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Evaluation of Mixing Performance in Different Kinetic Static Micromixer; A Numerical Approach

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Abstract

This study examined the dynamic and thermal behaviours of several kinetic static mixer forms using a numerical simulation, which can create the chaotic advection using splitting-recombining and twisting mechanism of the fluid streams. The static mixer's three-dimensional model was created.To examinate the mixer's performance, multiple parameters was taking in consideration. The fluid velocity and it characterized using Reynolds numbers varying from 10 to 100, as well as factors such as shear rate and pressure drop for calculating the dynamic performance. Additionally Nusselt number and fluid temperature was examinee to gain insights into thermal characteristics. In this investigation, the effectiveness of four various mixer shapes was thoroughly evaluated. The outcomes underlined the significant impact changes in mixing micromixer can have on the fluid's dynamic characteristics, which in turn affects thermal performance. Case 3 configuration has the best heat transfer rate, and with the geometry (case 3) you have approximately 45% reduced pressure drop compared to standard KMS. Remarkably, among the proposed micromixer shapes, case three stands out as the best performer, according to our findings.

Keywords: Lab On Chip, Micromixer, Micromachine, TLCCM.

“1. Introduction”

Micromixers serve a range of uses, spanning biomedical, environmental, and chemical analysis. They are crucial components of micro-total analysis systems, which require the rapid and full blending of species over a variety of activities [1]. Various characteristics of micromixers were developed to generate quick and homogeneous mixing; micromixers are often classed as either active or passive devices based on the mixing principles [2]. To mix species, active micromixers require external energy. Because of their simple designs, ease of manufacture, and increased robustness and stability, passive micromixers are preferred [3].

However, fresh ideas are being produced, while innovative uses are being explored. Statical mixers are employed in-line as a substitute for the traditional agitator during a single-pass process as well as a recycling cylinder. Their application in continuous operations is an intriguing alternative to classical agitation since they can produce comparable and superior outcomes at a cheaper cost. Fixed mixers consume less energy and demand less maintenance due to the fact that they don't include moveable elements. In lot-fed systems, they provide a more predictable as well as evolvable dilution rate and may allow for the homogeneity of nutrient fluxes with a short duration of residence.[4]. Producers of static mixers offer an array of applications, including laminar and turbulent systems. The laminar flux mixture is founded on flux fractionation and recombination. During the course of turbulence, the components produce more turbulence than an identical flat tube. In processes requiring mixing, reaction, dispersion, transmission of heat, and transfer of mass, mixtures have been used [5-7]. Hobbs et al. [8] studied Kenic's static mixer and employed lagrangian methods to assess it digitally. The properties of the mixer's laminar flux performance. They examined the performance of the mixer at different Reynolds numbers. Analysis of laminar mixtures in an SMX static mixer Positron emission particle tracking and magnetic resonance imaging were used to assess the situation. This research focuses on the mixing indices, which combine both local speeds and concentration fields in the mixing element structure at 0.5 mm intervals along the length of nine SMX static mixer elements [9].

Meng et al [12] performed a new model of static mixer with various of twisted leaves (single, double, triple and quadruple) using different values of Reynolds number [Re = 0.1–150] and high viscosity of Newtonian fluid. Lagrangian tracking method was used to assess the influence of geometry construction, Re number and aspect ratio on the chaotic mixing characteristics. The triple and quadruple twisted leaves have significant efficiency

than double leaves. Jiang et al. [13] investigated the Kenics static mixer thickness according to pressure drop based on the turbulent flow for Newtonian fluids. Different parameters such as Reynolds number, the aspect ratio, the thickness and the friction factor were used to define the pressure drop using the proposed method of partial least squares regression combined with Latin hypercube sampling. Moreover, the aspect ratio of length to diameter (0.2–2) was evaluated on the Kenics static mixer. The good ratio which makes the model work with a shorter mixing time and mixer length was the small aspect ratio [14]. Furthermore, the increasing of wall thickness has a great influence on the gradient of velocity and shear stress. Rahmani et al. [15] used two common static mixers (SMX and helical) with a single-phase of newtonian fluid and laminar flow (Re = 0.1 - 100) numerically. According to their obtained results, the SMX static mixer showed a higher performance than helical mixer. However, some modifications and developments were added to the helical mixer compared with the Kenics static mixer. These modifications presented a good mixing than the Kenics mixer depended on pressure drop measures [16]. A new geometrical model of static micromixer was investigated by Li et al. [17] experimentally and numerically using a heterogeneous system of diesel/water. The effect of particle size in the swirl mixer was analyzed by Malvern laser. They proved that the micromixer has a great improvement on the static mixing.

The aim of the study, a numerical CFD of Newtonian fluid and laminar flow circulating in a Kenic static mixer was performed to predict the effect of dynamic and thermal performance on Kenic static mixer. Four modified cases were proposed for static mixer in order to improve the thermal performance of static mixer.

"2. Geometric discussion and boundary conditions"

In this study, three-dimensional geometry of static mixer was studied using CFX18.2 CFD software. The simulation was carried out in order to investigate the effect of heat transfer parameters (Nusselt Factor and performance ratio) in a static mixer with four different modified cases. A cylindrical pipe and helical of Kenics static mixer were designed as shown in figure 1. The dimensions of cylindrical pipe are a length L, diameter D, and thickness W are 0.867 mm, 0.052 mm and 0.0032 mm respectively. The SM is composed with six principal fixed elements of helical shape (L/6).

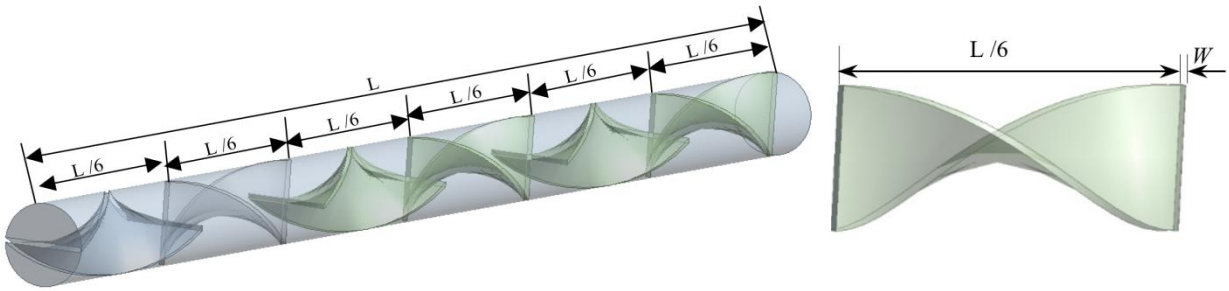


Figure 1: Reference geometry

Figures 2 (a-d) illustrate the different modified cases which proposed in the static mixers. There are four cases as shown in below figures; (a) first modified case with one whole along the static mixer, (b) second case with two holes, (c) third case with three holes. Each hole in the modified case revolves with the same rotation of static mixer between the angles of 0° and 90°. The width of hole empty is 10 mm.

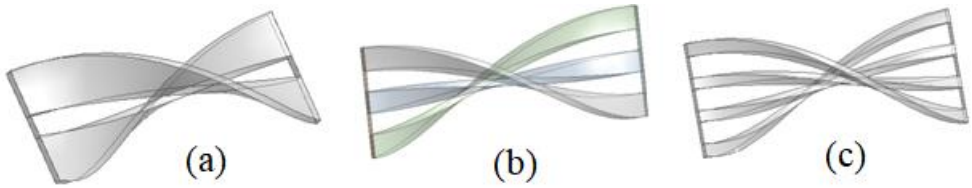


Figure 2: Different cases studied, (a) Case N°1, (b) Case N°2, (c) Case N°3

3. Computational Domain and Mesh independency test

Figure 3 shows the unstructured tetrahedral mesh which constructed for pipe and modified case N°4. The grid resolution was refined in the regions near to the static mixer surfaces. Table 2 illustrates the mesh statistics for different defeature on case N°4.

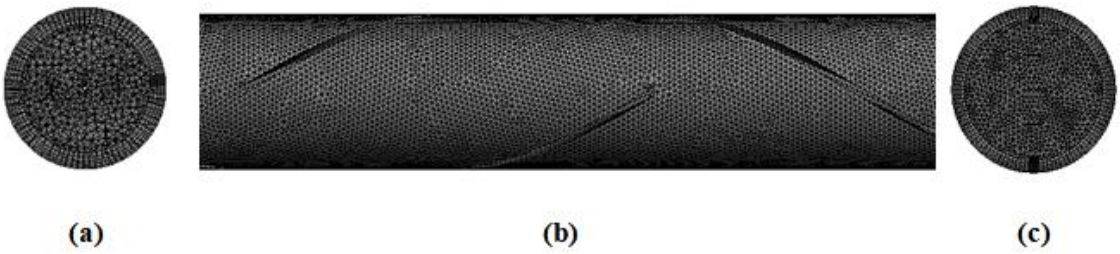


Fig. 3. Tetrahedral mesh (a) inlet, (b) pipe, (c) outlet,

To select an appropriate mesh, an unstructured mesh with tetrahedral elements was constructed, and multiple grids were tried for the suggested geometry (Fig.2). After the marked cell size, numerical differences are unimportant; thus, this can be studied as the superior mesh for the calculation. This mesh size with 338438 cells will produce better outcomes in less time than the finer mesh.

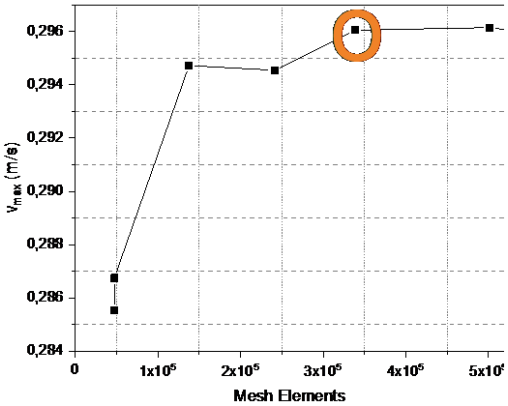


Fig. 4. Mesh Independency Test

"4. Governing equations & numerical methodology"

The flow and mixing in the micromixers have been examined using a commercial CFD-code called ANSYS CFX-11.0 [12]. The Navier-Stokes equations are solved using the coupled solver in the ANSYS CFX-11.0 package, which also solves the stable continuity and momentum (Navier- Stokes) equations. Modelling fluid mixtures with numerous distinct physical components, each of which may have a unique set of physical properties, is possible with ANSYS CFX. To determine the fluid flow, the CFX-solver will determine the appropriate average values of the attributes for each control volume in the flow volume. These numbers are based on the percentages of each component contained in the control volume as well as the values of each component's attributes. It was supposed that multi-component fluids are mixed at the molecular level and that the properties of the fluids rely on the component ratios. The mass-fraction is also thought to form by convection and diffusion. Relative mass flux terms are used to calculate the separate components of the mixture's differential movements. Relative mass flux is modelled using factors such as pressure gradients, concentration gradients, etc. A CFD code is used to solve steady conservation equations of incompressible fluid [12]. These equations are stated as follows:For incompressible and stable flows, the 3D governing equations are continuity, momentum, and species mass fraction convection diffusion equation:

$$\nabla U = 0 \quad (1)$$

$$\rho U \cdot \nabla U = -\nabla P + \mu \nabla^2 U \quad (2)$$

$$U \cdot \nabla C = D \nabla^2 C \quad (3$$

Where U signifies velocity, ρ is fluid density, P static pressure, μ viscosity, C concentration, and D diffusion coefficient.The apparent viscosity of power-law non-Newtonian fluids is given by:

$$\mu_a = k\dot{\gamma}^{n-1} \quad (4)$$

Where k denotes the consistency coefficient and n is the power-law index, γ denotes the shear rate.

The generalized Reynolds number (Reg) of a shear thinning fluid is defined as;

$$Re_g = \frac{\rho U^{2-n} D^n}{\frac{k}{8}\left(\frac{6n+2}{2}\right)^n} \quad (5)$$

The mixing rate is described as follows to assess the efficiency of Kenics micromixers:

$$MI = 1 - \frac{\sigma}{\sigma_0} \quad (6)$$

Where σ represents the mass fraction standard deviation and is denoted as:

$$\sigma^2 = \frac{1}{N}\sum_{i=1}^{N}(C_i - \bar{C})^2 \quad (7)$$

N is the number of sampling locations within the transversal division, C_i denotes the mass fraction at examining point i, and $\bar{C}$ denotes the ideal mixing mass fraction of C_i, which is equal to 0.5. σ_0 denotes the standard deviation at the inlet section.

The inputs were described as velocity inputs with boundary constraints, the outlet's static gauge pressure was set to zero (p = 0), and the wall was chosen as a stationary wall with no sliding condition. The simulation was restarted, but the rate of entry into the laminar flow regime was altered (by changing the Reynolds number: 10 ~ 250). The concentrations of lateral input are 0 and 1, respectively.

"5. Result & discussion"

The numerical method using CFD calculation is considered as one of the best techniques to analyze the behavior of mixing efficiency of all modified static mixer geometries. In this work, the influence of laminar flow at low values of Reynolds numbers in mixing system with modified mixer geometries was studied based on different parameters such as, velocity profile, pressure drop, friction factor, Nusselt number and performance ratio. The Reynolds number is a constant value which describes the situation of fluid flow in mixing systems. At low Reynolds numbers (Re = 10, 30, and 50), the fluid flows as a laminar. Figure 4 Shows that as the Reynolds number increases mixing performance is increases.

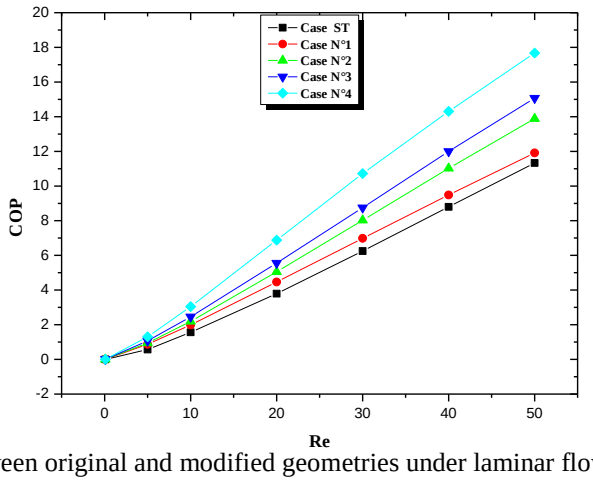


Figure 5: Comparison between original and modified geometries under laminar flow (a) Nusselt factor, and (b) performance ratio.

The flow pressure represents the kinetic energy of the fluid at a given section. Since we know that there may be different speeds at the other point of a cross section, each point of the cross section will therefore have a different velocity pressure. Thus, the total velocity pressure of a cross section must be the average area of velocity pressures at all points, which may be different for different cross sections. The results obtained of the pressure drop and the friction factor in cases modified with respect to the original geometry are presented in Figure 6. It is clear that pressure drops (Figure 6) and the friction factors increase significantly linearly with the increase in the Reynolds number. In addition, the pressure drop value increases almost with the increase of holes in the modified casing compared to the original geometry. In the contract, the friction factor is decreased with the increase of the holes.

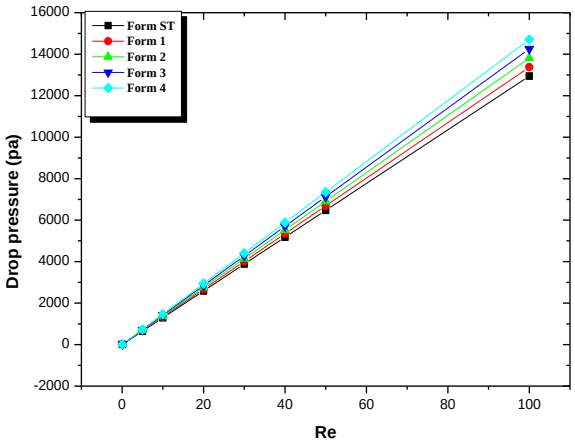


Figure 6: Comparison between original and modified geometries under laminar flow (a) pressure drop,

Velocity profile is an important quantity to define the behavior of water flow in the static mixers with the change of Reynolds Number (Re = 10, 30 and 50). As illustrated in the below figures 7, the effect of Re number on the original static mixers and modified cases is presented according to the velocity distribution.

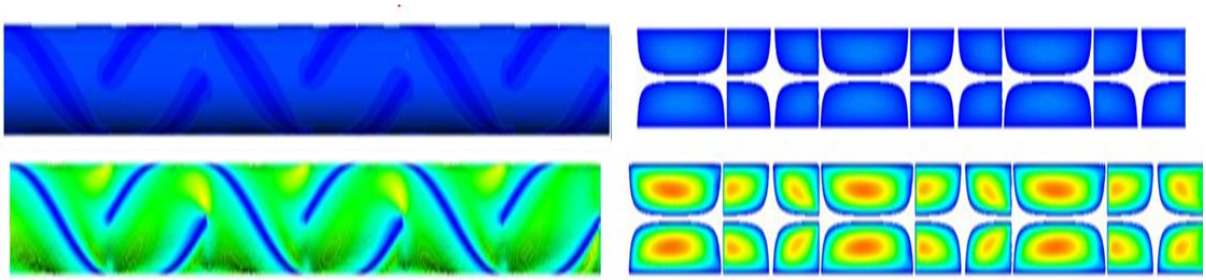


Figure 7: Velocity contour distribution for reference geometry at different Reynolds number (a) Re = 10, (b) Re = 30, and (c) Re = 50.

"6. Conclusions"

In this paper, a numerical simulation to was carried out to investigate the dynamic and thermal behaviors of various shapes of a kinetic static mixer. Three-dimensional model of the static mixer was designed. To examinate the mixer's performance, multiple parameters was taking in consideration. The fluid velocity and it characterized by Reynolds numbers varying from 10 to 100, as well as factors such as pressure drop and shear rate for evaluating dynamic performance. Furthermore, fluid temperature and the Nusselt number was examinate to gain insights into thermal characteristics. Describe the mixing and flow characteristics of stationary mixers. There are a number of factors to take into consideration, including pressure loss, mixing quality, time, as well as the effect of geometry. As a result, we tested a number of open helical geometries to see how they affected heat transfer in the stationary mixer. The geometry of the fixed helical elements inside the static mixer and the effect of the Reynolds number are discussed. Thermally, it is possible to schematically distinguish two zones depending on the evolution of the wall temperature and the Nusselt number along the four mixers. Rapid wall temperature changes in the first zone indicate the dominance of the thermal facility zone. The second zone experiences a much slower decline and is characterized by outflow conditions. Geometry 4 configuration has the best heat transfer rate, and with geometry 4 you have approximately 45% reduced pressure drop compared to standard KMS. Four-slot KMS technology facilitated better expansion efficiency, allowing higher dispersion and flows compared to other slot geometries.

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