Chemical Engineering & Processing: Process Intensification 122 (2017) 31–43

Contents lists available at ScienceDirect

Chemical Engineering & Processing: Process Intensification

journal homepage: www.elsevier.com/locate/cep

Effects of internal geometry modifications on the dispersive and distributive mixing in static mixers

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ARTICLE INFO

Keywords:
Distributive mixing
Static mixer
Dispersive mixing
Mixing performance
Internal geometry modifications

ABSTRACT

In this article, different static mixer geometries are studied with an objective of achieving enhanced mixing performance. Design modifications such as incorporating perforations of varying size and different shapes of serrations are introduced to a standard Sulzer SMX geometry. CFD simulations are performed using COMSOL Multiphysics software to investigate mixing performance in these mixers under laminar flow conditions with an incompressible fluid as a working medium. For dispersive mixing, computational results were compared in terms of velocity field, pressure field, shear rate and extensional efficiency of each type of static mixer. Further, binary cluster particle tracer simulations in the flow domain are performed to compute the distributive mixing capacity of these static mixers which is quantified in terms of the standard deviation. Based on the computational results of both dispersive mixing and distributive mixing, the best modified static mixer geometry is proposed which facilitates significantly improved mixing compared to that of a standard SMX geometry.

1. Introduction

Static mixer (SM) is a mixing device in which alternate mixing elements are arranged perpendicular to each other. Static mixers, unlike the conventional dynamic mixers, have no moving parts. They are also known as motionless mixers. SMs have a wide range of applications in the process industry, which involves processing of both Newtonian and non-Newtonian fluids. They are used in wastewater treatment, paper industry, food industry, pharmaceutical industry, petrochemical industry and polymer industry. Depending on the process requirements, SMs can be used for batch or continuous operation. Although mixing can also be achieved using dynamic mixers such as agitators, rotators and impellers; use of SM facilitates enhanced mixing, narrower residence time distribution, generation of higher interfacial area and near plug flow behavior [1]. Other advantages of SMs over dynamic mixers are low space requirement, low installation cost, low maintenance and operating cost and less erosion/scaling. In case of SMs, mixing solely depends on the movement of fluid streams which eventually gets twisted, rotated, spread and recombined by the internal geometry of the SM elements. Due to this, momentum of fluid is converted into mechanical energy of static mixing at the expense of pressure drop. From the engineering perspective, an ideal static mixer would be the one which delivers desired extent of mixing with a minimum pressure drop. Based on different geometries and internal mixer elements, SMs are categorized into open design with helices, open design with blades, corrugated plates, multi-layer designs, closed design with channels/holes and wire matrix structure [2,3]. Each static mixer has a unique geometry and is designed for a particular range of operations. Each one performs differently from others with respect to the flow behavior which in turn affects the mixing of fluids. Among these various types of SMs, for laminar flow mixing/blending of highly viscous fluids or for dispersing of immiscible phases, open design with blades or multilayer designs such as Sulzer SMX or SMXL are used. SMX mixer has a symmetric flat open blade structure and it is the proprietary design of Sulzer. Similar to SMX structure, Chemineer Inc. has developed KMX mixer which has intricate concavely curved open blade elements. Heniche et al. [4] compared mixing performance of SMX and KMX static mixer using computational fluid dynamics (CFD) simulations and showed that due to some minor modifications, KMX mixer gives enhanced mixing than SMX mixer at the cost of higher pressure drop.

To select an appropriate static mixer for specific application, knowledge about mixing performance and flow characteristics inside SM geometry is necessary. Experimental investigation of performance of different SMs is an expensive and time consuming task. With the development of CFD and advanced computers, it has become much easier to analyze the mixing characteristics of static mixers for various types of fluids. The first publication involving CFD simulations for the study of mixing properties of Kenics mixer is dated in 1985 [5], which

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http://dx.doi.org/10.1016/j.cep.2017.10.001
Received 17 March 2017; Received in revised form 2 September 2017; Accepted 1 October 2017

used CFD simulations to mix two similar fluids using Kenics mixer. Further, several research groups such as Dackson and Nauman [6], Ling and Zhang [7], Hobbs and Muzzio [8], Fourcade [9] performed computational studies to understand the mixing behavior of Kenics mixers. Apart from helical designed SMs, an open blade designed static mixer such as SMX were also studied by several groups such as Wuensch and Boehme [10], Fradette et al. [11], Zalc et al. [12] and Rauline et al. [13]. Among these research groups, Rauline et al. [14] performed computational simulations for Kenics, Inliner, LPD, Cleveland, SMX and ISG static mixers and showed that SMX mixer is more efficient than Kenics static mixer.

Earlier research groups have studied the mixing performance of SMX and Kenics static mixers in terms of different mixing parameters. However, majority of published work was limited to SMX and Kenics mixer only. Only a few research groups, studied the influence of the change in geometry on mixing performance and pressure. Liu et al. [15] studied the effects of design modifications to the standard SMX design by changing the aspect ratio and showed that new design geometries give higher mixing rate and strain rate distribution than that of standard SMX mixer. van der Hoeven et al. [16] used a newly designed multi-flux static mixer and proposed that by introducing additional elements with separating walls at the inlets and at the outlets of the mixing elements, an increase in the homogeneity can be achieved. Meijer et al. [17] developed a new type of static mixer SMX (n) in which by changing the number of cross-bars in standard SMX mixer, optimal stressing is achieved. Recently, a study of mixing performance of a combination of Kenics and SMX static mixer is performed with regard to the polyacrylamide solution [18]. In this work, pressure drop and degree of non-uniformity of this new type of SM are studied and it was shown that the proposed new SM is more suitable choice than standard SMX or Kenics for mixing processes involving Newtonian and power law fluids.

Design modifications to current SM geometries are targeted for enhanced mixing and reducing energy cost. By increasing the number of mixing elements it is always possible to obtain an improved axial dispersion but at the cost of very high pressure drop. In this article, by introducing different size of perforations and subsequently by introducing various shapes of serrations (such as circular, triangular and square), standard SMX static mixer is modified. These design modifications led to the additional benefit of minimizing the pressure drop. The main objective of this research is to study the effects of different types of design modifications in order to achieve enhanced mixing. For that purpose, computational simulations are performed and the performance of different modified SMs is analyzed in terms of dispersive and distributive mixing parameters.

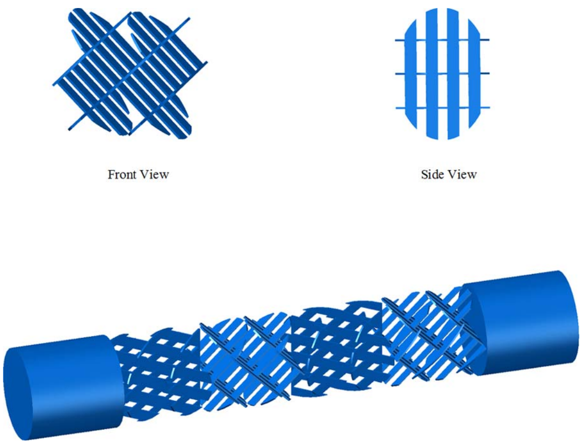

Fig 1. SMX static mixer geometry with four elements inside a pipe.

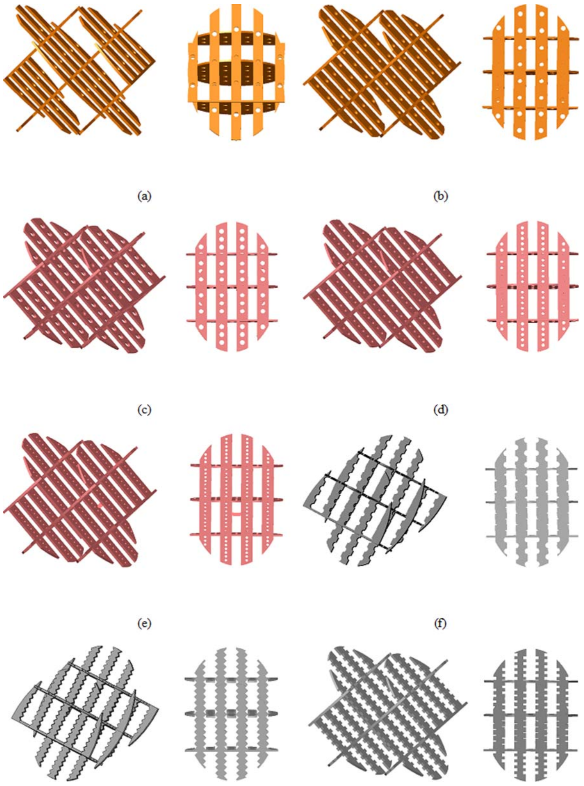

Fig. 2. Front view and side view of (a) Perforated SMX (b) Perforated SMX 4 holes (c) Perforated SMX maximum number of D/20 holes (d) Perforated SMX maximum number of D/30 holes (e) Perforated SMX maximum number of D/40 holes (f) SMX with circular serrations (g) SMX with triangular serrations (h) SMX with square serrations.

2. Static mixer geometries and computational method

In this research work, Sulzer SMX is used as a standard reference static mixer geometry for computational simulations and for comparisons with the proposed modifications in the internal geometries. This static mixer geometry is shown in Fig. 1. Each element of these static mixers is made up of stacked lamella, which creates an intricate network of flow channels. Each mixer element is placed at 90° rotation angle with respect to its neighboring element. All elements are arranged axially along the length of the pipe. The rotational arrangement imposes higher shear on the flowing fluid and the series of crossed blades split the fluid stream repeatedly into layers by spreading it all over the cross section of pipe. For the case considered here, each mixer element has a diameter (D) of 0.0526 m and a length to diameter (l/D) ratio equal to one. The thickness of each blade is 0.001 m. Since in all practical applications, static mixer assembly has to slide inside the tube, the pipe diameter has to be kept 2–3% greater than the diameter of the static mixer element. Due to this reason, in all computational simulations pipe diameter (D_t) is 0.053 m. In all computational simulations, eight static mixer elements are used. Further, the front and side views of different modified SMX geometries used for computational modeling are shown in Fig. 2 and the corresponding dimensions are shown in Table 1. Design modifications to a standard SMX static mixer geometry were done in two ways: the first one is by introducing perforations of different size to SM blades and the second modification is by introducing serrations of different shapes such as circular, triangular and square. Initially, to study the effect of number of perforations, only two holes of size D/20 are introduced on each blade (Fig. 2(a)). The number of perforations on each blade is increased from two to four and from four to the maximum possible number of perforations on each blade (Fig. 2(b) and 2(c) respectively). Further, to study the effect of the size of perforations, maximum possible number of holes of size D/30 and D/40 were introduced on each blade respectively, which is shown in Fig. 2(a) through (e) respectively. Next set of modification is done by