UTILIZING SUBMERGED VANES FOR ENHANCING TRANSVERSE MIXING IN STREAMS

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ABSTRACT

Pollution is a very serious threat to our surface as well as ground-water resources. In order to sustain the quality of water, it is important to know the process of mixing of pollutants. The transverse mixing is very important which is needed to be modeled to understand mixing phenomenon. It was observed that transverse mixing is a strong function of secondary currents, thus, submerged vanes, which are aerofoil skewed at angle of 10^o-$40^o$with respect to flow, generate transverse circulations that can be utilized to induce secondary currents in the flow to enhance transverse mixing. Present study is an attempt to utilize submerged vanes as an instrument to enhance the transverse mixing by incorporating various vane configurations.

1 INTRODUCTION

It is essential to know the complete mixing process of pollutant in flowing streams, so that their effect on water quality and aquatic life can be studied thoroughly. If the pollutant gets accidently spilled in the surface water source, then it suffers the rapid mixing in the vertical direction due to dominance of flow turbulence along vertical direction, this rapid mixing of pollutant is called as vertical or near-field mixing (Fischer et al., 1979; Rutherford, 1994; Singh et al., 2009 and 2010; Zhang and Zhu, 2011a; Sharma and Ahmad, 2014). After completion of mixing in vertical direction, pollutant not only moves in longitudinal direction but also spreads laterally. This mixing of pollutant across the width or in transverse direction is called as transverse or mid-field mixing (Ahmad et al., 2011) as can be seen in Fig. 1. Transverse mixing process is a two-dimensional phenomenon (Fischer et al., 1979; Rutherford, 1994). After complete mixing of pollutant in vertical and lateral directions, now tracer moves uni-directionally along the flow. This unidirectional mixing of pollutant is called as longitudinal or far-field mixing (Azamathulla and Ahmad, 2012). Since, the vertical mixing takes place very rapidly in the area proximal to source of pollution while in longitudinal mixing pollutant spreads very slowly and takes place at fat distance from source of pollution, hence, in order to observe the mixing of pollutants in stream it is essential to study the mid-field mixing. Also it was observed by Fischer (1969) that longitudinal mixing and transverse mixing are inversely proportional processes and transverse mixing being a strong function of secondary currents. Thus, present study in an attempt to observe effect of vane generated secondary currents on the transverse mixing.

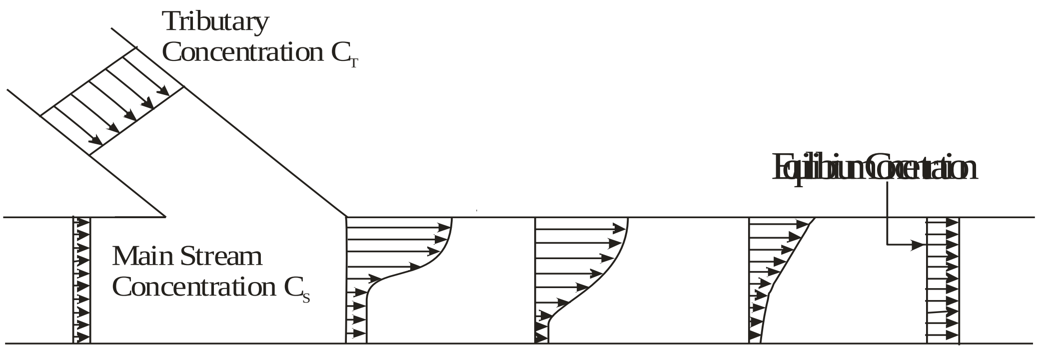

Figure 1. Conceptual sketch of transverse mixing process

2 LITERATURE REVIEW

Fischer (1969) experimentally studied effect of bend on the dispersion of tracers and found that transverse mixing is enhanced in the bend region due to secondary currents. Holley et al. (1972) studied the various aspects and factors affecting the transverse diffusion across the river and henceforth introduced the generalized change of moment method. Engmann and Kellerhals (1974) studied the effect of ice over on the transverse mixing and observed that rate of transverse mixing reduced in presence of ice-cover. Yotsoukura and Sayre (1976) developed a new method called as stream tube method and observed that it predicted the transverse dispersion more accurately than previous methods. Lau and Krishnappan(1981) numerically solved the two-dimensional tracer transport equation and included sinuosity to be an important parameter to affect the transverse dispersion. Bruno et al. (1990) experimentally studied the effect of buoyancy on transverse mixing and observed that buoyancy generated currents helped in enhancing the rate of transverse mixing. Boxall and Guymer (2003) studied the transverse mixing in natural stream and observed secondary currents to enhance rate of transverse dispersion.Seoet al.(2006) studied the transverse mixing under slug test conditions by utilizing Stream Tube Routing method and estimated the transverse mixing process accurately. Albers and Steffler (2007) analytically solved the three-dimensional advection-dispersion equation using Vertically Averaged Moment (VAM) equations to obtain the transverse mixing coefficient. Ahmad (2008) developed a finite volume model to study the steady state transverse mixing and observed that variable transverse mixing coefficient model predicts the transverse mixing process more precisely than constant transverse mixing coefficient model. Zheng et al. (2008) experimentally studied the transverse mixing phenomenon in the trapezoidal compound channel and observed that mixing in flood plain is slower than the main channel section. Dow et al. (2009) conducted their experimentations on the North Saskatchewan River and utilized the cumulative discharge method to calculate the transverse dispersion coefficient. They also observed that presence of secondary currents enhanced the transverse mixing. Zhang and Zhu (2011b) proposed a modified Stream-tube method in order to calculate the transverse mixing coefficient in ice-covered rivers.

3 EXPERIMENTAL SETUP AND PROCEDURE

The experiments were performed in a recirculating concrete flume of width 1.0 m, depth 0.30 m and length 19 m. The bed slope of the flume was 0.000632 as shown in Fig. 2. The water was supplied to the flume through an overhead tank, in which the level of water was kept constant to have a constant discharge for a particular opening of the valve-fitted in the delivery pipe of the tank. Flow from the flume was taken into a sump through a channel fitted with a sharp-crested weir for discharge measurement. The Rhodamine WT was used as tracer due to its high detectability and conservative in nature. The tracer injector, used in the present experimental work, consisted of four tubes of size 2 mm diameter placed at 35 mm spacing as shown in Fig.3. After taking the concentration profile, concentration profiles were normalized for conservation of tracer mass by multiplying measured concentration profiles from recovery factor (R. F.) which represents the amount of dye recovered downstream of vane rows and connected to a manifold. Polythene pipe from the injection system fed the tracer to the manifold. In present study R.F. was observed to be between 95% and105%.

The tubes had a number of vertical holes at the interval of 20 mm and connected to a manifold. Polythene pipe from the injection system fed the tracer to the manifold. The tracer was injected in channel of 100 mm formed by placing a plate in the main channel at a distance of 100 mm from left wall of the main channel.

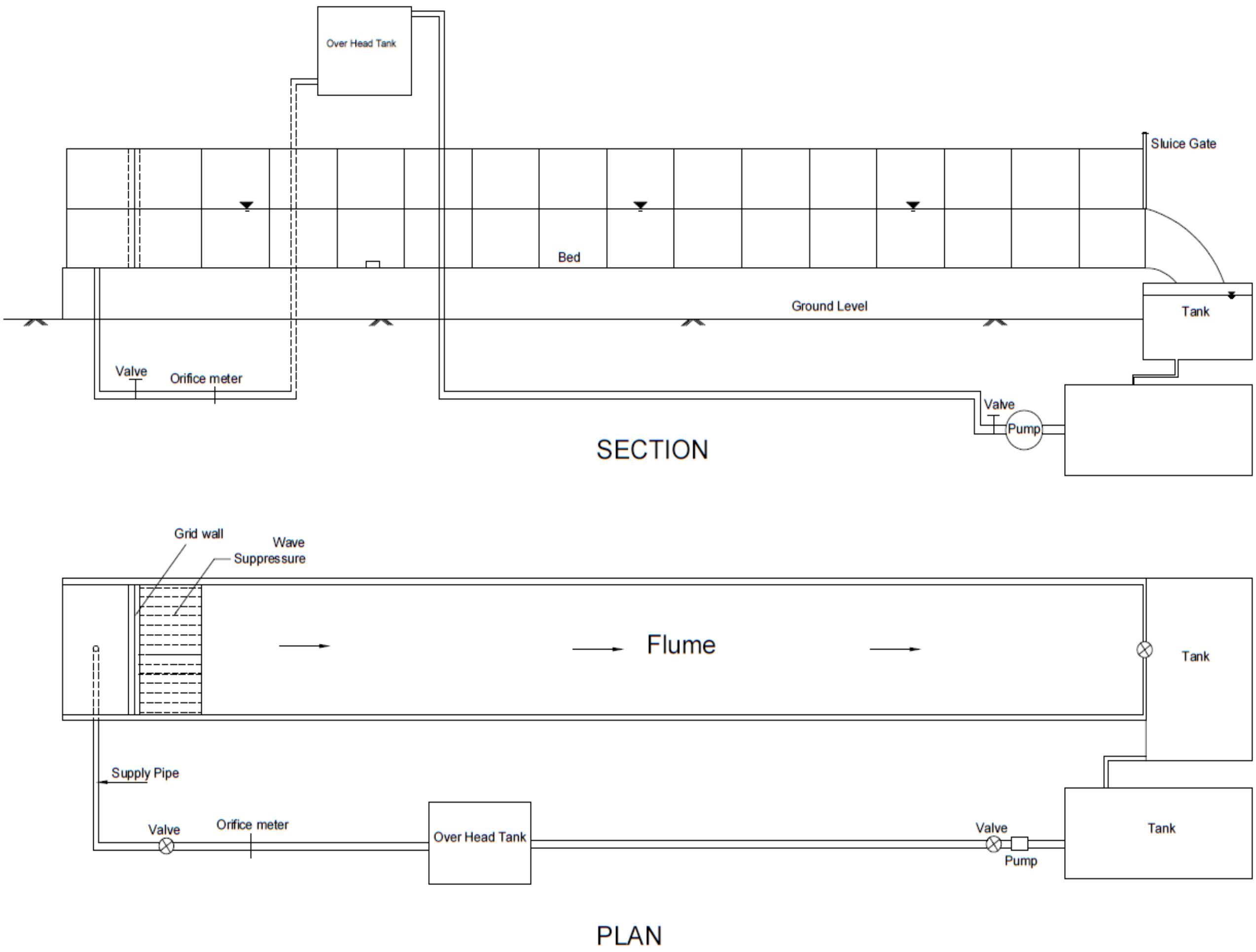

Figure 2. Layout of the flume.

The injection of tracer represents the plane source of width 100 mm.The Rhodamine WT dye concentration was measured across the width of the channel downstream of injection point using Hydro lab MS-5 probe as shown in Fig. 4. The measurements were taken at distance from upstream end of the flume x = 5m and 15 m in longitudinal direction from injection point.

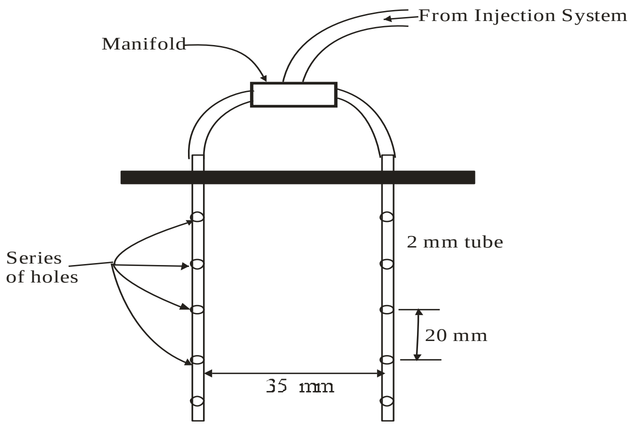

Figure 3. Tracer Injector

Figure 4.Photograph showing MS-5 Probe

On each transects, the Hydro lab MS-5 probe was allowed to take observations along y (transverse distance from left bank of the channel) = 0.02 m, 0.1 m, 0.2 m, 0.3 m, 0.4 m, 0.5 m, 0.6 m, 0.7 m, 0.8 m, 0.9 m and 0.95 m across the channel cross-section for no. of vane rows N = 0, 1, 2, 3 and 4 with each vane having angle of attack of 30^{o} with respect to direction of flow (Fig. 5). Hydro lab MS-5 has accuracy of $\pm 3\%$ while measuring a concentration equivalent to 1ppb. After taking the concentration profile, concentration profiles were normalized for conservation of tracer mass by multiplying measured concentration profiles from recovery factor (R. F.) which represents the amount of dye recovered downstream of vane rows. It took nearly 40 seconds for the water to recirculate once. Blank concentration is the concentration measured prior to release of tracer from the source and the injection of tracer in the present study is a continuous injection. Injection of dye in the flow in the present study is continuous.

Figure 5. Four arrays of installed vanes

4 EFFECT OF SUBMERGED VANES ON TRANSVERSE CONCENTRATION PROFILES

It is evident from Figs. 6 and 7 that due to dominance of circulation over advection, four vane rows generated circulation field was large and was extended to a greater distance; hence the mixing is highest in the case of 4 vane rows. As the number of vanes were reduced from four to three the amount and magnitude of circulations reduced. This reduction in extent of circulation field again created accumulation of dye near the bank and concentration profile started to regain its Gaussian nature. Further reducing the number of rows, it was observed that concentration distribution skewed further near the bank.Under no vane case, tracer dye has maximum concentration around the left bank and have got a peak around x = 0 m.

Figures 6 and 7, reinstate the fact that as the number of vane rows increases, the extent of transverse dispersion increases. It shows that across any transect as the number of rows of vane was increased the dye is uniformly mixed across the channel cross sections and as the number of rows of vanes were reduced the uniformity of mixing reduced and concentration became more and more skewed towards left bank from where dye was discharged, this implies that transverse dispersion has reduced to great extent.

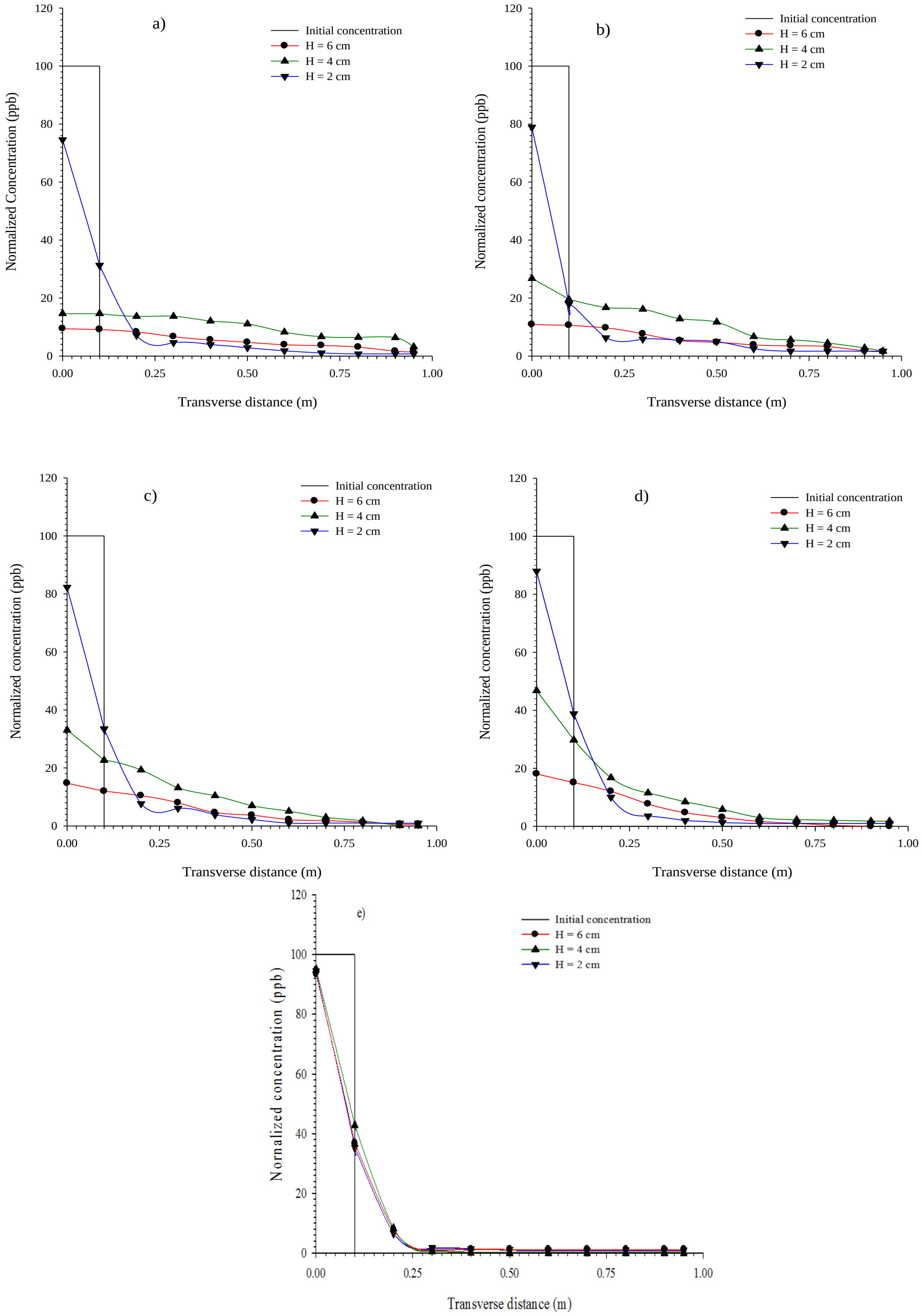

Figure 6. Concentration distribution of dye across the transects for a) 4 vane rows; b) 3 vane rows; c) 2 vane rows; d) 1 vane row; e) no vane rows for h (depth of the flow) = 0.1241 m and x = 5 m (Here, H = height of vane).

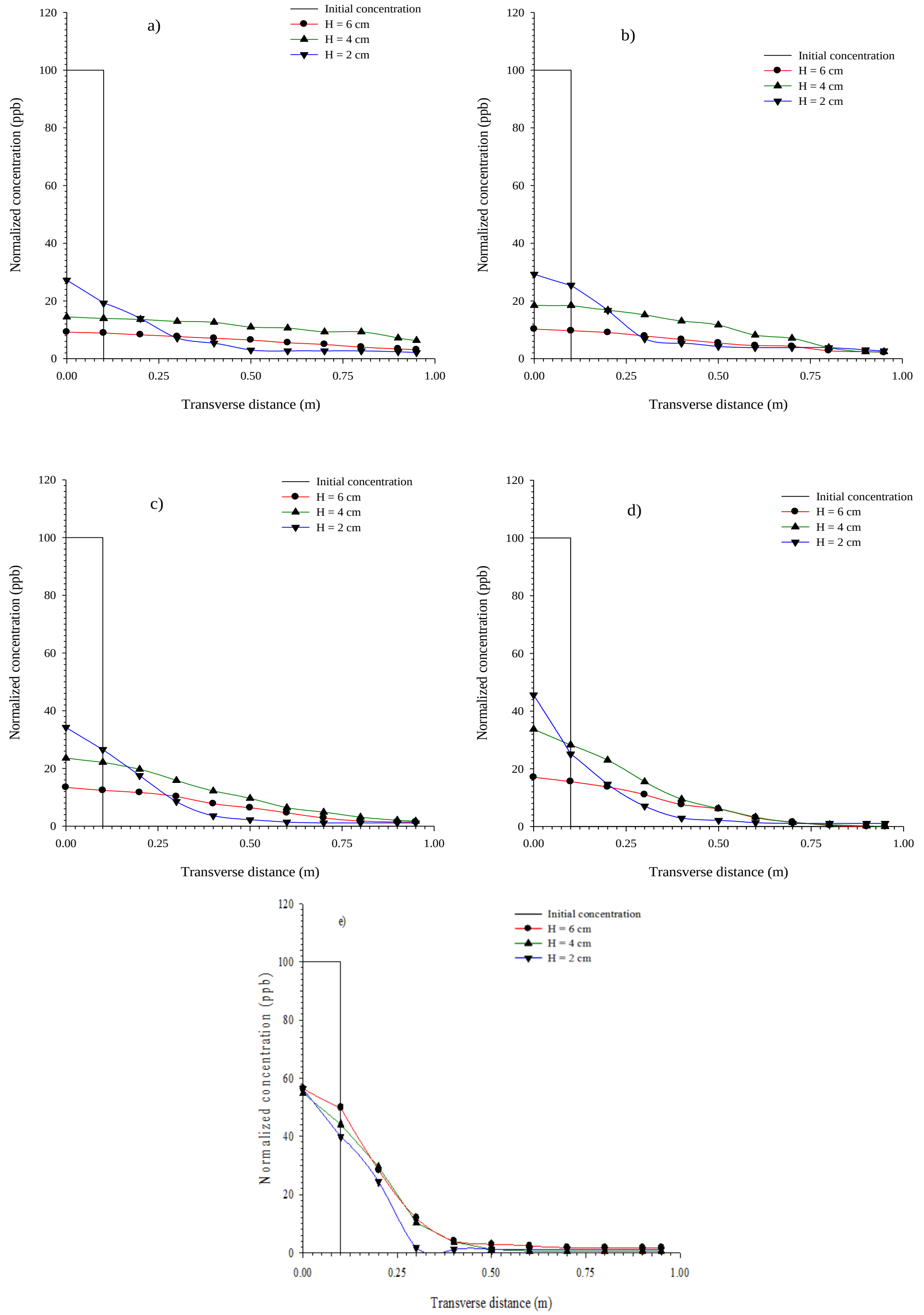

Figure 7. Concentration distribution of dye across the transects for a) 4 vane rows; b) 3 vane rows; c) 2 vane rows; d) 1 vane row; e) no vane row for h = 0.1241 m and x = 15m.

Figure 8, shows variation of ratio of transverse mixing coefficients with vane (E_{yv}) and without vane (E_y) with ratio of height of vane and depth of flow. It can be seen from Fig.8 that as the vane size increases, the transverse mixing coefficient increases drastically. This is due to the fact that a high magnitude of transverse circulations is generated in the flow as vane size increases.Further, it can be seen that the transverse mixing coefficient for higher arrays/rows of vanes is high. However, such order of increase in the transverse mixing coefficient was observed to be low for the vane in low flow depth. It can be seen that for H/h $\leq$ 0.25, vane does not affect the transverse mixing.

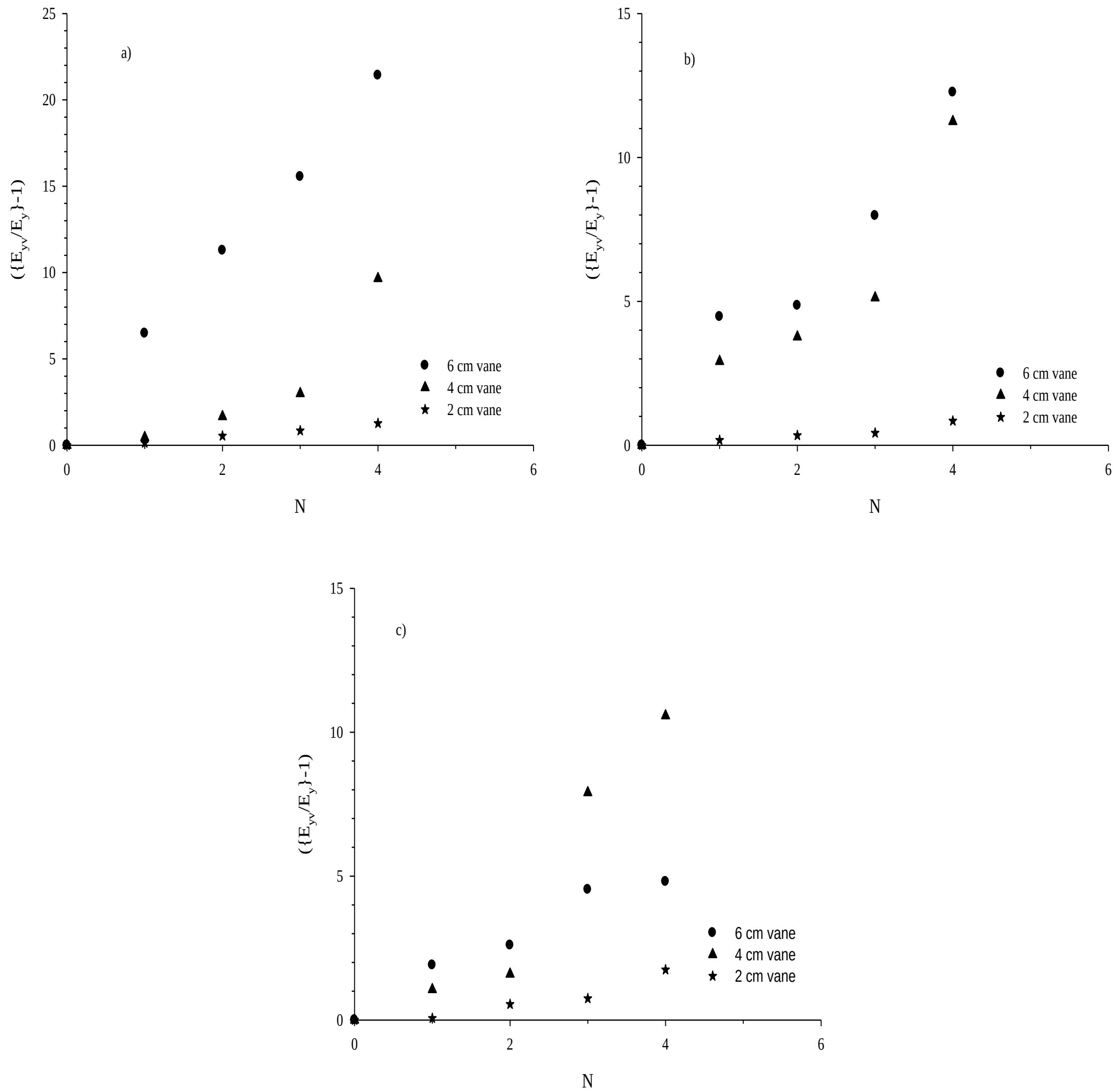

Figure 8. Variation of transverse mixing coefficient with number of vane rows for depth of flow a) 0.1241 m; b) 0.1025 m and c) 0.09 m.

5 CONCLUDING REMARKS

From the present study, it can be concluded that for z/H ≤ 0.5, (z = vertical distance from bed and H= height of vane), the advection is the major mode of transport of pollutant near the submerged vane. Due to the dissipation of smaller of the two counter-rotating vortices at leading edge of vane, hence, near to the bed the advective transport of pollutant overtook the transport of pollutant by vortices. It was observed that for z/H > 0.5, the vortex from leading edge and that separating from trailing edge interacted with each other to form a larger circulation field. For multiple vane rows, it was observed that advective transport of pollutants was reduced due to increment in circulation field. As the number of vane rows was increased, the transverse mixing was also observed to increase. It was also observed that transverse mixing coefficient increases with number and size of vanes.

LIST OF SYMBOLS USED

C_T	=	Concentration of pollutants coming from tributary
C_S	=	Concentration of pollutants in main stream
E_y	=	Transverse mixing coefficient of flow without vane rows
E_{yv}	=	Transverse mixing coefficient of flow with vane rows
H	=	Height of vane
h	=	Depth of flow
N	=	Number of vane rows
x	=	Horizontal distance of transects from inlet of flow
y	=	Transverse distance across width measure from left bank
z	=	Vertical distance along the flow depth measured from bed

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