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Dispersion of oil droplets in rotor–stator mixers: Experimental investigations and modeling

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ABSTRACT

Forming emulsions by mixing of immiscible liquids, water and silicone oils was carried out by applying the in-line high-shear rotor–stator mixers. In experimental part investigations were carried out using experimental rig consisting of two tanks and an in-line Silverson rotor-stator (150/250) MS; the system was operated in a multiple pass (MP) mode, which can be compared with a single pass (SP) mode experiments. Emulsification of 1 wt.% silicone oils (Dow Corning 200 fluid) with viscosities of 9.4, 48 and 339 mPa s was investigated. Emulsions were stabilized by adding 0.5 wt.% of sodium laureth sulphate. Effects of rotor speed, number of passes and the drop viscosity on the drop size were investigated.

Numerical simulations were carried out using the k–ε model of turbulence and the multiple reference frame method (MRF) linked to the population balance equation. The population balance was expressed and solved using the quadrature method of moments (QMOM). The breakage kernel for drops whose diameter falls within the inertial subrange of turbulence was defined based on the multifractal model of intermittent turbulence.

1. Introduction

The rotor–stator high-shear devices are known from their ability to generate very high shear stresses due to focused delivery of energy. Using the high-shear rotor–stator mixers one is able to control the product quality and for this reason the rotor–stator mixers are used in many technologies in the chemical, pharmaceutical, biochemical, agricultural, cosmetic, health care and food processing industries for homogenization, dispersion, emulsification, grinding, dissolving, performing chemical reactions with high selectivity, cell disruption and shear coagulation [1]. Another, important reason, is that the energetic efficiency of the high-shear rotor–stator devices is regarded as high. High stresses and large values of the rate of strain are generated in the rotor–stator devices for two reasons: first reason is that the rotor is situated in a close proximity of the stator and the second reason is that very high rotor speeds are applied. Both reasons lead to very high agitation power. Development of methods that can be used to predict agitation power and efficiency of mixing is thus of high importance. Much has been done in recent years in development of methods for predicting the agitation power [2–4]. However, as shown by Jasińska et al. [5,6], the efficiency of mixing of completely miscible, homogeneous fluids in the rotor–stator device, where micromixing controls the course of chemical reactions, decreases from 35% to 7% with increasing the rotor speed from 1000 to 9000 rpm. Such decrease results from the fact that for smaller rotor speed the reaction zone is localized close to the screen in the region of high dissipation rate, whereas for higher rotor speed reaction zone shrinks and is localized closer to the feeding point, where the rate of energy dissipation is relatively smaller. Hence, in this case focusing of energy is more effective for smaller rotor speed, and for this reason the ratio of the characteristic process time to the residence time in the zone of high energy dissipation rate (and thus high rate of micromixing) decreases with increasing the rotor speed. The second reason is significant increase of the inertial form drag and the wall shear friction factors.

In this paper we are interested in using the in-line high-shear rotor–stator mixers for mixing of immiscible liquids to form stable emulsions.

The liquid–liquid dispersions are involved in many engineering operations including extraction, chemical reaction, emulsion polymerization, so they are important for industry. Investigation of relations between turbulent flow and drop breakage can help to

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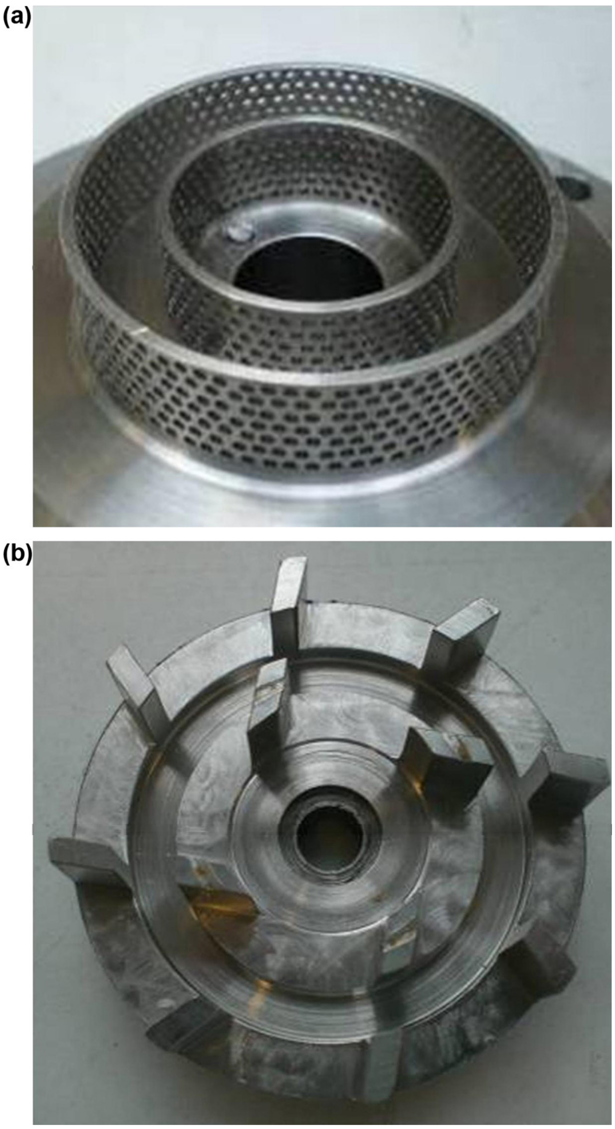

Fig. 1. Silverson 150/250 (MS) rotor-stator mixer: (a) double rotors and (b) double emulsor screens.

validate the drop breakage models as well as help us to understand the question how the fluid-mechanical forces generated by turbulence in the rotor–stator devices cause drop breakup. We also would like to check efficiency of focusing energy. Namely, when the drop breakage in the zone of the high rate of energy dissipation (and thus high stresses) is fast enough so that one pass of dispersion through the in-line rotor–stator results in drop dispersion down to the maximum stable drop sizes, the process can be regarded as efficient. To check if the drop breakage in the rotor stator device is fast and efficient, the process will be carried out in a multiple pass (MP) mode.

2. Experimental

A Silverson double screen mixer 150/250 (MS) that has been applied in experiments is presented in Fig. 1. The mixer is equipped with twin rotors that rotate with the same frequency within close fitting screens. The inner rotor has the inner diameter equal to 2.62×10^{-2} m, the outer diameter equal to 3.81×10^{-2} m, and is equipped with four blades. The outer rotor diameters are equal to 4.99×10^{-2} m and 6.35×10^{-2} m respectively, and this rotor is equipped with eight blades. The inner stator screen has six rows of 50 circular holes each of diameter equal to 1.59×10^{-3} m. The inner stator screen of diameter 42.4 μm has six rows of 50 circular holes each of diameter 1.59×10^{-3} m (1/16 in.) on a 0.100 in. tri pitch. The outer screen of diameter 67.6 μm has seven rows of 80 circular holes each of diameter 1.59×10^{-3} m on a 0.100 in. tri pitch. The rotor–stator gap is equal to 0.24 mm. The rotor was driven by a 22 kW motor controlled by frequency inverter.

The in-line rotor–stator device was placed in the experimental rig as shown in Fig. 2. In the rig there was a tank in which the coarse emulsions were prepared. The 800 dm^3 vessel was fitted with 0.31 m diameter Cowles Disk type impeller. Except of the rotor–stator, the rig was equipped with the Coriolis flow meter, the flow control valve, centrifugal pump and the data logging system. Emulsions were pumped to the rotor–stator through a 38.1 mm pipeline; in the case of multiple pass experiments the emulsion after each pass was collected and pumped once again in the next emulsion pass through the same pipeline. In experiments the oil-in-water emulsions containing 1 wt.% of silicone oils (poly-dimethyl siloxane, Dow Corning 200 fluid) with viscosities of 9.4 mPa s, 48 mPa s and 339 mPa s were investigated. Emulsions were stabilized by adding the sodium laureth sulphate surfactant (SLES) in amount necessary to obtain the 0.5 wt.% solution of SLES. SLES was dissolved in water at 25 ± 1 °C in the vessel before adding

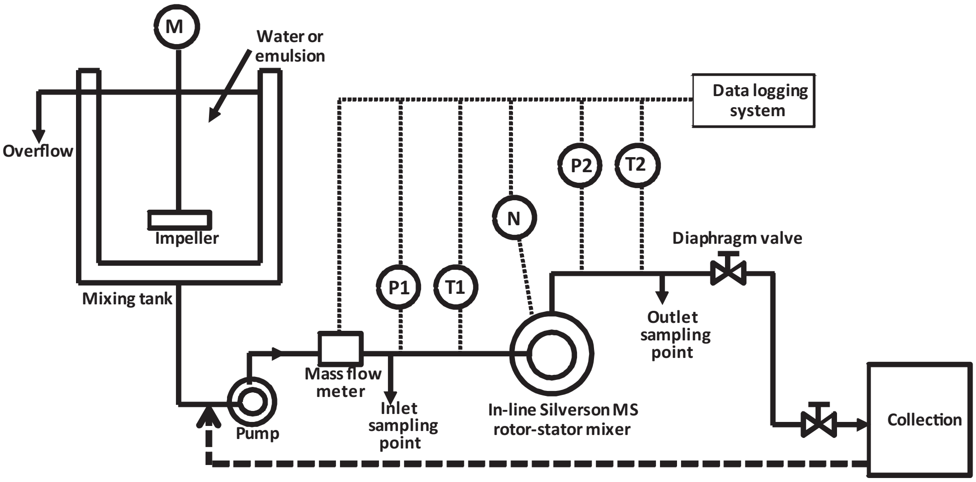

Fig. 2. Schematic of the experimental rig.