# Mixing performance of a chaotic micro-mixer: a *CFD* study

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Micro-mixing of liquids is a complex problem given that the mixing performance is governed by the slow diffusive mass transfer. During the last decade, experimental and computational studies were performed to determine the rate of mixing in various types of micro-mixers operating at the low Reynolds numbers that are of interest to micro-fluidic applications (Baier et al., 2005). In a previous work conducted in this Lab (Mouza et al., 2008) a prototype of a *Dean* mixer, consisting of a micro-channel (*i.d.*=1mm) with consecutive curves, has been experimentally studied. This μ-mixer comprises several features that are known to promote chaotic mixing, i.e., curved conduits, split and recombine structures as well as backward and forward facing steps. The understanding of the flow processes in μ-mixers is essential for the design of micro-fluidic devices and can be considered an essential step towards process intensification.

The aim of the present work is to extend the previous study by numerically investigating the effect of the various geometrical parameters of the conduit as well as the *Re* of the fluid on the mixing efficiency (i.e., the extent of mixing) of this type of equipment. *CFD* is used for simulating the flow inside the micro-mixing device and obtaining results concerning the extent of mixing. For the needs of the present study a parallel computing cluster is employed. For this purpose, a module of a prototype micro-mixer is designed, based on the dimensions of a previously employed experimental device. Two fictional fluids resembling the physical properties of water are entering the module, while each fluid occupies initially half of the inlet section. A Design-of-Experiments (*DOE*) method is used for the selection of appropriate design points (***Table 1***).

**Table 1.** Training points for *CFD* simulations.

| *DOE#* | *$D_1$ (mm)* | *$D_2$ (mm)* | *Re* | *DOE#* | *$D_1$ (mm)* | *$D_2$ (mm)* | *Re* | *DOE#* | *$D_1$ (mm)* | *$D_2$ (mm)* | *Re* |
|---|---|---|---|---|---|---|---|---|---|---|---|
| 1 | 3.5 | 8 | 100 | 5 | 3.5 | 9 | 50 | 9 | 4.5 | 8 | 50 |
| 2 | 5.5 | 8 | 100 | 6 | 5.5 | 9 | 50 | 10 | 4.5 | 10 | 50 |
| 3 | 3.5 | 10 | 100 | 7 | 3.5 | 9 | 150 | 11 | 4.5 | 8 | 150 |
| 4 | 5.5 | 10 | 100 | 8 | 5.5 | 9 | 150 | 12 | 4.5 | 10 | 150 |
| | | | | | | | | 13 | 4.5 | 9 | 100 |

The various configurations are then studied by performing computational *CFD* simulations of a tracer (i.e., mass-less seed particles) injected instantaneously (a pulse input) in one of the fluids. The extent of mixing is investigated by monitoring the residence time distribution (*RTD*) of the tracer while the shape of *RTD* is used as an indicator of the mixing efficiency(Adeosun and Lawal, 2009). The *RTD* curves for the various simulations are presented in ***Figure 1***.

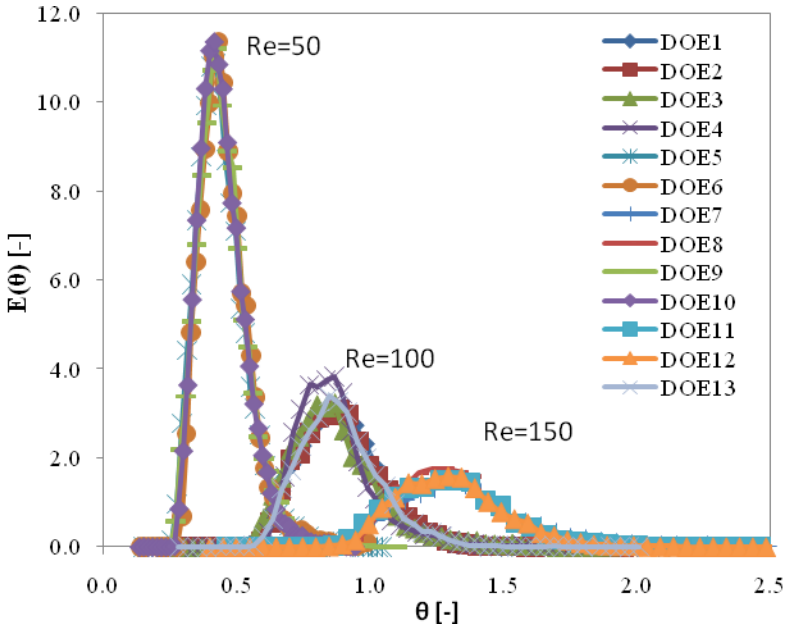


**Figure 1.** Dimensionless RTD of particle tracking with random walk simulation for all the cases studied.

It is obvious that the *RTD* curves become narrower when *Re* is increased indicating that better mixing is achieved for Re=150, even though at higher *Re* the contact time between the fluids is shorter. This is attributed to of secondary flows formed by increasing the *Re*, which cause chaotic advection. A closer inspection of the results for *Re=100*, reveal that, as expected, the worst mixing performance is observed for DOE4, i.e., when both the small and the large circular segment have the larger diameter, i.e. the smaller curvature. Moreover, the mixing efficiency is more influenced by the curvature, i.e., the diameter $D_2$, of the larger semi-circular part of the conduit. It is obvious that cases DOE1 and DOE2 which have the same $D_2$, the extent of mixing is practically the same (identical *RTD* curves).

A quadratic model (***Eq.1***) has been also formulated for the prediction of maximum E(θ)

$$E(\theta) = a_0 + a_1 D_1 + a_2 D_2 + a_3 Re + a_{11} D_1^2 + a_{22} D_2^2 + a_{33} Re^2 + a_{12} D_1 D_2 + a_{13} D_1 Re + a_{23} D_2 Re$$

The model coefficients are predicted using the *CFD* results (***Table 1***). The model is found to be in very good agreement with the *CFD* data. The results of the present study confirm that *CFD* is a practical tool for designing and studying such type of devices.

**Table 2.** Coefficients of quadratic model for predicting *E*(θ*)* peak value in *RTD* plots.

| | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|
| $\alpha_0$ | 25.4770 | $\alpha_2$ | -0.113548 | $\alpha_{11}$ | -0.0659745 | $\alpha_{33}$ | 0.0012170 | $\alpha_{13}$ | -0.0011582 |
| $\alpha_1$ | -0.531248 | $\alpha_3$ | -0.331695 | $\alpha_{22}$ | -0.0241266 | $\alpha_{12}$ | 0.157850 | $\alpha_{23}$ | -0.0002943 |

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