

CHAPTER 183

Numerical Simulation on Thermal Diffusion Concerning Air-Sea Heat Exchange Effects

By

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Abstract

The numerical simulations on thermal diffusion always concentrated upon the raised temperature and temperature distributions after the heated water discharged from outlet into surrounding water, and the surrounding water temperature was assumed to be a constant. Actually, the water temperature on surface layer in shallow water area varies several centigrade degrees depended upon the weather conditions during a whole day. In order to obtain the absolute water temperature prepared for the ecological changes assessment and even provided for the operation basis of the cooling water system that air-sea heat exchange has to be considered in the numerical simulation of thermal discharges.

For the practical application of this numerical simulation, the first nuclear power plant in Taiwan was taken as an example and simulated in this paper. And the results were presented in figures.

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1. Introduction

The temperature rise due to air-sea heat exchange is a important factor on the water body where the warmed water discharged from the outlet of a power plant. We know, different species exhibit different tolerant temperature ranges and are restricted within different temperature zones. Under this condition, as the increase in temperature of water body resulting from the discharge of warmed water and air-sea heat exchange is out of the upper tolerant limits that the species will move away and induce ecological changes.

In general, the thermal discharges can be obtained from numerical model calculations based on the boundary conditions (topography and water depth of computational domain, tide variation and current motion) and initial conditions (include ambient water temperature, intake and outlet discharge and temperature rise of the outlet). However, the variations of water surface temperature resulting from air-sea heat exchange are influenced by solar radiation, water temperature, air temperature, humidity, cloud and wind action. Now, we take the air-sea heat exchange as a source term in the numerical model that the thermal diffusion concerning air-sea heat exchange effects can be obtained in the simulations. And a practical example on the first nuclear power plant in Taiwan was simulated in this paper.

2. Governing Equations

The hydrodynamic equations and equation of heat conservation used in the model for thermal discharge can be written in time-averaged form:

$$\frac{\partial(\rho u)}{\partial t} + \frac{\partial(\rho u u)}{\partial x} + \frac{\partial(\rho u v)}{\partial y} + \frac{\partial(\rho u w)}{\partial z} = -\frac{\partial p}{\partial x} + f\rho v + \frac{\partial \tau_{xx}}{\partial x} + \frac{\partial \tau_{xy}}{\partial y} + \frac{\partial \tau_{xz}}{\partial z} \quad (1)$$

$$\frac{\partial(\rho v)}{\partial t} + \frac{\partial(\rho u v)}{\partial x} + \frac{\partial(\rho v v)}{\partial y} + \frac{\partial(\rho v w)}{\partial z} = -\frac{\partial p}{\partial y} - f\rho u + \frac{\partial \tau_{xy}}{\partial x} + \frac{\partial \tau_{yy}}{\partial y} + \frac{\partial \tau_{yz}}{\partial z} \quad (2)$$

$$\frac{\partial p}{\partial z} + \rho g = 0 \quad (3)$$

$$\frac{\partial T}{\partial t} + \frac{\partial(uT)}{\partial x} + \frac{\partial(vT)}{\partial y} + \frac{\partial(wT)}{\partial z} = e_x \frac{\partial^2 T}{\partial x^2} + e_y \frac{\partial^2 T}{\partial y^2} + e_z \frac{\partial^2 T}{\partial z^2} + S_T \quad (4)$$

and the equation of continuity is

$$\frac{\partial \rho}{\partial t} + \frac{\partial(\rho u)}{\partial x} + \frac{\partial(\rho v)}{\partial y} + \frac{\partial(\rho w)}{\partial z} = 0 \quad (5)$$

where e_x , e_y , e_z are thermal diffusion coefficients in x,y,z, directions respectively. And S_T is the source terms of heat content flux per unit mass which includes solar radiation, evaporation, heat conduction and so on.

Now, integrating the above equations from bottom to water

surface, that they could be reduced to a two-dimensional flow motion and expressed as follows:

$$\frac{\partial U}{\partial t} + U \frac{\partial U}{\partial x} + V \frac{\partial U}{\partial y} - fV + g \frac{\partial \zeta}{\partial x} + g \frac{U(U^2 + V^2)^{1/2}}{C^2 H} - \frac{1}{\rho H} r_s - (K_{x,} \frac{\partial^2 U}{\partial x^2} + K_{y,} \frac{\partial^2 U}{\partial y^2}) = 0 \quad (6)$$

$$\frac{\partial V}{\partial t} + U \frac{\partial V}{\partial x} + V \frac{\partial V}{\partial y} + fU + g \frac{\partial \zeta}{\partial y} + g \frac{V(U^2 + V^2)^{1/2}}{C^2 H} - \frac{1}{\rho H} r_s - (K_{x,} \frac{\partial^2 V}{\partial x^2} + K_{y,} \frac{\partial^2 V}{\partial y^2}) = 0 \quad (7)$$

$$\frac{\partial \zeta}{\partial t} + \frac{\partial(HU)}{\partial x} + \frac{\partial(HV)}{\partial y} = 0 \quad (8)$$

$$\frac{\partial(HT)}{\partial t} + \frac{\partial(HTU)}{\partial x} + \frac{\partial(HTV)}{\partial y} - \left[\frac{\partial(HD_x \frac{\partial T}{\partial x})}{\partial x} + \frac{\partial(HD_y \frac{\partial T}{\partial y})}{\partial y} \right] - S_r = 0 \quad (9)$$

where

$$U = \frac{1}{H} \int_{-h}^{\zeta} u dz, \quad V = \frac{1}{H} \int_{-h}^{\zeta} v dz$$

3. Air-sea Heat Exchange

The rate of heat exchange on the water surface can be formulated from the algebraic sum of the rates at which heat is transported across the water surface by solar radiation, back radiation, evaporation, heat conduction and so on, it is

$$Q_v = Q_s - (Q_b + Q_e + Q_h) \quad (10)$$

where Q_v is the net rate of heat perpendicular to the water surface, Q_s is the net incoming radiation, Q_b is the back radiation emitted from water surface, Q_e is the heat loss due to evaporation and Q_h is the heat loss or gain due to conduction. All of the above terms have to be obtained from field measurements and will be described as follows.

Since the reflected radiation from water surface is about 6-8% of the total incoming radiation at 25 degree of the latitude that the net incoming radiation can be expressed as

$$Q_s = 0.93 Q_{s_0} \quad (11)$$

And the back radiation is dependent on air and water temperature, cloud, air-vapor pressure and so on. According to the studies

from Central Research Institute of Electric Power Industry (1974), that the back radiation would be

$$Q_r = 1.32 \times 10^{-11} \theta_s (0.49 - 0.066 \sqrt{e(T_w)}) (1 - 0.65n^2) + 5.27 \times 10^{-12} \theta_s (T_w - T_a) \quad (12)$$

where $\theta_s = (273 + T_w)^3$, T_w and T_a indicates the water and air temperature respectively, n is the cloud and $e(T_w)$ is the air-vapor pressure which can be calculated from the relationships of humidity and temperature.

As for the heat conduction, it is easy to obtained as

$$Q_h = K_c (T_w - T_a) \quad (13)$$

$$K_c = 2.77 \times 10^{-4} (0.48 + 0.272W) \quad (14)$$

here, K_c is the coefficient of heat conduction and W is the wind velocity. And the heat loss due to evaporation can be estimated as

$$Q_e = K_e [e_s(T_w) - f e_s(T_a)] \quad (15)$$

where K_e is the transfer coefficient of evaporation and its value is about $1.5K_c$. f is the relative humidity, $e_s(T_w)$ and $e_s(T_a)$ is the saturation vapor pressure corresponding to the water and air temperature respectively.

According to the above equations the net heat flux between air and sea water surface can be calculated to provide the numerical calculations.

4. Practical Example

For the practical application of this numerical simulation, the first nuclear power plant located in the northern coast of Taiwan was taken as an example and simulated in this paper. Fig-1 is the schematic diagram of the first nuclear power plant and the location of current measurements. Fig-2 is the tide variation of coastal water around this plant. Based on the field measurements of meteorological conditions which provided by Taipower Survey Team that the heat flux hour by hour was calculated and listed in Table-1. The currents boundary conditions were set at the east and west sides of the finite-difference grid domain, but the boundary condition at the south was controlled by tides. The numerical model covered an area of $2.88\text{Km} \times 2.88\text{Km}$ with a grid size of 120m. And the numerical simulations were accomplished throughout 4500 time-steps with a value of time step by 30 seconds. Fig-3~Fig-5 show the simulated flow pattern on the water area of the first nuclear power plant under no wind condition. Fig-6 ~ Fig-8 are the flow pattern at the same conditions under 5m/sec wind action. And the corresponding temperature distributions were shown in Fig-9~Fig-14 respectively.

From the results of temperature distributions, we can see the

ambient water temperature rise is about 3.08°C (the initial ambient water temperature is 25°C) for no wind condition and 3.73°C for 5m/sec wind action.

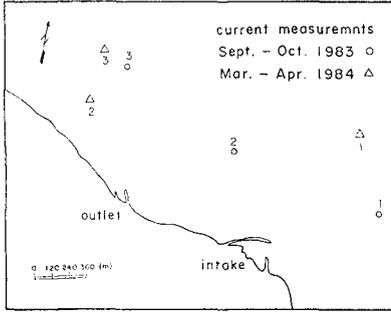


Fig-1

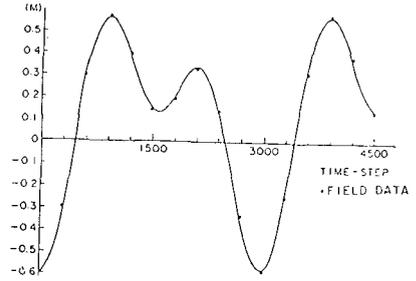


Fig-2

Table-1

Time	3	4	5	6	7	8	9	10
Heat Flux (cal/cm ² ·hr)	0.0	0.0	0.0	0.0	0.0	0.0	0.0	62.4
Air Temp. (°C)	27.9	28.0	28.2	28.4	29.0	30.1	31.6	32.0
Time	11	12	13	14	15	16	17	18
Heat Flux (cal/cm ² ·hr)	70.8	76.8	78.0	74.4	63.6	44.4	24.0	8.2
Air Temp. (°C)	32.7	32.9	33.4	33.6	33.8	32.0	30.7	30.4
Time	19	20	21	22	23	24	1	2
Heat Flux (cal/cm ² ·hr)	2.6	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Air Temp. (°C)	29.8	28.8	28.5	27.9	27.7	27.4	27.0	27.6

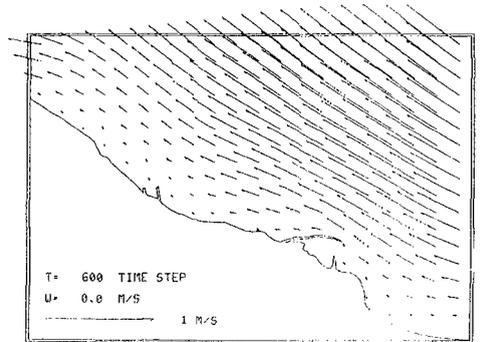


Fig-3

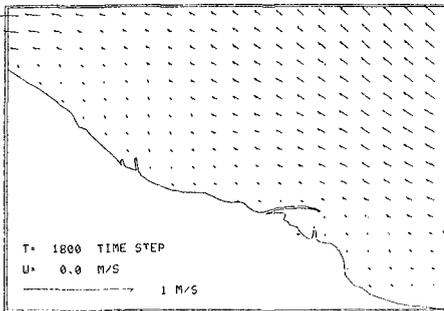


Fig-4

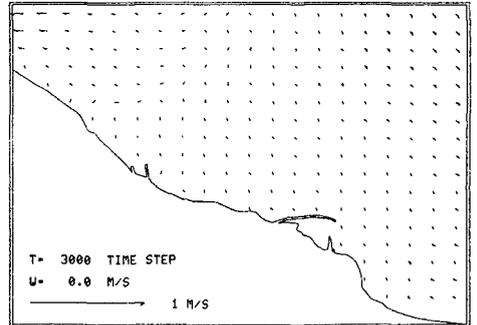


Fig-5

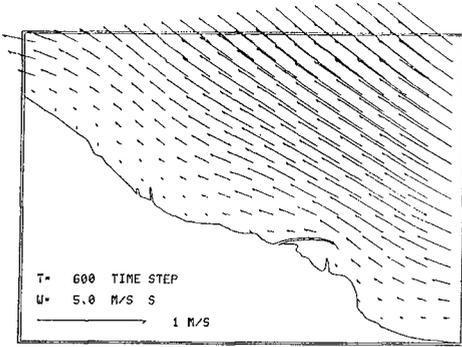


Fig-6

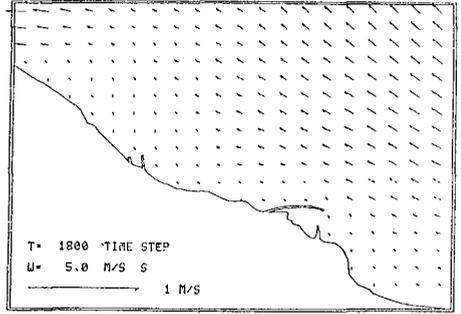


Fig-7

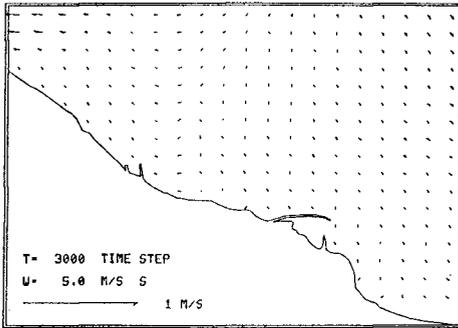


Fig-8

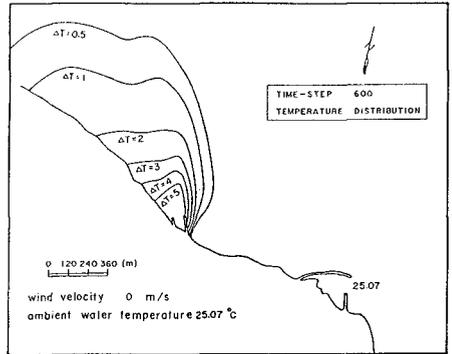


Fig-9

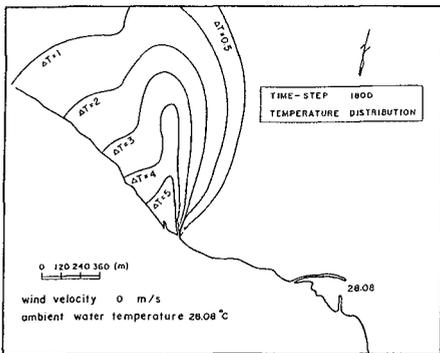


Fig-10

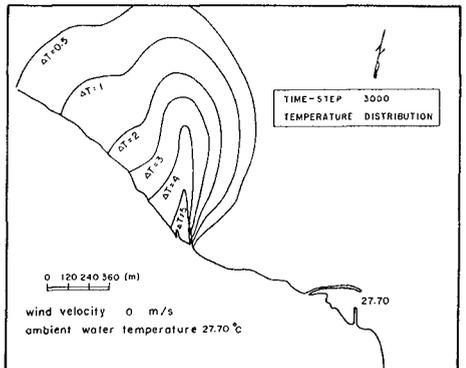


Fig-11

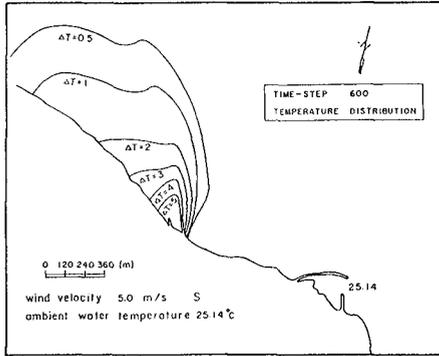


Fig-12

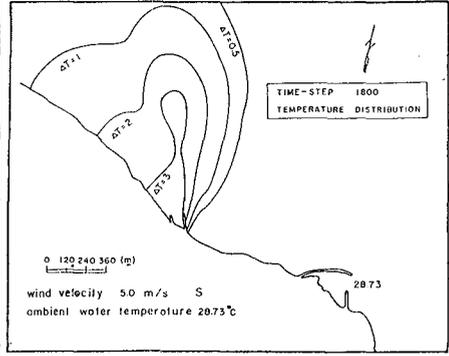


Fig-13

5. Conclusion

From this numerical model simulations, not only the water temperature rise resulting from the thermal discharges of the power plant can be obtained, but also the temperature rise due to air-sea heat exchange will be calculated simultaneously. That it is more significant to provide enough information for the assessment of ecological changes before a power plant will be planned.

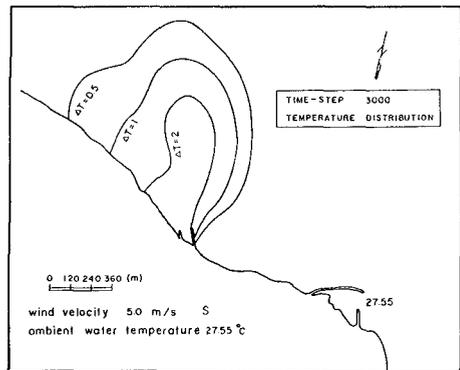


Fig-14

6. Reference

1. Frederick, L.W. Tang and H.H. Hwung (1979). "Studies on the Thermal Diffusion of The Third Nuclear Power and The Field Investigations of Lin-Ko Power Plant", Tainan Hydraulic Laboratory, Bulletin 42.
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