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Estimation of the Penetration Depth of the Pollution in the River Bed for Evaluation of the Self-Purification Characteristics of the Rivers by Developing a Novel Theoretical Relationship

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ABSTRACT: In the current study, it was tried to determine the mechanism of the tracer penetration through the depth of the river beds to investigate the self-purification nature of the rivers. For this purpose, experimental tests were carried out, and an analytical solution was developed. The electrical conductivity sensors and sodium chloride tracer (as a conservative contaminant) were operated in the operations. Also, for the derivation of the analytical equation, a conceptual model was presented based on the hybrid cells in the series model. Then, by imposing the mass conservation to each cell of the depth column, the governing differential equation was obtained and solved. Next, the results were evaluated by the framework of the developed equation. Moreover, the applicability of the new model was checked and confirmed by the recreation of the breakthrough curves. The time parameters of the new model were extracted. Then, their variation by the other parameters was queried. It was observed that the sum of temporal parameters (α,T_1,T_2) have a reverse relationship with the vertical dispersion coefficient. On the other hand, its value has been raised by an increment of the bed depth. Furthermore, the product of the void scale and the pore velocity was used for the calculation of the vertical dispersion coefficient. Also, the magnitudes of the pore velocity and dispersivity were commuted. The results revealed that by the increase of the bed depth, the mentioned parameters were decreased.

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1- Introduction

The self-purification characteristic of the rivers is one of the most critical issues among water engineers. Nowadays, a lot of efforts have been made for improving this characteristic to have a better quality of the diverted water. Dissolved oxygen moves from the water surface towards the river bed as a result of vertical mixing. Therefore, by an increment of the mixing intensity, the purification capability of the river would be improved. By focusing on the mentioned criterion, the investigation of the vertical mixing of the pollutions in the river bed is essential [1, 2].

The mass mixing in the bed interface is due to the pressure gradient and boundary turbulence. The contaminant transport modeling showed that the vertical dispersion coefficient in the porous beds has the most critical impact on the temporal and spatial characteristics of the exit breakthrough curves [3-6].

By careful reviewing of the literature, it can be found that still there is a lack of knowledge about the mixing mechanism of the contaminants through the porous bed. Therefore, the current study is designed to investigate the mixing mechanism from experimental and theoretical viewpoints.

2- Methodology

2.1. Experimental Apparatus

For the gathering of the experimental data series of the current study, a laboratory flume was used. A porous bed has been created inside of it with 20 cm depth. Two discharges of the 0.19 and 0.37 (l/s) have been operated. Four EC sensors have been installed along with the porous bed, and then by imposing the four initial concentrations of the 25, 45, 65, and 100 (gr/l) upstream of the porous bed, the EC data has been recorded with 2 seconds interval. The schematic view of the experimental apparatus is depicted in Fig. 1.

2.2. Derivation Of The Theoretical Model

For the derivation of a new theoretical model, a length unit of the porous bed has been divided into the three interconnected cells according to the method of Gosh *et al.* (2004) [7]. Frist cell is a convection cell, and the other cells are dispersion cells. A Gaussian type of the boundary condition was used at the flow and bed interface, and then the differential equations of each cell have been derived. By considering the exit concentration of each cell as the entrance concentration of the next cell, the final analytical solution has

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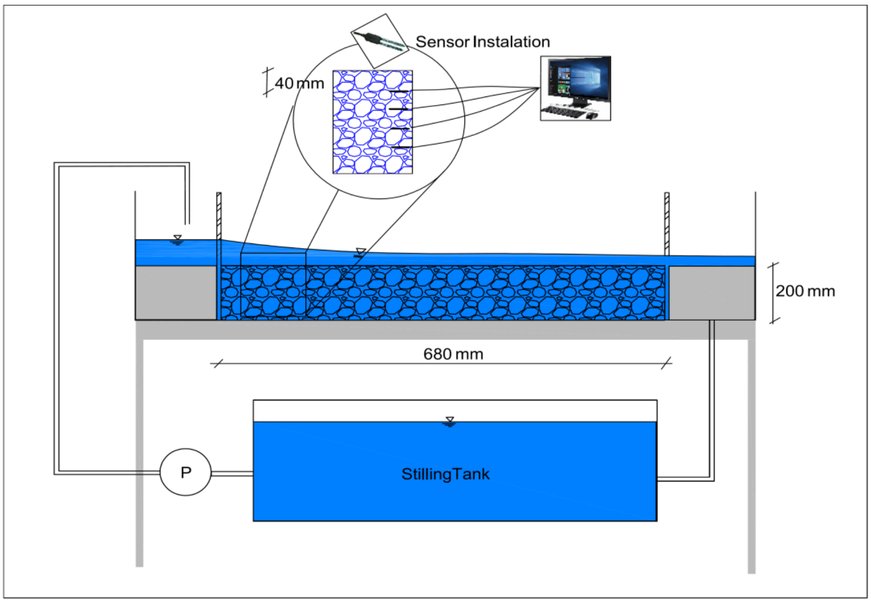

Fig. 1. General view of the experimental apparatus

been reduced to Eq. (1). α is the residence time of convection cell, T_1 and T_2 are the residence time of dispersion cells, C_0 is the entrance concentration, *Heaviside* is the step function, u average flow velocity, D is dispersion coefficient and X is the longitudinal distance from the pollution source.

The schematic view of the cell system is depicted in Fig. 2.

$$C_2(t)=\left(\frac{Heaviside(t-\alpha)\times C_0}{T_1-T_2}\right)\times \left(\exp\left(\frac{-T_1\alpha^2u^2+2\alpha T_1ux+4D\alpha^2-4Dt\alpha-T_1x^2}{4D\alpha T_1}\right)-\exp\left(\frac{-T_2\alpha^2u^2+2\alpha T_2ux+4D\alpha^2-4Dt\alpha-T_2x^2}{4D\alpha T_2}\right)\right) \quad (1)$$

3- Results and Discussion

By changing the electrical conductivities to the concentration using calibration equations of the designed instrument, the experimental BC curves have been acquired and depicted. In Fig. 3, an example of them is shown. As is illustrated, by an increase of the bed depth, the extracted BC curves changed to dispersive form, and the base concentration of all of them is more than zero. It means that some portion of the contaminant mass is trapped inside the bed. Therefore, the complete exit of pollution mass will take a long time.

For the simulation of the theoretical curves, firstly, it is needed to extract the dispersion coefficient at the flow and bed interface. Therefore, by codding in the MATLAB software, the longitudinal dispersion coefficient was obtained above the bed surface. Then, by operation of the framework of Eq. (1), the particular parameters of the presented model were extracted, and the theoretical curves were depicted. As is shown in Fig. 4, it was observed that the model works perfectly. For quantifying the goodness of fit, the statistical parameters of the root mean square error (*RMSE*) and Nash-Sutcliff were computed as 0.13, and 0.8, respectively.

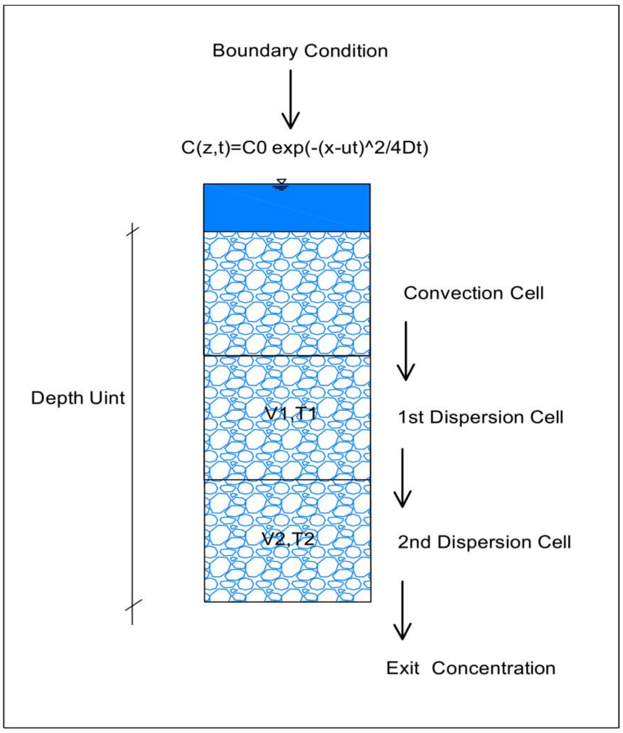

Fig. 2. Separation of each length unit of the porous bed to the three cells system

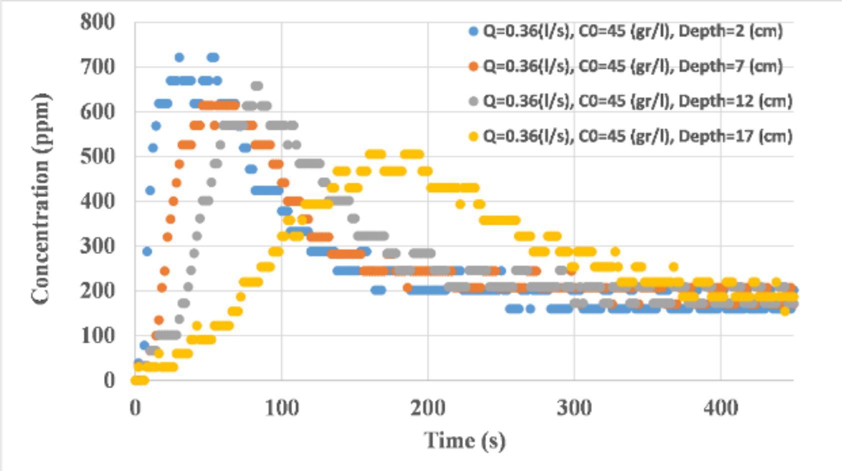

Fig. 3. Extracted BC curves from different depths of the porous bed

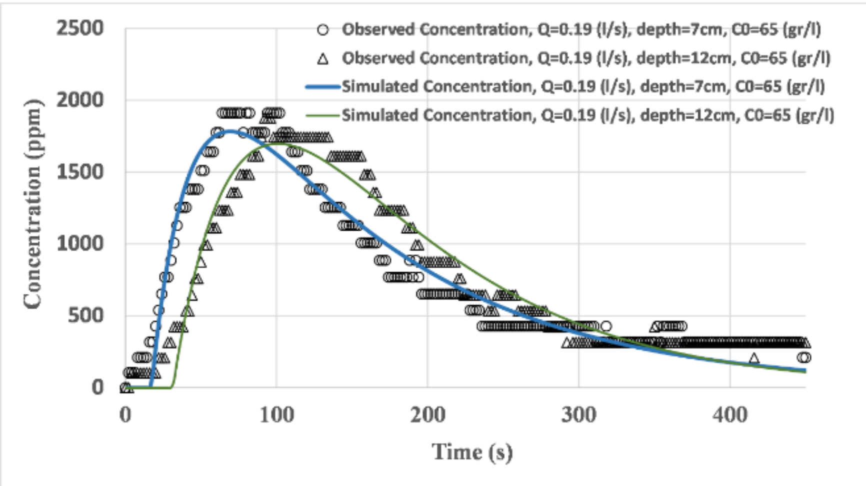

Fig. 4. Experimental BC curves at different depths versus simulated ones using the presented model

The experimental observations showed that the vertical dispersion coefficient is dependent on the flow depth over the porous bed and geometrical characteristics of the porous bed, which is directly related to the material dimensions. It is also mentioned that the turbulence characteristic of the flowing water over the bed is one of the most effective parameters in the mass penetration and motion in the porous bed [6]. As is presented in Eq. (1), the dispersive nature of the porous bed was explained using time parameters of the model (α, T_1, T_2). Therefore, it is important to interpret them using physical parameters. It is found that the α parameter is only a function of the penetration velocity. But, T_1, T_2 are indices of pollution propagation. It was observed that the dispersion coefficients and vertical velocities are reduced by an increment of the bed depth. Moreover, Sum of the model temporal parameters $(\alpha + T_1 + T_2)$ were increased by increasing the bed depth, which relates an indirect relation with dispersion coefficients.

4- Conclusion

In the present study, mass penetration through the river beds has been investigated using an experimental model. By the creation of the conceptual model of the river bed, a length unit is divided into three interconnected cells system. Governing differential equations are derived and then solved. The performance of the extracted relationship was examined using experimental data. It was found that the model works precisely and the goodness of fit parameters showed desirable values. Furthermore, the dispersion coefficients were extracted, and their variation inside the bed was discussed. It was found that there is a reverse relationship between the sum of temporal parameters of the presented model and dispersion coefficients.

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