Electronic Supplementary Information (ESI)

**PDMS-based Turbulent Microfluidic Mixer**

Jae Bem You,† Kyowon Kang,‡ Hongkeun Park,‡ Thanh Tinh Tran,§ Wook Ryol Hwang,§ Ju Min Kim,‡,§* and Sung Gap Im,‡,§*

---

**a** Department of Chemical and Biomolecular Engineering, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea 305-701

**b** Department of Chemical Engineering, Ajou University, Suwon, Republic of Korea 443-749

**c** School of Mechanical Engineering, ReCAPT, Gyeongsang University, Jinju, Republic of Korea 660-701

**d** KAIST Institute (KI) for NanoCentury, Korea Advanced Institute of Science and Technology (KAIST), Daejeon, Republic of Korea 305-701

**e** Department of Energy Systems Research, Ajou University, Suwon 443-749, Republic of Korea

**Figure S1. Analysis locations**

![Diagram](image)

Details of locations at which analyses were performed: (a) inlet and outlet intensities and (b) coefficients of variation.
Figure S2. Inlet and Outlet images and concentration profile for 6, 8 and 14 ml/min

S3. Details of computational fluid dynamics

The Reynolds-averaged Navier–Stokes equations for mass and momentum conservation are as follows:

\[
\frac{\partial u_i}{\partial x_i} = 0,
\]

\[
\rho \frac{\partial u_i}{\partial t} + \rho u_j \frac{\partial u_i}{\partial x_j} = -\frac{\partial p}{\partial x_i} + \frac{\partial}{\partial x_j} \left[ \mu \left( 2D_{ij} - \frac{2}{3} \delta_{ij} \right) \frac{\partial u_k}{\partial x_k} \right] - 2\mu_t D_{ij} - \frac{2}{3} \rho k \delta_{ij}.
\]
The symbols $\rho, \mathbf{u}, D_{ij} = \frac{1}{2} \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} \right)$, $\mu, \mu_t$, and $k$ are the density, velocity, rate-of-deformation tensor, hydrostatic pressure, dynamic viscosity, turbulent viscosity, and turbulent kinetic energy, respectively.

The $k-\omega-SST$ turbulent model

The equations for the kinetic energy $k$ and turbulence energy dissipation rate $\omega$ are as follows:

$$\frac{\partial k}{\partial t} + \mathbf{u} \cdot \nabla k = \frac{\partial}{\partial x_j} \left( \tau_{ij} - \beta \rho \omega k + \frac{\partial}{\partial x_i} \left( \mu + \sigma_k \mu_t \right) \frac{\partial k}{\partial x_i} \right),$$

$$\frac{\partial \omega}{\partial t} + \mathbf{u} \cdot \nabla \omega = \frac{\gamma}{v_t} \frac{\partial u_i}{\partial x_j} - \beta \rho \omega^2 + \frac{\partial}{\partial x_j} \left( \mu + \sigma_\omega \mu_t \right) \frac{\partial \omega}{\partial x_j} + 2(1 - F_1) \rho \sigma_\omega \frac{1}{\omega} \frac{\partial k}{\partial x_j} \frac{\partial \omega}{\partial x_j}.$$

The constants $\sigma_k, \gamma,$ and $\sigma_\omega$, denoted by $\phi$ collectively, are computed from the weight-average constants $\sigma_{k1}, Y_1,$ and $\sigma_{\omega1},$ denoted by $\Phi_1$, of the shear-stress transport (SST) model, and the constants $\sigma_{k2}, Y_2,$ and $\sigma_{\omega2}, \phi_2,$ of the $k-\varepsilon$ model: $\phi = F_1 \Phi_1 + (1 - F_1) \Phi_2$, where the blending function $F_1$ is

$$F_1 = \tanh \left( \min \left\{ \max \left\{ \frac{\sqrt{k} \sqrt{500\nu}}{0.09 \omega}, \frac{4 \rho \sigma_\omega \sqrt{\varepsilon}}{C_D \omega \gamma^2} \right\} \right\} \right),$$

with $C_D = \max \left( \frac{2 \rho \sigma_\omega \sqrt{\varepsilon}}{\omega \gamma^2} \right), 10 - 20$.

The constants are $\sigma_{k1} = 0.85$, $\sigma_{\omega1} = 0.5$, $\beta_1 = 0.075$, $\alpha_1 = 0.31$, $\beta^* = 0.09$, $\kappa = 0.41$, and $Y_1 = \beta_1 / \beta^* - \sigma_{\omega1} \kappa^2 / \sqrt{\beta^*}$ for the SST model, and $\sigma_{k2} = 1.0$, $\sigma_{\omega2} = 0.856$, $\beta_2 = 0.0828$, $\beta^* = 0.09$, $\kappa = 0.41$, and $Y_2 = \beta_2 / \beta^* - \sigma_{\omega2} \kappa^2 / \sqrt{\beta^*}$ for the $k-\varepsilon$ model.

The following definitions are used:

$$\tau_{ij} = \mu \left( \frac{\partial u_i}{\partial x_j} + \frac{\partial u_j}{\partial x_i} - \frac{2}{3} \frac{\partial u_k}{\partial x_i} \delta_{ij} \right) - \frac{2}{3} \rho k \delta_{ij}.$$
\[ \nu_t = \frac{a_1 k}{\max(a_1 \omega; S F_2)} \]

\[ F_2 = \tanh \left[ \max \left( \frac{\sqrt{k}}{0.09 \omega y^2}; \frac{500 \nu}{y^2 \omega} \right) \right] \]

; \( S \) is the second invariant of the rate-of-deformation tensor \( D \).

**Convection–diffusion equation for dye transport:**

The concentration of a dye, denoted by \( c \), is described by the following convection–diffusion equation:

\[
\frac{\partial c}{\partial t} + u_i \frac{\partial c}{\partial x_i} = \frac{\partial}{\partial x_i} \left[ D_m + \frac{\nu_t}{S c_t} \frac{\partial c}{\partial x_i} \right]
\]

where \( D_m, \nu_t, \) and \( S c_t \) are the mass thermal diffusion coefficient, turbulent kinematic viscosity, and turbulent Schmidt number, respectively.