Effect of Porosity on Circle Grid Perforated Plate Performance as a Static Mixer in Laminar Flow

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Abstract. Mixing is one of the important processes to the many industries. Fluid mixing process typically involves three phases of fluid in the form of liquids, gases and solids. To obtain a desired type of mixing, one of the devices that can be use is a static mixer. In this study, a perforated plate static mixer with circle grid fractal design with two grades of porosity which are 50% and 75% will introduce. The purpose of implementing the two grades porosity of perforated plate in this study is to determine a performance of the two static mixers. In order to achieve the objective, the simulations of mixing fluid were carried out by using ANSYS CFX software. The simulation was carrying out primarily in cylindrical pipe with insertions of circle grid perforated plate. Three levels of laminar flow had been used which is Reynolds numbers (Re) equal to 100, 200 and 400. The performance of circle grid perforated plate static mixer will be evaluated by determining the Coefficient of Variation (COV). The simulation results also were compared in term of homogeneity level of mixing fluids to the Kenics static mixer. Based on the simulation results, the value of COV at selected plane in pipeline simulated for Kenics static mixer and the two grades porosity of perforated plate at Re = 400 are 0.000703, 0.0247and 0.00427 respectively. Since the values of COV between 0.01 and 0.05 are a reasonable target for many industry applications, the results for new approach of static mixer represent completely homogeneous mixing fluid for this application. Definitely this new approach of circle grid perforated plate with fractal design gave better results because of lower number of inserts and simple design of static mixer.

Introduction

An application of the static mixers is widely applied in many industries such as petrochemical and refining, as chemical and agricultural chemicals production and many others. The static mixers are used in continuous processes as an alternative way to conventional agitation since similar and sometimes better performance can be achieved at lower cost [1]. The static mixers have not involved in moving parts and at the same time it will have lower energy consumptions, smaller space requirements, low equipment cost and reduced maintenance requirements compared with mechanically stirred mixers [2]. There are a lot of static mixers that had been proposed, where an approximately 2000 US patents and more than 8000 literature articles that described static mixers and their applications [3]. Each of static mixers has their own arrangement and shape of mixer that is designed in order to get better efficiency to mix the fluid homogeneously.

This research study will come out with simple a design of static mixer that contains of perforated plate with fractal design. The porosity for each perforated plate is 50% and 75% and the results will compare with the standard static mixer that already available in market name as Kenix static mixer. One of the reasons for the proposing of these kind of static mixers is to introduce a new static mixer that have a low manufacturing cost (in term of simple design) but still having same results of mixing fluid as other static mixers. The design of fractal baffles and impellers already proved that the designing optimal mixer geometries, appropriate tools are needed to characterize the flow conditions and their influence on the mixing process. A widely used measure for presenting the uniformity of concentration at a cross section of static mixer is the Coefficient of Variation (COV).

In this study, the simulation work will be used to predict the fluid flow through the statics mixer introduced in the pipeline. This study will focus on simulation of fluid flow after the fluid flow pass through the static mixer. The efficiency of static mixer can be measured by looking at COV results on the interested sections after static mixer. Besides that, the pressure drop occurred in the pipeline also will observed to make sure that the efficiency not only in term of the homogeneous of the mixing but not increase the pressure drop due to the insertion of the static mixers.

Simulation Model

The perforated plate static mixer introduced here is based on circle grids fractal, as shown in Fig. 1. The circle grid fractal design used gave good results in term of low pressure drop across the plates [4]. By using the motivation of the low pressure drop and simple manufacturing of the plate, circle grids perforated plate with 50% and 75% porosity were used as a static mixer in this study. The plates with 50% and 75% porosity have two grades of holes, as described in Table 1. The smaller holes are concentrated near the plate edge because the major concentration of eddies and swirl is near the wall. On the other hand, this radial reduction of holes diameter assists in stabilizing the velocity distribution. In order to determine a performance of the plates introduced here as a static mixer, 5 inserts of circle grid perforated plate for each plate porosities were applied in order to perform high level of homogeneity of mixing fluids.

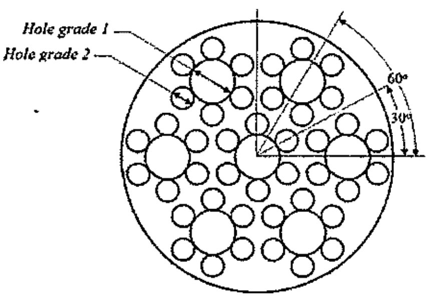

Fig. 1 Circle grid fractal plate

Table 1 Details of circle grids perforated plate geometry

Hole grade	No of holes	Hole diameter (50% porosity)	Hole diameter (75% porosity)
1	7	0.055D ±0.02 D	0.08D ±0.002 D
2	42	0.11D ±0.002 D	0.125D ±0.02 D
Standard plate thickness		0.12D ±0.005 D	0.12D ±0.005 D

For the simulation work, the model consists of a 25 mm cylindrical tube with a length of 500 mm. The tube was fitted with five plates of static mixer with a distance of 0.5D each. There was an empty piece of tube at the beginning and at the end of cylindrical tube with a length of one element. Table 2 shows the mean velocity of the two-phase mixture for the value at Reynolds Number 100, 200 and 400. The refined Carboxy-methyl-cellulose (CMC) solution was used as continuous phase with a viscosity of 0.050 Pa s and the silicon oil 50 was used as dispersed phase with a 0.047 Pa s. The liquid density for CMC solution was 998 kg/m^3 and silicon oil 50 was 949 kg/m^3. The properties of the fluids are based on previous research that study the liquid-liquid mixing in Kenics static mixers [5].

Table 2 The continuous CMC and dispersed (silicon oil 50) phase velocities and oil drop size

Reynolds	Mean inlet velocity, (m/s)	Oil drop diameter, (μm)

number, Re	Continuous phase	Dispersed phase	Oil 50
100	0.202	1.28	1753
200	0.405	2.56	620
400	0.811	5.11	219

Analysis of Mixing Performance

When the fluids flow through a static mixer, the energy of the flowing fluid will divide and separate a streamlines in a sequential method. Because of that, there are needs of an appropriate tool to characterize the flow conditions and their influence on the mixing process. In mixing process, the Coefficient of Variation (COV) was used as a tool to analyse homogeneity of fluid mixing. In this case, the COV will define as the standard deviation of concentration over the mean of concentration for given set of N data points [6]. The standard deviation of the concentration can be shown in equations as below:

$$COV = \frac{\sigma}{x} \tag{1}$$

$$\sigma = \sqrt{\frac{\sum_i^n (x_i - \bar{x})^2}{n-1}} \tag{2}$$

To obtain the data to calculate the COV, a specified number of grid nodes at a cross section identical plane were taken. The value of COV that more or equal to 0 represents a completely homogeneous in fluid mixing while the COV value between 0.01 and 0.05 are acceptable value for many applications [7]. The efficiency of static mixer will be measured by evaluate the distribution of the local volume fraction for the dispersed phase, Silicon oil 50 in refined CMC at selected section downstream the static mixer. Besides that, the pressure drop across the static mixers also will determine since the pressure drop also become the most consideration for the static mixers application in the most mixing industries.

Results and Discussion

In this study, the effectiveness of circle grid perforated plate with 50% and 75% porosity static mixer have been evaluated by comparing the homogeneity level of mixing fluids and pressure drop to the Kenics static mixer that readily available in industries applications at Re = 100, 200 and 400 respectively.

Fig. 2 shows the comparison of an effect of Kenics static mixer, circle grid perforated plate with 50% and 75% porosity on COV with different Reynolds number. Based on the comparison graph, it shows that circle grid perforated plate with 75% porosity having the value of COV close to Kenics static mixer at Re = 400. So, the quality of homogeneous mixing fluid for 75% porosity circle grid perforated plate with 5 inserts and Kenics static mixer with 10 inserts nearly at the same condition. In other words, this study give positive result which is the 5 inserts of 75% porosity circle grid perforated plate having same result as 10 inserts of Kenic static mixer.

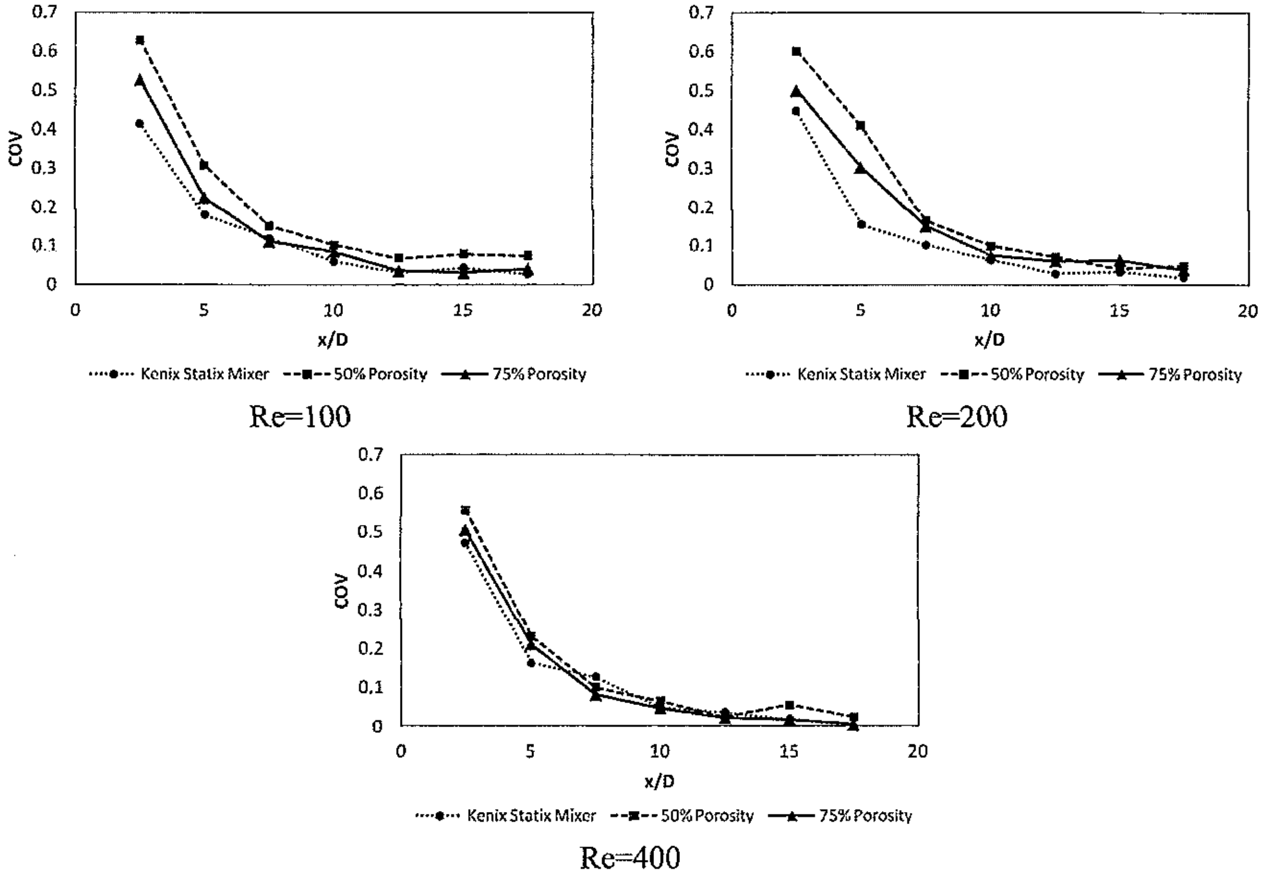

Fig. 2 COV for Kenix static mixer and perforated plate static mixers

Fig. 3 shows the graph for pressure drop at Re = 100, 200 and 400 for Kenics static mixer, circle grid perforated plate with 50% and 75% porosity. Since a high pressure drop is undesirable in mixing process, the pressure drop should be as low as possible to reduce the power being wasted during the processes. By selecting the appropriate position and insert numbers of static mixer having the lowest pressure lost, an optimized level of homogeneity mixing fluids in terms of its power consumption can be designed. From the results obtained and showed in Fig. 3, it shows that the perforated plates static mixer have lower pressure drop compared to the Kenics static mixer. In case of pressure drop of static mixer, 75% porosity circle grid with 5 inserts has lowest pressure drop compared to the others. So, the 75% porosity circle grid with 5 inserts is the best design to this application in term of energy loss due to static mixers.

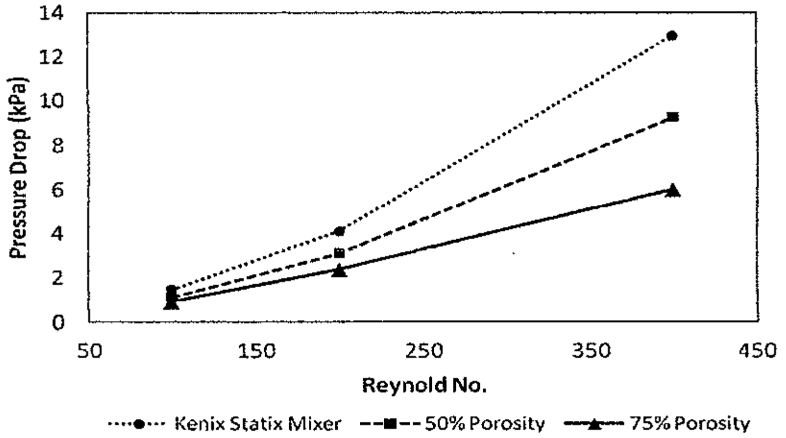

Fig. 3 Pressure Drop versus Reynolds number at outlet pipeline

Conclusion

In this research study, the effectiveness of static mixer has been measured by simulating the result of volume fraction in dispersed phase fluid. Based on the volume fraction of dispersed phase, the COV can be determined in order to define the concentration distribution or mixing homogeneity level. Based on the simulation results for Re = 400, the value of COV at plane x/D = 17.5 (outlet of mixing pipeline) for Kenics static mixer, circle grid perforated plate with 50% porosity and circle grid perforated plate with 75% porosity are 0.000703, 0.0247and 0.00427 respectively. So, the results for new approach of static mixer introduced here completely homogeneous mixing fluid for this application. Since the values of COV between 0.01 and 0.05 are a reasonable target for many industry applications, it can be conclude here that the circle grid perforated plate with 75% porosity is more suitable to apply for this application. Other than that, this new approach of static mixer has been designed with simple design and at the same time having standard efficiency of mixer in order to reduce current cost of manufacturing but still having same results of mixing fluid as other static mixers.

Acknowledgement

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