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THE EFFECT OF RADIATIVE POLLUTION ON THE PROPERTIES OF WATER IN DEEP LAKES

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Abstract:- In this paper the effect of increasing radiative properties, turbidity factor and absorption coefficient on lake temperature has been investigated by a numerical method CFD. An experimental equation which accounts for back radiation and evaporative heat loss has been used as boundary condition at the water surface. During the day, a portion of solar radiation is absorbed at the surface and the remainder is absorbed exponentially inside the lake. Neglecting the convective and turbulent diffusion in the energy equation will result in an unstable temperature and density distribution near the surface. Considering energy due to free convection will cause a stable isothermal temperature in the epilimnion layer.

*Keywords:-*radiation , absorption , pollution , turbidity , solar energy , fraction

Nomenclature

a: average absorption coefficient of the air over all wavelengths (m^{-1})

a_{ms} : average molecular scattering over all wavelengths (m^{-1})

a_{ps} : average particulate scattering over all wavelengths (m^{-1})

a_t : total attenuation coefficient over all wavelengths (m^{-1})

β: fraction of absorbed radiation at the water surface

c: specific heat of water ($\frac{J}{kg^\circ c}$)

θ: altitude angle (deg)

q':rate of heat generated per unit volume ($\frac{J}{hr-kg-^\circ c}$)

I_s: direct cloudless sky flux at earth´s surface ($\frac{J}{m^2-hr}$)

α: molecular thermal diffusivity ($\frac{m^2}{hr}$)

t: time (hr)

I_0: flux at outer limits of the earth´s atmosphere ($\frac{J}{m^2-hr}$)

I_z: flux at a depth z($\frac{J}{m^2-hr}$)

I_{sc}: solar constant ($\frac{J}{m^2-hr}$)

I'_{sc}: extra-terrestrial flux ($\frac{J}{m^2-hr}$)

i , j , k: unit vectors in x, y, z coordinate directions

r: index for radiative

k: thermal conductivity ($\frac{W}{m-K}$)

u , v: velocity in x and y directions ($\frac{m}{s}$)

. : scalar product

x , y, z: subscripts in the x, y and z directions

q_r: radiative flux vector

V: velocity vector

P: pressure (pa)

I: index for space

M: relative thickness of the air mass

N:day of the year measured from the 1st January, index for time

$q_L(t)$: energy lost by evaporation and radiation ($\frac{J}{m^2-hr}$)

ρ: density of water ($\frac{kg}{m^3}$)

T: temperature (°c)

Δz: special step

z: coordinate in the vertical direction measured downward from the water surface (m)

t_f: turbidity factor

w: vertical velocity ($\frac{m}{s}$)

a_w: average absorption coefficient of water over all wavelengths (m^{-1})

α_t: vertical thermal eddy diffusivity

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Φ : energy dissipation
L: lake depth (m)

1 Introduction

Previous studies on unsteady vertical temperature distribution in the water can be classified as two groups:(1)turbulent diffusion models and (2)internal radiation absorption models.

1.1 Turbulent Diffusion Models

Some investigators have assumed that the main mode of vertical heat transfer is through turbulent diffusion. It is assumed that solar radiation is entirely absorbed at the surface.

Hutchinson assumed vertical thermal eddy diffusivity to be constant. Dutton and Bryson considered unsteady temperature distribution in lake Mendota, using vertical thermal eddy diffusivity independent of depth. It is concluded that neglect of heat absorption leads to artificially large values of eddy diffusivity.

1.2 Internal Radiation Absorption Models

Kraus and Rooth and Turner and Kraus [6] used the concept of internal radiation absorption in the study of ocean thermoclines. It can be concluded that a general approach should include the effect of internal radiation absorption. In this study the combined effect of surface and internally absorbed solar radiation along with the effect of days and nights have been considered.

2 Governing Equation

The resulting partial differential equation is a linear parabolic equation with variable coefficients. The resulting equation in the epilimnion layer (a very small region near the surface where the temperature fluctuation is small) can be obtained by simplifying the energy equation. So after simplification the final equation will be as follows [1]

$$\frac{\partial T}{\partial t} + w\frac{\partial T}{\partial z} = (\alpha + \alpha_t)\frac{\partial^2 T}{\partial z^2} - \nabla q_r \qquad (1)$$

where [4]

$$w = L - 13.3 \times 10^{-8} z(\frac{m}{s})$$

$$V = u\,i + v\,j + wk$$

$$\nabla = i\frac{\partial}{\partial x} + j\frac{\partial}{\partial y} + k\frac{\partial}{\partial z}$$

$$q_r = i\,q_{r,x} + jq_{r,y} + kq_{r,z}$$

beneath the epilimnion layer the convective term will be neglected. At night the heat source term will be zero for 12 hours.

3 Calculation of Solar Flux

The earth revolves around the sun in an elliptical orbit having a very small eccentricity and with the sun at one of the foci. Consequently, the distance between the earth and the sun varies a little through the year. The value on any day can be calculated from the equation [5].

$$I'_{sc} = I_{sc}\left(1 + 0.033\cos\frac{360n}{365}\right) \qquad (2)$$

A value of 1376 (w/m^2) has been recommended for it. The insolation at the outer edge of atmosphere for a horizontal surface will be

$$I_0 = I'_{sc}\sin\theta$$

The flux transmission inside the atmosphere will vary exponentially according to the following relation.

$$I_s = I_0 e^{-a_t m} = I_0 e^{-t_f a_{ms} m} \qquad (3)$$

defining turbidity factor as

$$t_f = \frac{a_t}{a_{ms}}$$

where

$$a_t = a_{ms} + a_{ps} + a$$

the turbidity factor is a convenient means of specifying atmospheric purity and clarity; its value ranges from about 2.0 for very clear air to 4 or 5 for very smoggy industrial environments.The molecular scattering for air at atmospheric pressure is given as [7]:

$$a_{ms} = 0.128\text{-}0.054 \log m$$

4 Radiation Absorption

Neglecting scattering inside the water body and due to absorption of radiation at the water surface and the albedo(reflected energy/incident energy)of water surface varying from 3% to 10%, the radiation at the water surface and the albedo of water surface varying from 3% to 10%, the radiation transmitted through the water is obtained from

$$I_z = (1\text{ - albedo})(1\text{ - }\beta)I_s e^{-a_w z} \tag{4}$$

where the change in radiative flux in equation (1) can be evaluated by the following relation.

$$\nabla q_r = -\left(\frac{\partial I_z}{\partial z}\right) \tag{5}$$

absorption coefficient has the value 0.05 m^{-1} for extremely clear water of Lake Tahoe [1] and a value of 0.89 m^{-1} for the more turbid water of Lake Castle, California [6]. β apears to have the value of 0.4 for all lakes for which data is available [1].

5 Initial and Boundary Conditions

The analysis begins in the early spring when an isothermal state exists in the lake. So we have

$$T(z,0) = T_0 = 4^\circ c \tag{6}$$

The surface boundary condition requires that the conducted heat into the water by diffusion and energy lost by evaporation and reradiation from the surface must be equal to the absorbed energy at the surface, so

$$\beta I_s = -\rho c(\alpha + \alpha_t)\left.\frac{\partial T}{\partial z}\right|_{z=0} + q_L(t) \tag{7}$$

at night the absorbed solar energy is zero and $q_L(t)$ is an experimental formula obtained in the laboratory [1].

$$q_L(t) = 0.004\beta I_s \sqrt{t} \tag{8}$$

Due to analysis in a deep lake the solar energy reaching the bottom of the lake will be small and we have

$$T(z, L) = T_0 \tag{9}$$

A computer code has been developed to solve the governing equation using the computational fluid dynamics methods. The method used for solving the equation is full implicit where

$$w_i = [L - (i-1)\Delta z] \times 13.3 \times 10^{-8}\left(\frac{m}{s}\right) \tag{10}$$

$$g_i^{n+1} = \lfloor a_w(1-\beta)\, I_s^{n+1} / \rho c \rfloor \exp[-a_w(i-1)\Delta z] \tag{11}$$

6 Temperature Profiles

The effect of increasing turbidity factor on temperature distribution inside a lake of depth 100 meters has been shown in figures. The plots have been obtained from numerical analysis. Also stability and convergence have been investigated for each plot. Figure 1 and 2 show unstable temperature distribution resulting from neglecting convection term in equation 1.Figure 3 show stable temperature distribution obtained by considering convection term.

7 Conclusion

An analysis of the plots shows that unstable temperature distribution results from radiation and evaporation from water surface and neglecting convection.

The effect of increasing turbidity factor shows a decrease in temperature so according to the definition of turbidity factor increasing particulate scattering and air absorption coefficient or decreasing molecular scattering will result in a decrease of temperature distribution. Also increasing water absorption coefficient will result in a increase of temperature.

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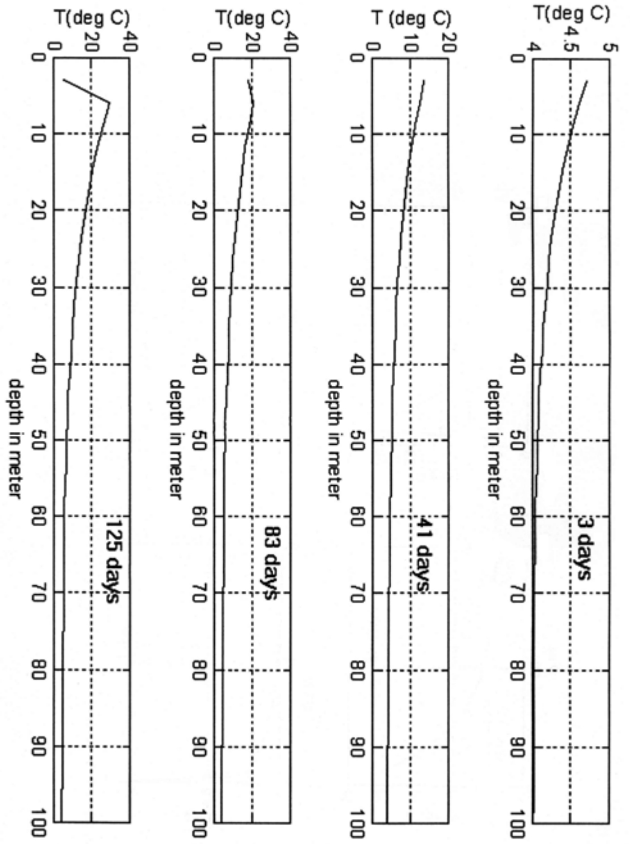

Fig.1. Analytical plots for constant flux of 1315.97(W/m^2),without free convection.

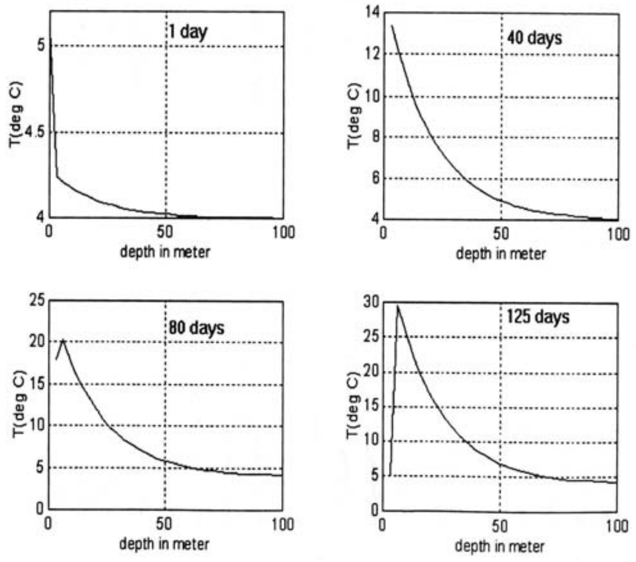

Fig.2. Analytical plots for constant flux of 1315.97(W/m^2),without free convection.

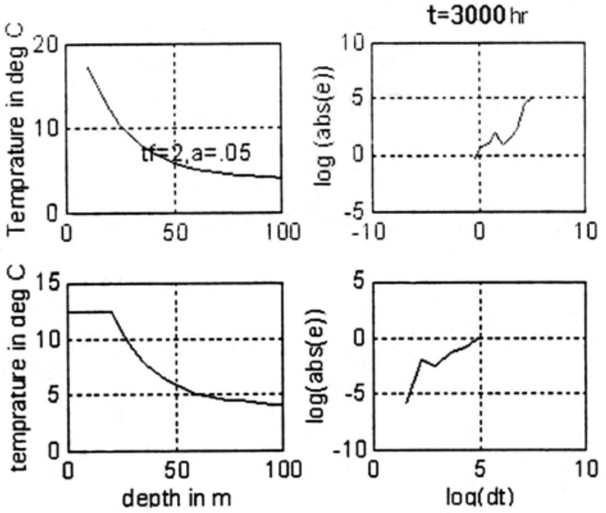

Fig.3. Temperature distribution distance in lakes for t = 3000 hr , $t_f = 2$, a = 0.05.