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Passive scalar mixing efficiency in open-channel confluences

Emmanuel Mignot (1), Sebastien Pouchoulin (2), Nicolas Riviere (3), and Gislain Lipeme-Kouyi (4)

(1) Univ-Lyon, INSA Lyon - LMFA, Villeurbanne, France (emmanuel.mignot@insa-lyon.fr), (2) Univ-Lyon, INSA Lyon - LMFA, Villeurbanne, France (sebastien.pouchoulin@insa-lyon.fr), (3) Univ-Lyon, INSA Lyon - LMFA, Villeurbanne, France (nicolas.riviere@insa-lyon.fr), (4) Univ-Lyon, INSA Lyon - DEEP, Villeurbanne, France (gislain.lipeme-kouyi@insa-lyon.fr)

The work deals with the efficiency of passive scalar mixing within and downstream open-channel confluences. Mixing in confluences is imposed by the local 3D hydrodynamics including: i) the slow recirculation zone, ii) the contraction zone with flow acceleration on its side, iii) downstream secondary currents and iv) a mixing-layer at the interface between the two incoming flows. The mixing efficiency thus strongly depends on the characteristics of these large structures that exchange fluid from one flow region to another and that are, themselves, strongly impacted by the characteristics of the confluence geometry (angle, roughness, bed forms. . .) and of the inflows (momentum and density ratio, density...). The present work aims at investigating the influence of i) the confluence geometry and ii) inflow characteristics on the mixing efficiency at the confluence. In the literature, this efficiency is for example related to the evolution, along the streamwise axis of the downstream branch, of parameter E, accounting for the variability of scalar concentration c_i measured in cell i (normalized by the upstream concentration c_u of the polluted incoming flow) within a section of mean concentration c_m, as:

$$E = \sqrt{\frac{1}{n}\sum_{i=1}^{n}\left(\frac{c_i - c_m}{c_u}\right)^2}$$

where n is the number of measurements in each section.

These results then permit to estimate the so-called “length for perfect mixing” L_m, defined as the distance from the confluence to the section where the differences of local concentrations from a uniform one become lower than a given threshold value (typically 5%).

The selected approach combines an experimental and a numerical approach. In a first step, the experiments aim at measuring for a selected configuration, the 3D spatial distribution of passive scalar in a simplified subcritical 90° angle confluence in order to better understand the mixing processes and to validate the selected numerical calculation methods. A novel laboratory technique able to measure the 3D concentration field within a closed-loop flume is presented along with corresponding limits, precautions and uncertainties. The data set obtained experimentally is then used to calibrate and validate 3D-LES and 3D-RANS numerical codes. In a second step, a series of calculations using the calibrated model will be undertaken in order to estimate the impact of the confluence geometry and of the inflows parameters on the passive scalar dispersion efficiency.