with uniform water depth, constant flow velocity and constant dispersion coefficients can be written as (Tracor[2])

$$\frac{\partial c}{\partial t} + U\frac{\partial c}{\partial x} + V\frac{\partial c}{\partial y} - D_x\frac{\partial^2 c}{\partial x^2} - D_y\frac{\partial^2 c}{\partial y^2} + Kc = 0, \tag{1}$$

where c is the substance concentration,

U and V are the flow velocities in the x and y-directions,

D_x and D_y are the dispersion coefficients in the x and y-directions,

K is the decaying rate of the substance.

For an instantaneous source of strength M/H (total mass per unit depth) discharged from a point source at location (x_o, y_o) at time t = 0, the substance concentration at any point (x,y) can be expressed as (Christodoulou *et al*[3])

$$c(x,y,t) = \frac{M/H}{4\pi\sqrt{D_x.D_y.t}} \exp\{-\frac{(x-x_o-Ut)^2}{4D_x.t} - \frac{(y-y_o-Vt)^2}{4D_y.t} - Kt\}. \tag{2}$$

Next, consider a line source parallel to the y-axis, between the locations (x_o, y_{o1}) and (x_o, y_{o2}), Fig. (1a). Assume that the total mass M is distributed uniformly along the discharging length L and throughout the uniform water depth H. The strength of the instantaneous line source can be expressed as m = M/LH (total mass per unit length per unit depth).

The increment concentration in the dc due to a small source dm = m dy_o, discharged at (x_o, y_o), can be expressed as

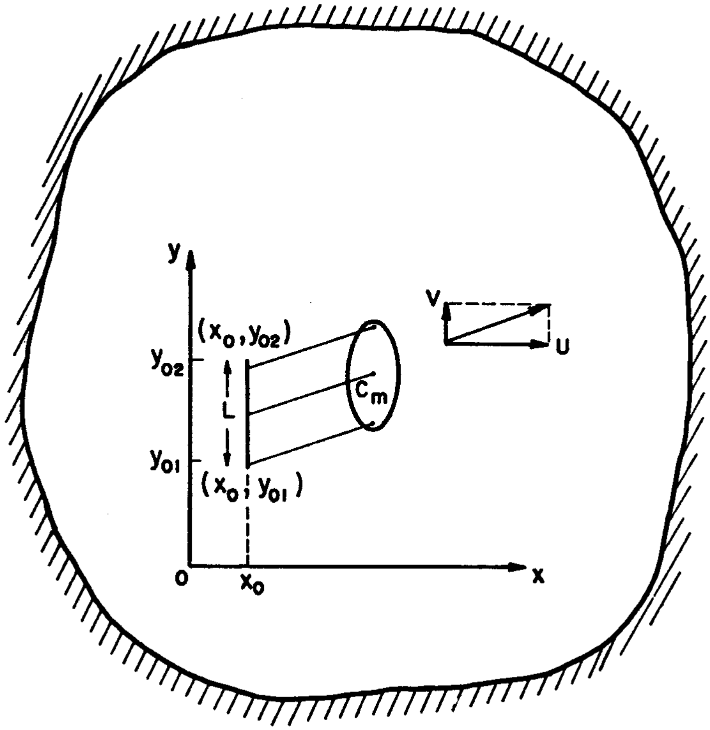
$$dc = \frac{m\,dy_o}{4\pi\sqrt{D_x.D_y.t}} \exp\{-\frac{(x-x_o-Ut)^2}{4D_x.t} - \frac{(y-y_o-Vt)^2}{4D_y.t} - Kt\}. \tag{3}$$

The total concentration c(x,y,t) is obtained by integrating for the whole source, i.e.,

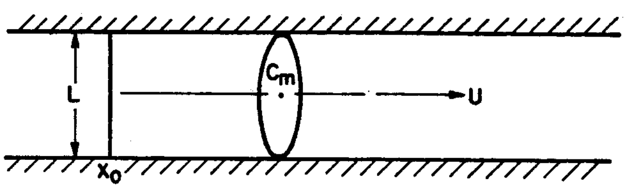
$$c(x,y,t) = \int_{y_{o1}}^{y_{o2}} \frac{m}{4\pi\sqrt{D_x.D_y.t}} \exp\{-\frac{(x-x_o-Ut)^2}{4D_x.t} - \frac{(y-y_o-Vt)^2}{4D_y t} - Kt\}\, dy_o \tag{4}$$

which yields

$$c(x,y,t) = \frac{m}{4\sqrt{\pi D_x.t}} \exp\{-\frac{(x-x_o-Ut)}{4D_x\, t} - Kt\}.\{\text{erf}(\frac{y-y_{o1}-Vt}{\sqrt{4\,D_y t}}) - \text{erf}(\frac{y-y_{o2}-Vt}{\sqrt{4\,D_y t}})\} \tag{5}$$



(a) Two – Dimensional Dispersion



(b) One – Dimensional Dispersion

Fig. 1 Dispersion from an Instantaneous Line Source (Plan View)

$$\text{with } \operatorname{erf}(\alpha) = \frac{2}{\sqrt{\pi}}\int_0^{\alpha} e^{-z^2}\, dz. \tag{6}$$

Note that erf (0) = 0 and erf (∞) = 1 .

Eq. (5) can be used to compute the distribution pattern of a substance when the flow velocity, discharge loading, and dispersion coefficient are known.

At the center of the dispersion cloud, i.e., at location (x', y'), where $x' = x_o + Ut$ and $y' = 0.5\,(y_{o1} + y_{o2}) + Vt$, the substance concentration has a mximum. The peak concentration, c_m, is given by

$$c_m = \frac{m}{4\sqrt{\pi D_x . t}} \exp(-Kt)\{\operatorname{erf}(\frac{y_{o2}-y_{o1}}{4\sqrt{D_y t}}) - \operatorname{erf}(\frac{y_{o1}-y_{o2}}{4\sqrt{D_y t}})\} . \tag{7}$$

Using the property $\operatorname{erf}(-\alpha) = -\operatorname{erf}(\alpha)$, and replacing m by $\frac{M}{L.H}$, Eq. (7) reduces to

$$c_m = c_o \exp(-Kt) \operatorname{erf}\{\frac{L}{4\sqrt{D_y t}}\} \tag{8}$$

$$\text{with} \quad c_o = \frac{M}{LH\sqrt{4\pi D_x t}} \tag{9}$$

For specified values of the total discharge loading M, the water depth H, the dispersion coefficients D_x and D_y, the decaying rate K, and the length of the discharge line L, the peak concentration c_m at any time t after instantaneous dumping can be computed.

One-Dimensional Dispersion from a Line Source

For one-dimensional dispersion (Fig. 1.b), Eq. (1) can be simplified by setting V and D_y to zero:

$$\frac{\partial c}{\partial t} + U\frac{\partial c}{\partial x} - D_x\frac{\partial^2 c}{\partial x^2} + Kc = 0 . \tag{10}$$

The one-dimensional line source will be assumed to satisfy the following initial and boundary conditions:

Initial condition: for a finite source of waste load M being instantaneously dumped into the sea at time t = 0,

$$c(x,0) = \frac{M}{LH}\delta(x) , \qquad (11)$$

where $\delta(x)$ = delta function with the property of

$$\int_{\infty}^{\infty} \delta(x)\, dx = 1 . \qquad (12)$$

Boundary conditions: at long distance from the dumping area, the concentration is negligible:

$$c(\pm\infty, t) = 0 \text{ for } t \geq 0 . \qquad (13)$$

The solution of this one-dimensional dispersion from a line source is

$$c = c_o \exp\{-\frac{(x-Ut)^2}{4 D_x t} - Kt\} , \qquad (14)$$

where c_o is given by Eq. (9).

The peak concentration c_m is the concentration at the distance $x' = Ut$ from the dumping point. Eq. (14) yields

$$c_m = c_o \exp(-Kt) . \qquad (15)$$

Comparing Eqs. (8) and (15) it can be seen that the only difference is the term $\mathrm{erf}(\frac{L}{4\sqrt{D_y t}})$ which enters into the solution of the two-dimensional equation. This factor represents the reduction in the value of c_m of the one-dimensional solution due to lateral dispersion.

Application to the Upper Gulf of Thailand

The Upper Gulf of Thailand (Fig. 2) has an area of approximately 100×100 km^2 and average depths of 10 and 15 m for the upper half and the entire gulf, respectively. A depth of 10 m will be used in this study.

In order to apply the analytical solution to the Upper Gulf of Thailand, one must obtain appropriate values for the various parameters. These include the flow velocities U and V, the dispersion coefficients D_x and D_y, and the decaying rate K. Moreover, in order to specify initial conditions, Eq. (11), one requires data on waste discharging in terms of total waste load M, line length of dumping L and water depth H.

The physical condition in the upper gulf of Thailand has been studied by Vongvisessomjai *et al.*[4] It was found that the predominant currents in the upper gulf of Thailand are tidal currents which oscillate back and forth with almost zero net drift, small wind driven currents confined to a thin layer at the surface, and fresh water currents which influence only the vicinity of the river mouths. Vongvisessomjai *et al.*[5] have determined the diffusion coefficients in the upper gulf of Thailand from measured current data. They found that the diffusion coefficients in the x and y directions have almost the same magnitudes of about 3 m^2/s.

In this study the biological oxygen demand (BOD) will be used as a pollution indicator. Various factors have been found to affect the decaying rate of BOD; they include temperature, salinity, waste characteristics, etc. At present very few attempts have been made to determine the dacaying rate of BOD in the upper gulf of Thailand. In this study, only the decrease of BOD due to the dilution process caused by turbulent dispersion will be considered.

For an instantaneous loading M = 10,000 kg, water depth H = 10 m, and dispersion coefficient $D_x = 3$ m^2/s, the values of peak concentrations at any time t during one-dimensional dispersion have been plotted (Fig. 3), for different values of length L.

In order to evaluate the effect of lateral dispersion, the term $\mathrm{erf}\left(\frac{L}{4\sqrt{D_y t}}\right)$ has been plotted against time t for some values of L (Fig. 4). The peak concentrations during two-dimensional dispersion are then obtained by multiplying the peak values during one-dimensional dispersion (Fig. 3) by this reduction factor. The obtained values are shown in Fig. 5.

Discussion

An analysis of one-dimensional dispersion shows that the peak concentration varies inversely with the cross-sectional area of the channel and the square root of the dispersion coefficient and time.

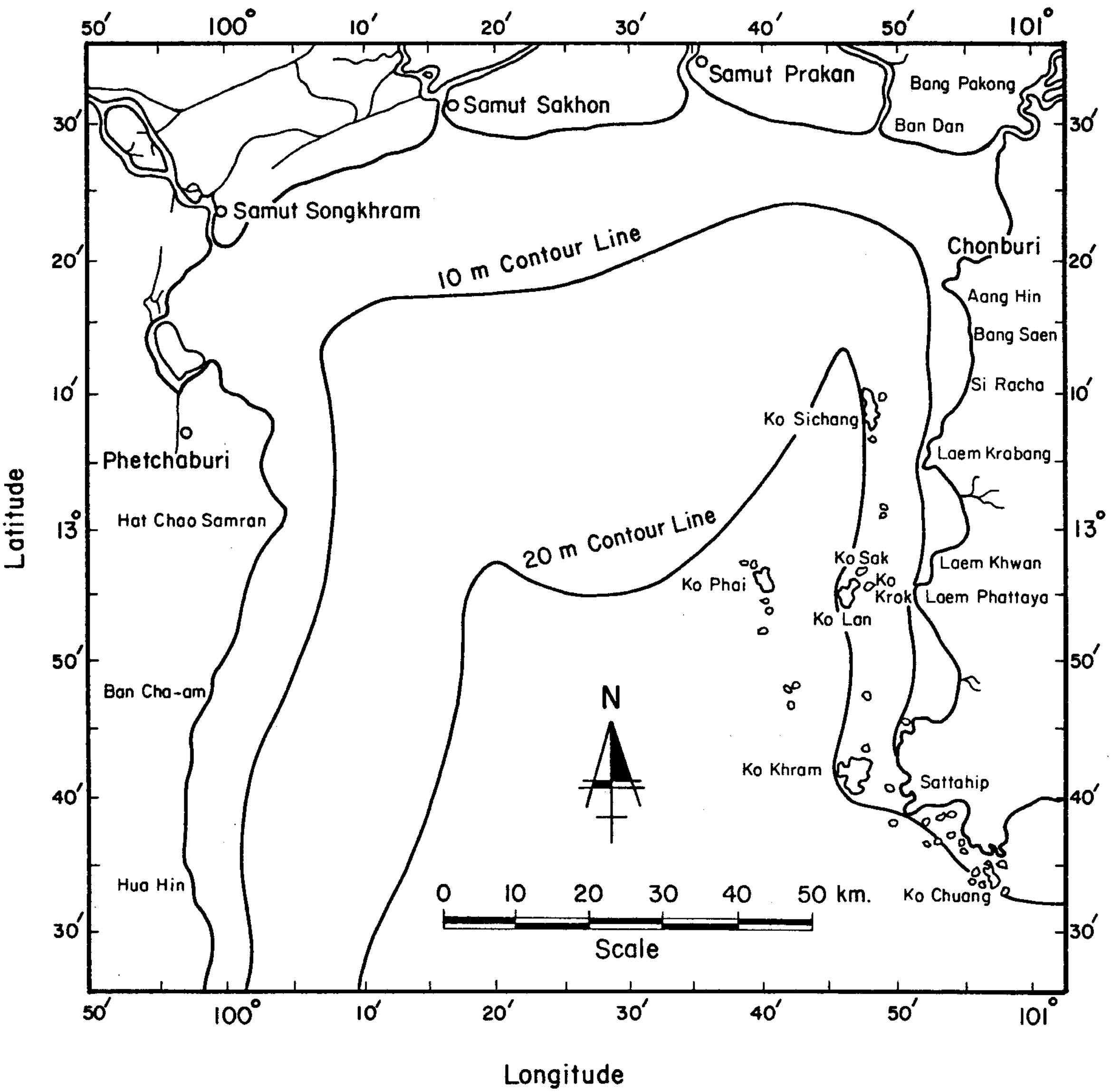


Fig. 2 The Upper Gulf of Thailand.

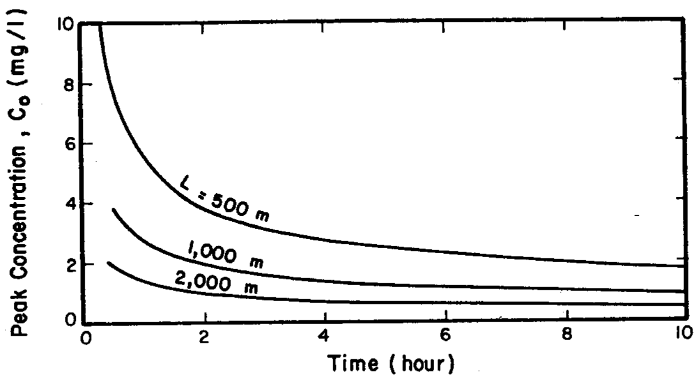


Fig. 3 One-Dimensional Dispersion from a Line Source (D_x = 3 m^2/s, M/Hz 1,000 kg /m, K = 0)

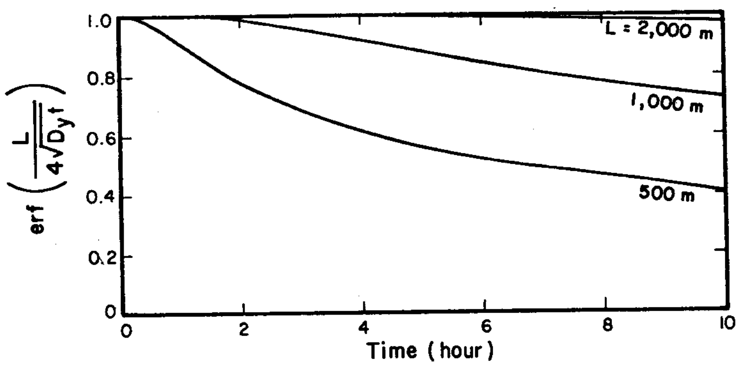


Fig. 4 Value of erf $\left(\frac{L}{4\sqrt{D_y t}}\right)$ v.s. Time t (Dy = 3 m^2/s)

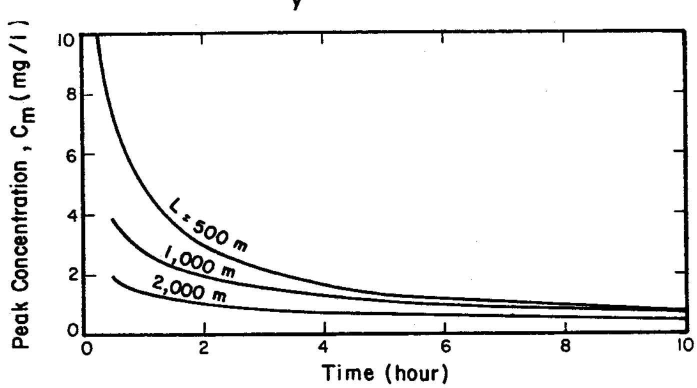


Fig. 5 Two-Dimensional Dispersion from a Line Source (D_x = 3 m^2/s, D_y = 3 m^2/s, M/H = 1,000 kg/m, K = 0)

In two-dimensional dispersion, lateral dispersion reduces the peak concentration. The reduction factor, expressed in terms of the error function erf $(\frac{L}{4\sqrt{D_y t}})$, decreases from unity when its parameter $(\frac{L}{4\sqrt{D_y t}})$ decreases, i.e., L decreases while D_y and t increase, as shown in Fig. 4. When there is no additional dilution due to lateral dispersion, the reduction factor is unity during the first 10 hours with L = 2,000 m; it decreaees from unity to about 0.7 from 2 to 10 hours with L = 1,000 m and it decreases from unity to about 0.4 from the beginning of dumping to 10 hours later. The peak concentrations of the two-dimensional concentrations which are the products of the peak concentrations of the one-dimensional dispersion and the reduction factors as plotted in Fig. 5 show significant differences in magnitude for different lengths of dumping lines during the first five hours after dumping. For longer times, due to lateral dispersion, no significant differences in peak concentrations occur.

This analysis is based on the assumptions that the waste is uniformly distributed over the dumping line, and the whole water depth during two-dimensional dispersion, and is uniformly distributed over the dumping section of the channel during one-dimensional dispersion. In order to apply this analysis to real dispersion phenomena such as waste disposal in the Upper Gulf of Thailand, the mixing conditions must be taken into account. A longer mixing time should be allowed to ensure that the waste is thoroughly mixed with the sea water throughout almost the entire depth.

The solutions infer that the dispersion in a river is limited by its limited width, while it is wider in the sea. This answer the question why pollution is severe in rivers where the downstream drift is small, i.e., in lower reaches subject to tidal influence; in the gulf the water quality is bound to be much better. However, care must be exercised not to exceed the natural assimilative capacity of the gulf. The Fishery Department must be consulted for the vulnerable area of dumping.

Conclusions

The solutions of one and two-dimensional dispersions from a line source in a water body of uniform depth, flow velocity, and constant dispersion coefficients are derived and compared. The peak concentration of the one-dimensional dispersion (Eq. 9 and Fig. 3) is governed by the mass of waste, cross-section of channel dispersion coefficient and time.

The additional dilution due to lateral dispersion of the two-dimensional dispersion (Fig. 4) depends upon the length of dumping, lateral dispersion coefficient and time.

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บทคัดย่อ

เนื่องจากในปัจจุบันได้มีการพัฒนาอุตสาหกรรมรอบอ่าวไทยตอนบนเป็นบริเวณกว้างขวาง เป็นผลทำให้เกิดปัญหาและความไม่แน่ใจเกี่ยวกับปริมาณของเสียจากโรงงานที่ถูกปล่อยลงทะเลว่าจะต้องมีปริมาณมากน้อยเพียงไรจึงจะไม่มีผลกระทบต่อสิ่งแวดล้อมในบริเวณนั้น ธรรมชาติการแพร่กระจายของเสียในทะเลเป็นเรื่องยุ่งยากและสลับซับซ้อน ซึ่งไม่สู้จะมีการศึกษาหรือทำการสำรวจตรวจสอบเลย

เนื่องจากมีความจำเป็นที่จะต้องควบคุมสภาพสิ่งแวดล้อมในอ่าวไทย บทความนี้จึงเสนอวิธีการคำนวณการแพร่กระจายของเสียในอ่าวไทย โดยอาศัยทฤษฎีที่สร้างขึ้น และใช้ข้อมูลของกระแสน้ำและอัตราการแพร่กระจายของเสียซึ่งได้เคยสำรวจในบริเวณนี้มาก่อน ผลของการศึกษาในเรื่องนี้แสดงให้เห็นถึงขนาดความสามารถในการแพร่กระจายของเสียในบริเวณนี้ ซึ่งจะเป็นประโยชน์ในการควบคุมปริมาณการทิ้งของเสียลงในอ่าวไทย