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Research Paper

ASSESSMENT OF POLLUTANT DISPERSION IN A RIVER USING HP2S MODEL

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Abstract: Pollutant dispersion model in river was developed in accordance to conservation law of mass and energy and based on non linear function using partial differential mathematics and numeric methods. The model was influenced by river velocity or flow rate, by concentration of pollutant and wastewater discharge to the river at a given time; the so called HP2S model. The HP2S model should be preceded by identification of pollutant dispersion pattern, river flow, and correlation between river velocity and pollutant concentration. The model enables to (1) predict the direction and the distance of pollutant dispersion into the river, (2) determine the location of sampling point during the monitoring of water quality. The model could be applied to laminar and turbulent flow conditions, at discharge site of wastewater along the riverbank, and center of the river.

Keywords: Hydrodynamic, stream flow conditions, wastewater discharge site

INTRODUCTION

The direction of pollutant dispersion is caused by three processes of mass transport. In aquatic ecosystem, mass is transported due to advection, diffusion and dispersion. Models to express pollutant dispersion have been provided by many researchers [1, 3-5]. Application of finite difference methode of stream have irregular boundary and was carried out using co-ordinate transformation [2]. Then co-ordinate of Cartesian is transformed into the co-ordinate curve "coordinate curvilinear". In this way, hydrodynamic equation of pollutant transport in Cartesian co-ordinate transformated into co-ordinate curve form, and then hydrodynamic equation of pollutant transportation was discritized to finite difference scheme.

Approach of derivation in explicit method has been substituted into the equation of differential, the function value of a grid point at a certain phase (for example, phase (n+1) Δt can be calculated by using value of function around point on $n\Delta t$ phase directly). Hence, explicit leap frog method was an unstable method, so that required stability, consistency, and convergency test during running the model should be met.

To reach the stability in explicit leap frog, Δt is as a step of the time was limited by value of a number of Courant (Cr), which was expressed as $Cr = \frac{U\Delta t}{\Delta x} \leq 1$; hence, value of $Cr > 1$ the explicit leap frog was unstable condition. To reach the consistency, the difference value of function of definite solution F (exact solution) and form approach of definite solution f was approximately zero. The difference value of (F-f) was referred as a mistake of discritization. The finite difference approach was reached consistent if the length of grid was made more and more small, hence, an error of discritization would reached approximately zero value, and approach of finite difference form would be appropriated with the form of differential equation finally. To reach the convergency, the difference value of definite solution F (exact solution) and form approach of definite solution f was approximately zero. Finite difference approach reached convergent if the length of grid was made too small, hence $\| F_{j,n} - f_{j,n} \| \rightarrow 0$.

Models of single (1-D), double (2-D) and three (3-D) dimensions can be used to improve monitoring and control the quality of river water. One of the two dimension horizontal model within not partial is a model hydrodynamics model on pollutant dispersion in river the so called HP2S. The model was based on conservation law of mass and energy, mathematics structure of differential partial through leap frog explicit finite difference numerical method and visualized with Matlab computer program.

Model of HP2S identifies pollutant dispersion in river that is influenced by discharge of wastewater to river and can be expressed to correlate between hydrodynamics aspect (such as velocity, flowrate) and dispersion of concentration of pollutant in river. The model was designed to neglect its external interferences such as wind, evaporation, Eddy current, tidal effect, river branch, rain, pH change of water and ground water flow. The chemical parameters for running this model was dissolved oxygen (DO) and chemical oxygen demand (COD).

MATERIALS AND METHODS

The model of HP2S based on the non linear function, using the equation of partial differential mathematics and completed by numeric methods was influenced by three variables, i.e. the velocity and flowrate of the river, pollutant concentration and discharge of wastewater into the river at a given time. The model enables to predict the two direction of horizontal flow and the distance of pollutant dispersion into the river. The model could be referred to determine the location of sampling point during the monitoring of water quality, the variation of flow conditions, as well as variation of wastewater discharge site.

The program (*source code*) of model was designed for straight and meandering river during the condition of laminar and turbulent flows and for the discharge from the river side and also from the center side of river. The tests entailed the limitation conditions, i.e. Courant number ≤ 1 for stabilization, leap frog scheme ($F - f$) function should be approximately 0 for consistency, and the ($F_{j,n} - f_{j,n}$) should be approximately 0 for the convergent condition.

While for the river flow, the limitations were Reynold's number (*Nre*) ≤ 2400 and *Nre* > 2400 for the laminar and turbulent flow conditions respectively. External factors, such as wind influence, evaporation, Eddy current, tidal effect, river branch were neglected.

Tests of primary and secondary data (flow, velocity and concentration) were executed by correlation test with transformation of logarithm data test and with condition of $R^2 < 1$ or $r > 0,9$ (5 samples) and $r > 0,497$ (12 samples) using the table of critical value of correlation coefficient of Spearman.

Tests on the oxygenation coefficient k_a, the coefficient number of longitudinal (E_x) and lateral (E_y) dispersion of pollutants were carried out using linier regression test, while k_d was by means of trial and error due to k_d is an empirical function. A schematic of algorithm program for the model was presented in Fig. 1.

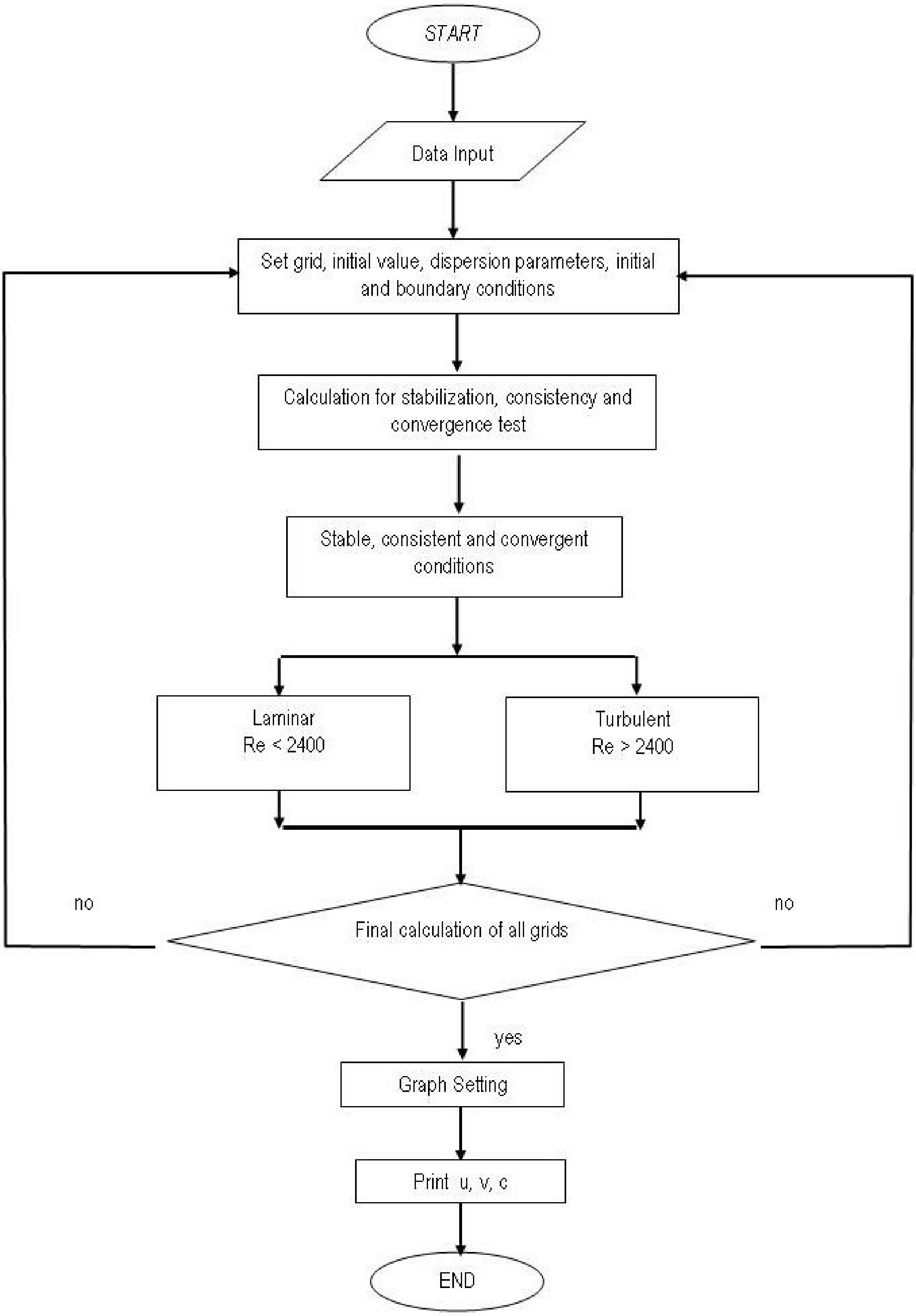

Fig. 1: Schematic of algorithm program

Model the HP2S was design by pursuant to mathematics structure, using basic equation of partial differential and with non–linear dispersion pattern. The mathematical structure was also designed by equation of energy conservation and momentum and this required the solving of very complex mathematics as follows.

Laminar flow without discharge of wastewater to x axis direction:

$$u_{i,j}^{n+1} = u_{i,j}^{n-1} - 2\Delta t\left[u_{i,j}^{n}\frac{u_{i+1,j}^{n} - u_{i-1,j}^{n}}{2\Delta x} + v_{i,j}^{n}\frac{u_{i,j+1}^{n} - u_{i,j-1}^{n}}{2\Delta y}\right] + \frac{2\Delta t}{\rho_{i,j}^{n}}\left[\left[Po + \rho_{i,j}^{n} gh\right] + \mu\frac{u_{i,j}^{n}}{\Delta x}\right] \quad (1)$$

Laminar flow without discharge of wastewater to y ordinate direction:

$$v_{i,j}^{n+1} = v_{i,j}^{n-1} - 2\Delta t\left[u_{i,j}^{n}\frac{v_{i+1,j}^{n} - v_{i-1,j}^{n}}{2\Delta x} + v_{i,j}^{n}\frac{v_{i,j+1}^{n} - v_{i,j-1}^{n}}{2\Delta y}\right] + \frac{2\Delta t}{\rho_{i,j}^{n}}\left[\left[Po + \rho_{i,j}^{n} gh\right] + \mu\frac{v_{i,j}^{n}}{\Delta y}\right] \quad (2)$$

Laminar flow with discharge of wastewater to x axis direction:

$$u_{i,j}^{n+1} = u_{i,j}^{n-1} - 2\Delta t\left[u_{i,j}^{n}\frac{u_{i+1,j}^{n} - u_{i-1,j}^{n}}{2\Delta x} + v_{i,j}^{n}\frac{u_{i,j+1}^{n} - u_{i,j-1}^{n}}{2\Delta y}\right] + \frac{2\Delta t}{\rho_{i,j}^{n}}\left[\left[Po + \rho_{i,j}^{n} gh\right] + \mu\frac{u_{i,j}^{n}}{\Delta x} - u_{i,j}^{n} q\right] \quad (3)$$

Laminar flow with discharge of wastewater to y ordinate direction

$$v_{i,j}^{n+1} = v_{i,j}^{n-1} - 2\Delta t\left[u_{i,j}^{n}\frac{v_{i+1,j}^{n} - v_{i-1,j}^{n}}{2\Delta x} + v_{i,j}^{n}\frac{v_{i,j+1}^{n} - v_{i,j-1}^{n}}{2\Delta y}\right] + \frac{2\Delta t}{\rho_{i,j}^{n}}\left[\left[Po + \rho_{i,j}^{n} gh\right] + \mu\frac{v_{i,j}^{n}}{\Delta y} - v_{i,j}^{n} q\right] \quad (4)$$

Furthermore, a leap frog method was arranged by program (source code) for the straight river and the discharge from the side and the center of river with laminar and turbulent flow conditions. The test entailed limitation conditions, i.e. leap frog scheme (F – f) function should be approximately zero for consistency, the ($F_{j,n} - f_{j,n}$) should be approximately zero for convergency and value of Courant number should be ≤ 1 for the stabilization of leap frog explicit finite difference method. While, the values of Reynold number (Nre) should be ≤ 2400 for the laminar and should be > 2400 for the turbulent.

RESULTS AND DISCUSSION

Results of various river flow conditions for five sampling points showed that the relationship between COD concentration and water velocity in *x* and *y* directions was non-linier. Similar results were obtained for dissolved oxygen (DO). While results of the correlation between DO and COD revealed the significant influence of river velocity to DO and COD concentrations.

The result of running the HP2S model with discharge point of industrial disposal at a riverbank and center of river (Fig. 2) was indicated that the pollutant dispersion was dominant in the length of river (17.5 m) instead of width (8.6 m) and was very influenced by velocity and flowrate values of the river at that time. Therefore, the monitoring the river water quality was needed to considering of the discharge point of industrial disposal (point source) and river flowrate along riverbank. The pollutant parameters was dispersed to the dominant current at river length direction, eventhough, result of dispersion at lateral direction (width direction) was smaller than dispersion of pollutant at length direction of river.

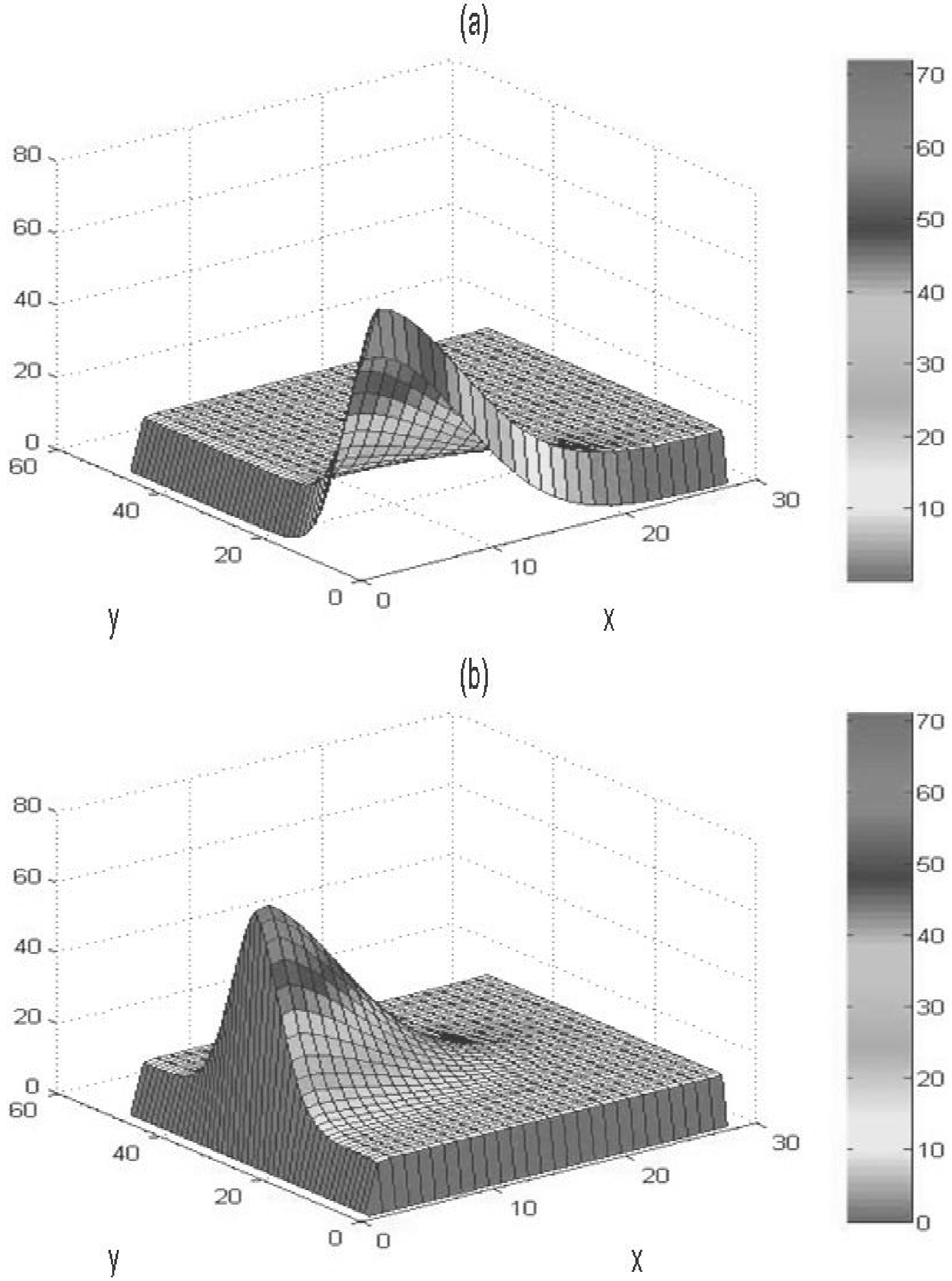

Fig. 2: Dispersion of pollutant in x and y direction per time and distance at laminar flow condition at discharge point of riverbank (a) and centre point of river (b)

CONCLUSIONS

The 2-D horizontal HP2S model or dispersion pollutant model, used numeric methods and as a non linear function based by the equation of partial differential mathematics and influenced by the velocity and flowrate of the river, influenced by values of concentration and discharge of industrial disposal wastewater to the river at that time.

The model could be used to predict the direction and the distance of pollutant dispersion in the river at that time. It could be referred to determine the location of sampling point during the monitoring of water quality at that time and could be applied for two kinds of river flow conditions (laminar and turbulent), and also at all discharge points of industrial wastewater disposal along riverbank and center of river.

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