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Effect of a liquid dispersed phase on the wall flow structure in static mixer

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Abstract

The effect of a liquid dispersed on the wall flow structure in static mixer is analyzed by using an electrochemical method. Both laminar and turbulent flows have been investigated. The axial wall velocity gradient and turbulent intensity have been studied along the static mixer in both flow regimes and for different dispersed phase concentrations. The spectral analysis of the wall velocity gradient fluctuations was analyzed in the turbulent regime. For volume fraction higher than 5%, the effect of the dispersed liquid phase is very important for all the studied parameters. The turbulence associated to the dispersed phase leads to an increase of the energy dissipation in the static mixer and also to a modification of energy dissipation mechanism.

Keywords: Electrochemical method; Liquid–liquid dispersion; Spectral analysis; Static mixer; Turbulence; Wall shear rate

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1. Introduction

The effect of a fluid or solid dispersed phase on flow turbulence is due to different parameters: particle sizes, physicochemical properties of both phases, shift velocity, droplet deformation, breakage and coalescence phenomena,... Yuan and Michaelides (1992) have summarized six mechanisms which contribute to modify turbulence characteristics in two-phase systems:

- turbulent kinetic energy dissipation by the particles,
- apparent viscosity increase due to the dispersed phase,
- particle wake,
- fluid mass-added to particles,
- velocity gradients between particles,
- deformation of dispersed phase.

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Several studies have been undertaken to analyze how turbulence and gas bubbles influence each other. Serizawa et al. (1975) experimentally studied the influence of bubbles on turbulence and the effect of the latter on the velocity and void fraction. Theofanous and Sullivan (1982) examined the enhancement of liquid turbulence by flowing bubbles. Nikotopoulos and Michaelides (1995) showed that the eddy diffusivity was enhanced due to variation of the density by considering the gas–liquid mixture as a homogeneous fluid of variable density across the pipe cross-section. Nakoryakov et al. (1981) and Souhar (1989) made measurements of wall shear stress in bubbly pipe flow. Souhar (1989) studied the effect of bubbles on energy spectra. Significant modification of turbulence were observed in the different studies (Gore and Crowe, 1989; Hestroni, 1989; Lance and Bataille, 1991; Mizukami et al., 1992; Parthasarathy and Faeth, 1987; Souhar, 1989; Theofanous and Sullivan, 1982; Yarin and Hestroni, 1994; Yuan and Michaelides, 1992; Hosokawa and Tomiyama, 2004).

Few studies are devoted to the effect of the dispersed phase on liquid–liquid flows. Nadler and Mewes (1997) reported that the pressure drop in pipeline flow of two immiscible liquids strongly depends on the flow regime. Yuge and Hagiwara (2004) visualized by direct numerical simulation the secondary flow in the droplet wake. Moreover, liquid–liquid dispersions with high volume fractions of the dispersed phase often behave as non-Newtonian shear thinning fluids (Loewenberg, 1998). Tsouri and Tavlarides (1994) observed a damping effect of the dispersed phase concentration on the turbulent fluctuations. The damping rate is proportional to $(1 - \alpha)^{-1}$.

Static mixers are applied in wide range of industrial processes, but the fundamental understanding of flow and mixing in static mixers, is however poor (Godfrey, 1992). The scarcity of information about static mixer flow is due to their complex structure, which makes non-intrusive investigation difficult. One of the most important applications of the static mixers is for immiscible liquid–liquid dispersion. Many research works were done in order to predict the drop size distribution obtained with different types of static mixer (Berkman and Calabrese, 1988; Haas, 1987; Legrand et al., 2001; Maa and Hsu, 1996; Middleman, 1974). However, to the best of our knowledge, no work has been devoted to the analysis of the effect of a dispersed phase on the flow in static mixers. In the present work, we have investigated the flow through static mixers by using non-intrusive electrochemical method, which allows to obtain wall shear stress along the housing tube of the static mixer elements. In a previous work (Hirech et al., 2003), we analysed the one-phase flow through SMX Sulzer static mixer with the same experimental method. In particular, we characterized the flow regimes: laminar regime for $Re_{\text{pore}} < 200$ and turbulent regime for $Re_{\text{pore}} > 1500$–3000. The pore Reynolds number, Re_{pore}, which takes into account the geometric structure of the static mixer, was defined by Morançais et al. (1999) by considering the static mixer as a porous medium and by using a capillary model. The objective of this work is to analyse the effect of a dispersed phase on the different flow characteristics in both laminar and turbulent flow regimes.

2. Materials and methods

2.1. Hydraulic loop and test cell

The experimental set-up is shown in Fig. 1. The two-phase mixture was prepared in a stirred tank with a temperature control system. The two-phase mixture was pumped through flowmeters to the test cell, which consisted of a calming section and a measured section containing the static mixer elements. The two-phase mixture was then returned to the stirred tank. The two-phase mixture flowrate was varied between 0.04 and 6 m^3/h. The test section contained four SMX Sulzer static mixer elements (Fig. 2) of 51.6 mm of nominal diameter, corresponding to the housing tube diameter. A SMX static mixer element consisted of corrugated plates perpendicular to each other and assembled at 90° from the flow axis (Fig. 2). The series of blades divide the passing fluid into layers and spread them over the pipe cross-section. The geometrical characteristics (pore diameter, d_p, and tortuosity factor, T, corresponding to the ratio of the mean length covered by the fluid to the mixer length) of the SMX static mixer have been determined through pressure drop measurements by using a capillary model (Morançais et al., 1999). The porosity, ε, of the static mixer is equal to 0.90, the pore diameter, d_p, to 15.15 mm and the tortuosity factor, T, to 1.46. The flow characteristics were characterized by using a pore Reynolds number, defined from a capillary model (Morançais et al., 1999) as: