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LAMINAR MIXING IN SMX STATIC MIXERS

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Abstract

This paper experimentally examines the performance of a commercial static mixer (SMX). Experiments were carried out to obtain the pressure drop across different numbers of mixing elements (4, 8, 12 and 16). The quality of mixing was visually assessed using flow visualization techniques. Experiments were performed for Reynolds number between 50 and 3000 (based on the unobstructed pipe diameter). The presence of the mixing elements in the flow stream promotes a non-laminar, turbulent-like flow which considerably enhances the mixing. Addition of more mixing elements triggered mixing in the flow at lower Reynolds numbers but this was achieved at the expense of higher pressure drop. This work represents the first stage of an on going work to develop correlations to assess the mixing quality and pressure loss in the SMX static mixers.

Keywords: Static Mixer, Flow Visualization, Pressure Drop.

Nomenclatures

D	Tube Diameter
f	Friction Factor
L	Length of the Test Section
Q	Volume Flow Rate
Re	Reynolds Number Based on Tube Diameter
V	Average Velocity Upstream of the Mixer
Greek Symbols	
ΔP	Pressure Drop across the Test Section
ρ	Density

1. Introduction

Mixing is an important process in many industries. It is usually achieved by using either mechanically stirred vessels or static mixers. Static mixers consist of a series of stationary and rigid inserts as the mixing element installed in pipes, ducts or transfer tubes. The purpose of these inserts is to redistribute fluid in a direction transverse to the direction of the main flow, both tangentially and radially. Static mixers find applications in wide variety of processes such as blending of miscible fluids both in laminar and turbulent flows, mixing and dispersion of immiscible fluids by helping to generate an interface, solid blending, heat and mass transfer and homogenization [1]. These processes, in turn, serve many industries such as chemical and agricultural chemicals production, grain processing, food processing, minerals processing, petrochemical and refining, pharmaceuticals and cosmetics, polymers, plastics, textiles, paints, resins and adhesives, pulp and paper, water and waste water treatment.

The use of static mixers in continuous processes is an attractive alternative to conventional agitation since similar and sometimes better performance can be achieved at lower cost. As they have no moving parts, stationary mixers typically have lower energy consumptions, smaller space requirements, low equipment cost and reduced maintenance requirements compared with mechanically stirred mixers. They offer a more controlled and scaleable rate of dilution in fed batch systems and can provide homogenization of feed streams with a minimum residence time. They also provide good mixing at low shear rates where locally high shear rates in a mechanical agitator may damage sensitive materials. Static mixers also come with self cleaning features. Interchangeable and disposable static mixers are also available [1].

Numerous static mixer designs have been proposed. Thakur et al [2] reported the existence of approximately 2000 US patents and more than 8000 literature articles that describe static mixers and their applications. More than 30 models have made their way into different industries and they are commercially available. Kenics mixers, KMS and SMX, (by Chemineer Inc.) are used in both laminar and turbulent flow regimes to achieve thermal homogenization of polymer melt [3], gas–liquid dispersion and dilution of feed to reactor [4] and dispersion of viscous liquids [5]. Another mixer manufactured by Chemineer Inc. is the HEV (high efficiency vortex) static mixer which is used for turbulent low viscosity liquid–liquid blending and gas-gas mixing [**Error! Bookmark not defined.**].

This paper reports an experimental investigation of the performance of SMX static mixers (shown in Fig.1). The quality of the mixing is visually inferred from the flow visualization results while the pressure drop across mixers were used to know the losses incurred due to the presence of the mixers. This work represents the first stage of a research project aiming at developing mathematical correlations for the mixing quality and the pressure drop across the SMX static mixers.

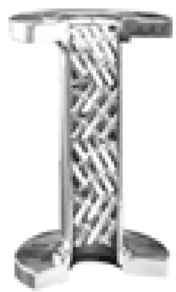

Fig. 1. SMX Static Mixer.

2. Experimental Procedures

The experimental procedures involved measuring the pressure drop and visualizing the flow across the SMX mixers fitted inside a transparent circular tube test section. A schematic diagram of the experimental apparatus is shown in Fig.2. Water flows by gravity from the supply tank through a bell-mouthed entrance, then a 35D development length before it enters the test section and exit through an outlet pipe length of 20D. Flow control is by means of two needle valves, one upstream and the other downstream of the test section. Flow rate is measured at the outlet of the downstream needle valve with a graduated cylinder and a stopwatch. The pressure drop in the test section was measured by means of an inclined water manometer.

Pressure tappings were located 1.5 D upstream of the first baffle and 1.5 D downstream of the last baffle. Pressure tappings were sealed for flow visualisation.

The flow is visualized by injecting a fluorescent dye (Fluorescen) upstream of the development length. Dye injection setup consists of a burette to store and control the flow, and the dye flows under gravity to the hypothermic needle, located at the geometric centre of the pipe. The pipe was illuminated by a fluorescent lamp. Flow structures were captured using a digital camera with a 4.0 mega pixel resolution.

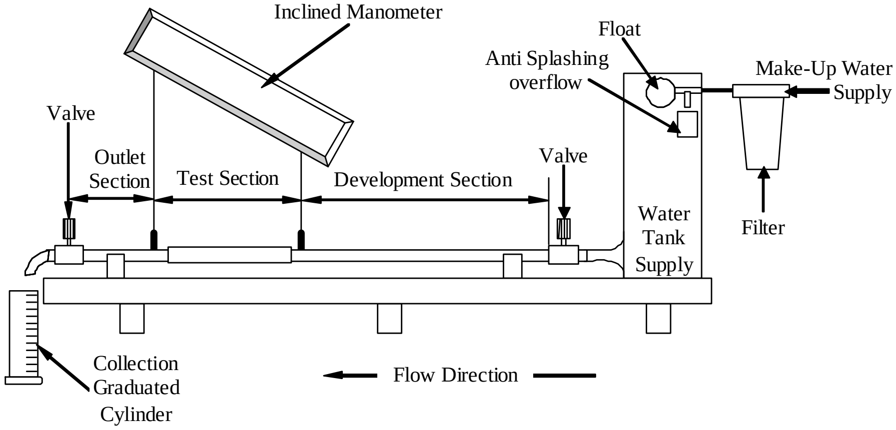

Fig. 2 Experimental Rig.

3. Results and Discussion

3.1Friction factor

The experimental rig was validated by comparison of the measured friction factor, f, of a straight circular tube without baffles, Eq.1, with the laminar Darcy friction factor, Eq. 2, over a range of Reynolds numbers.

$$f = \frac{\Delta P}{\frac{1}{2}\rho V^2}\frac{D}{L} \tag{1}$$

$$f = \frac{64}{Re} \tag{2}$$

where ΔP is the pressure drop over the length of the test section, L, D the tube diameter, ρ the density of water, and V the mean velocity defined by the volume flow rate Q

$$V = \frac{4Q}{\pi D^2} \tag{3}$$

Good agreement between the experimental results and the theoretical formula was reported indicating the adequacy of the experimental rig and the instrumentation.

Figure 3 shows the effect of the presence of different numbers of SMX mixing elements on the friction factor when plotted against the Reynolds number (Re). It is obvious that the static mixers increase the friction factors considerably when compared to open tube. Increasing the number of mixing elements also increased the friction factor. These results are rather expected since the plates of the mixer represent obstacles to the flow and do force the streamlines to assume curvilinear routes. Although this mechanism promotes mixing, it increases minor losses at the same time. This is shown in Fig. 4.

3.2 Flow visualisation

Samples of the flow visualization images are shown in Fig. 5. The effectiveness of the mixer is evident. Even when only four mixing elements are in use (Fig.5 a, b, c, & d), it is obvious that a single stream of dye get well mixed after passing through the mixing elements. As Reynolds number increases from 160 to 830, the mixing quality further improves until the flow is visually homogenous.

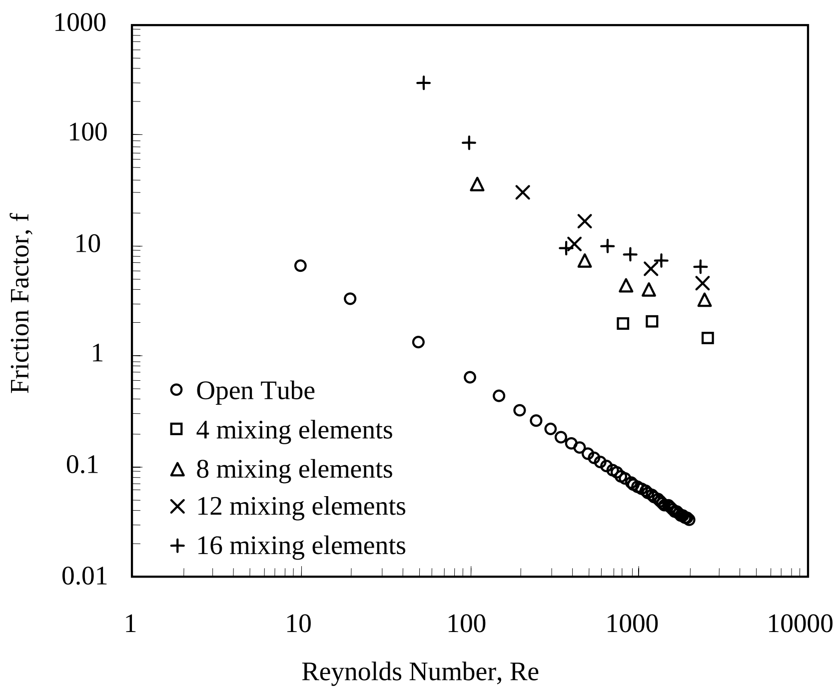

Fig. 3. Friction Factor Variation with Reynolds Number.

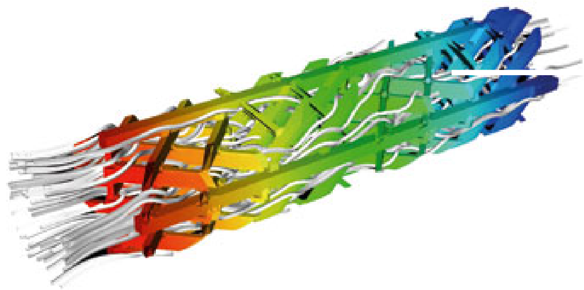

Fig. 4. Particles Path in SMX Static Mixer.

When the numbers of the mixing elements increase, it is evident that visual homogeneity is reached at even lower Reynolds numbers of around 400 for eight mixing elements and 60 for 12 mixing elements.

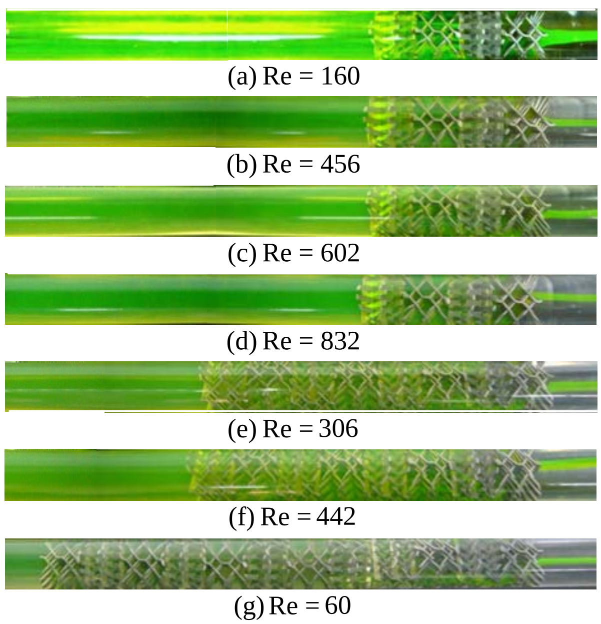

Fig. 5. Flow Visualisation Results.
4 Mixers (a, b, c & d), 8 Mixers (e & f), 12 Mixers (g) Flow from right to left.

4. Conclusions

SMX static mixer performance was assessed experimentally using pressure drop measurements and flow visualization. The experiments showed that the SMX static mixer is an effective mixing device. Mixing, however, is achieved at the expense of higher pressure loss.

The future work will involve measuring the coefficient of variance (CoV) to obtain quantitative knowledge regarding the mixing quality. Obtaining correlations for the pressure drop is also planned.

References

1. Etchells III A.W. & Meyer C.F. (2004). Mixing in pipelines. *Handbook of Industrial Mixing Science and Practice*, (E.L. Paul, V.A. Atiemo-Obeng and S.M. Kresta, eds).
2. Thakur R. K., Vial Ch., Nigam K. D. P., Nauman E. B. & Djelveh G. (2003). Static mixers in the process industries-A review. *Trans. IChemE*, 81, 787-826.
3. Chen S.J. (1975). Static Mixing of polymers. *Chem Eng Prog*, 71, 80–83.
4. Smith J.M. (1978). Gas dispersion in viscous liquids with a static mixer. *Chem Eng*, November, 827–830.
5. Berkman P.D. & Calabrese, R.V. (1988). Dispersion of viscous liquids by turbulent flow in a static mixer. *AIChE J*, 34, 602–609.