Micromixing in Fluidic Devices: Fluidic Oscillator, Helical Coil and Vortex based Cavitation Device

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Highlights

- Villermuax Dushman parallel reaction scheme was used to characterize micromixing time.
- Engulfment model was used to estimate micromixing time from experimental data.
- Three devices exhibiting widely different energy dissipation rates were characterized.

1. Introduction

Villermaux Dushman reactions are widely used for estimation of the micromixing time [1,2]. It is possible to relate local micromixing to the measured selectivity / segregation index using these reactions. This work focuses on characterizing micromixing in three fluidic devices namely: fluidic oscillator (FO), helical coil (HC) and vortex based cavitation device (VD). These devices have applications in crystallization, emulsions and synthesis nano-particles. Together, these three devices cover a wide range of shear rates and turbulence energy dissipation rates and thus collectively offer an attractive platform for a wide range of applications [3–5]. Quantitative characterization of micromixing in these devices obtained by carrying out the Villermaux Dushman reactions will help to select appropriate device and operating parameters as per the requirements of desired process application.

2. Methods

Villermaux Dushman rapid parallel competitive reaction system [1,2] was used to quantify the micromixing performance of the fluidic devices. Two parallel reactions – R1 and R2 (given below) are competitive, the first one being a neutralization reaction (instantaneous) and the second one being a redox reaction (fast–reaction time scale comparable to micromixing time). R3 is in equilibrium with R2.

$$H_2BO_3^- + H^+ \rightarrow H_3BO_3 \qquad \text{(R1)}$$

$$IO_3^- + 5I^- + 6H^+ \rightarrow 3I_2 + 3H_2O \qquad \text{(R2)}$$

$$I_2 + I^- \rightarrow I_3^- \qquad \text{(R3)}$$

Before performing reactions in the devices, each of the devices was characterized to obtain pressure drop and energy dissipation. The two reactant streams – buffer solution ($H_2BO_3^-/H_3BO_3$) with KI and KIO_3; and H_2SO_4 solution were passed through the fluidic devices using dosing pumps via a cross junction with equal flow rates. The concentrations of all the reactants were chosen from the literature [1-3]. The concentrations of the reactants KI, KIO_3, H_3BO_3, NaOH and H_2SO_4 were chosen as 0.0116 M, 0.00233 M, 0.25 M, 0.125 M and 0.036 M respectively. In the present work, we used the engulfment model [6,7] for interpreting experimental data and estimating characteristic micromixing time. The model is used to simulate micromixing experiments carried out with FO, HC and VD over relevant operating range. The fluidic devices (FO, VD, and HC) were sized and fabricated based on previous studies [4,8,9]. The devices were operated using a recirculation loop to intensify the mixing process. The experimental setup used in this work is shown in Figure 1. Throughout the course of the reaction, the pH was continuously monitored. Once the pH was constant, indicative of reaching a steady state achieved (usually after five residence times), the product sample was collected and analyzed using a UV-visible spectrophotometer. Using the engulfment model and experimentally measured segregation index, the micromixing time was estimated by fitting.

3. Results and discussion

The energy dissipation rate of VD is in the range of ~10^3-10^4 m^2/s^3, that of HC is ~10^2 m^2/s^3 and that of FO is ~10^1 m^2/s^3. This concentration set chosen above was selected to obtain absorbance of I_3^- between 0.1 and 2.5. Once the concentration of I_3^- was known, the segregation index (the relative amount of H^+ consumed by R2) was calculated. The flow rates of two reactant streams were adjusted from 10-40 mL/min to obtain the desired residence time. The recirculation flowrate for was varied from 1 to 3 L/min. By varying the recirculation flow rate, the micromixing time can be manipulated which affects the selectivity of the reaction. The values of micromixing time were estimated by fitting the model predictions with the experimental data. As the measured segregation index increases, the micromixing time also increases. The quantitative results of micromixing for the FO, VD and HC at different values of energy dissipations will be presented in the full manuscript.

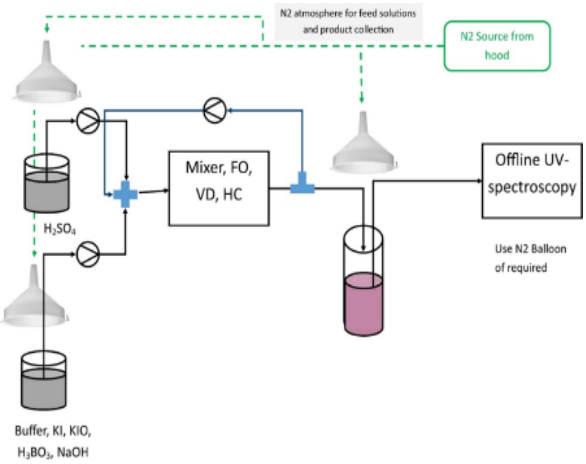

Figure 1: Schematic of experimental set-up

4. Conclusions

In this work, the engulfment model was used to estimate the micromixing time of the three devices – FO, HC and VD over the wide operating ranges covering energy dissipation rates from ~10^1 to 10^4 m^2/s^3. The effect of flow rate, recirculation rate, and device scale on the segregation index and thus on micromixing time was studied. The model, estimated micromixing time and a simplified correlation in terms of different reaction and process parameters will be presented in the full manuscript.

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Keywords
"Micromixing; Engulfment model; Villermaux Dushman reactions; Fluidic Devices"