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Analysis of transverse turbulent diffusivity data in straight rectangular channels

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The mixing of contaminants in anisotropic turbulent flow is a relevant problem in environmental fluid mechanics and river engineering. If vertical mixing analysis relies on well-known theoretical basis, a theory for transverse mixing does not exist although this process is of significant importance when dealing with the discharge of pollutants from point sources or the mixing of tributary inflows. It is believed that transverse mixing is due to turbulence generated by the channel boundaries, to vertical variations in the transverse velocity (velocity shear) and to secondary currents. The effect of these processes is usually combined into a single mixing coefficient since it is difficult to distinguish their own effects on contaminants spreading in the lateral direction.

In straight rectangular laboratory channels, the flow does not depart significantly from plane shear flow and transverse dispersion is negligibly small. Thus, in these conditions mixing is mainly due to turbulent diffusion even if secondary currents could occur increasing the rate of mixing in the channels. Since no established theory exists to predict transverse mixing rates even in these channels, turbulent diffusion coefficient and its dependence on the various flow parameters must be determined from experimental works.

This paper presents the analysis of 217 literature experimental data of transverse turbulent diffusivity D_{t-y} collected in straight rectangular laboratory channels. Notably this set of data is the largest ever collected in transverse turbulent diffusion studies. Since the coefficient is usually scaled using flow depth h and shear velocity $u*$, as first analysis the experimental data were plotted against *hu** confirming previous literature results. However, in this analysis, the role played by secondary currents on transverse mixing remains to be elucidated. Since their effect is usually related to the channel aspect ratio W/h, where W is channel width, transverse diffusivity data should be plotted against the shape factor. However, there is a something of controversy about the length scale to use for this comparison. Using flow depth h, non-dimensional diffusivity D_{t-y}/*hu** is independent of the channel aspect ratio W/h. On the contrary, using channel width W, non-dimensional diffusivity D_{t-y}/*Wu** varies inversely with W/h confirming the role of secondary currents in improving the rate of transverse mixing also in straight rectangular channels. Note that the available D_{t-y}/*Wu** data were divided in 13 groups depending on their W/h and the average values of D_{t-y}/*Wu** andW/h data were weighted using the number of data belonging to each Group. Also, a limited number of experimental data from straight rivers were inserted in the plot to confirm the observed trend.

Finally, it was demonstrated that the controversy about the proper length scale to use to non-dimensionalize the transverse turbulent diffusion coefficient D_{t-y} is only apparent. In fact, since from the data D_{t-y}*/hu*=0.179*, dividing both terms by the channel aspect ratio W/h, it is easy to obtain that D_{t-y}*/Wu*=0.179/(W/h)*. This equation demonstrates that the use of flow depth h or channel width W as characteristic length scale of transverse turbulent diffusion is equivalent. Moreover, the use of W can highlight the role of secondary currents on transverse mixing process in straight rectangular channels.