

A Mathematical Model of Water Pollution Control Using the Finite Element Method

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Water pollution assessment problems arise frequently in environmental science. In this research, the finite element method for solving the one-dimensional steady convection-diffusion equation with constant coefficients is presented; it is then used to optimize water treatment costs.

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1 Introduction

This paper describes a mathematical model for solving the dispersion of pollutant in a river. A finite element method for assessment of the chemical oxygen demand(COD) concentration in the river is considered. This model requires the calculation of the substance dispersion given the water velocity in the channel. A finite element model is used to compute the concentration of the pollutant for variable inputs. These are then subjected to the optimal control of the water treatment plants to achieve minimum cost. A numerical example given.

2 Dispersion in a uniform channel

The dispersion of COD is described by the convection-diffusion equation in the domain $[a, b]$,

$$-D_x \frac{d^2 C}{dx^2} + u \frac{dC}{dx} + RC - Q = 0 \quad (1)$$

where $C(x)$ is the concentration of COD at the point $x \in [a, b]$ (kg/m^3), u is the flow velocity in the x -direction (m/s), D_x is the diffusion coefficient (m^2/s), R is the substance decay rate (s^{-1}) and Q is the rate of change of substance concentration due to a source ($kg/m^3 s$). The boundary conditions are $C = C_0$ at $x = a$ and $\frac{dC}{dx} = T_0$ at $x = b$. By the method of weighted residuals, Eq.(1) can be written in the weak form

$$\int_a^b \{D_x \frac{d\omega}{dx} \frac{d\tilde{C}}{dx} + u\omega \frac{d\tilde{C}}{dx} + R\omega \tilde{C}\} dx = \int_a^b \omega Q dx + [D_x \omega \frac{d\tilde{C}}{dx}]_a^b. \quad (2)$$

Let $\varphi_i(x)$ be the global linear basis function in $[a, b]$ for all $i = 0, 1, 2, \dots, n$. Choose $\omega = \varphi_i$, $i = 0, 1, 2, \dots, n$, then the equation system Eq.(2) can be written in the matrix form

$$[K]\{\tilde{C}\} = \{F\} + \{B\} - \{G\} = \{g_1 \ g_2 \ \dots \ g_N\}^T \quad (3)$$

where for each element,

$$[K^{(e)}] = \frac{D_x}{h_e} \begin{bmatrix} 1 & -1 \\ -1 & 1 \end{bmatrix} + \frac{u}{2} \begin{bmatrix} -1 & 1 \\ -1 & 1 \end{bmatrix} + \frac{R h_e}{6} \begin{bmatrix} 2 & 1 \\ 1 & 2 \end{bmatrix}, \quad (4)$$

$$\{F^{(e)}\} = \frac{Q h_e}{2} \begin{Bmatrix} 1 \\ 1 \end{Bmatrix}, \quad (5)$$

$$\{B\} = [D_x \omega \frac{d\tilde{C}}{dx}]_a^b = D_x \{0 \ \dots \ 0 \ T_0\}^T, \quad (6)$$

The entries of $[K]$ are k_{ij} for each $1 \leq i, j \leq N$ where N is the number of nodes. We apply the boundary condition to Eq.(3), to give $k_{\alpha\alpha} = 1$ and $g_\alpha = C_\alpha$ where α indicates any inflow node and C_α is the corresponding given value. We denote the corresponding matrices by K^0 and G^0 , respectively. Let B be the inverse matrix of K^0 . Then $\{C\} = [B]\{G^0\}$ and we obtain $\tilde{C}_i = \sum_{j=1}^N b_{ij} f_j$ where $1 \leq i \leq N$.

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