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Study on the hydrodynamic characteristics of a rotor-stator reactor by electrical conductance and response time technique

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ABSTRACT

This work employed the electrical conductance and response time technique to experimentally investigate the hydrodynamic characteristics of a rotor-stator reactor (RSR). The effects of various operating conditions such as the rotation speed, liquid volumetric flow rate and number of rotor-ring layers on the hydrodynamic characteristics were examined, and correlations to predict the hydrodynamic characteristics of RSR were established. Results show that the predicted results are in agreement with those of the experiment with deviations within 10%, thus indicating the feasibility of employing the correlations to predict the liquid average velocity, holdup and number of liquid droplets in RSR.

1. Introduction

As one of the cutting-edge process intensification technologies, Higee, an acronym for high-gravity technology, was first introduced by Ramshaw [1], and has hitherto received considerable attention from academia and industry as an efficient gas-liquid contactor. The technology is based on centrifugal field generated by a Higee equipment, and the most classical Higee equipment is a rotating packed bed (RPB). The RPB comprises a rotor made of cylindrical packed bed, casing, shaft, cover cap, stationary distributor and inlet/outlet channels. Liquid is fed through a stationary liquid distributor and flows radially outwards while gas flows radially inwards from the casing to the device's center by pressure gradient. The high centrifugal field generated by the rapidly rotating packing enables an intense mass transfer, and very high shear forces within the device [2,3]. Consequently, RPB has been applied successfully in the synthesis of nanomaterials [4,5], organic compounds degradation [6–11], Hydrogen production [12], and distillation [13]. Nonetheless, there are still some inherent drawbacks associated with RPBs, such as blockage of the packing and uneven liquid velocity distribution [14].

In order to avoid these drawbacks, a rotor-stator reactor (RSR) was developed on the basis of the RPB [15]. The internal structure of RSR comprises a series of rotor-rings and stator-rings alternately configured in the radial direction. The rotor-rings and stator-rings serve as rotating component and disturbing component respectively. This reactor has been acknowledged to exhibit excellent mass transfer and micromixing effects [15,16].

Detailed information on the hydrodynamic characteristics is necessary for better understanding of mass transfer [17] and micromixing phenomena [18]. However, as a novel Higee equipment, the majority of work reported about RSR has involved either the analysis of mass transfer [19,20] or micromixing performance [21–23], with only little work focusing on its hydrodynamic characteristics. A study by Li et al. which employed a high-speed camera to obtain continuous and clear images of liquid in RSR confirmed that there exist two main flow types (film flow and droplet flow) in RSR [24]. Although their work also discussed the hydrodynamic characteristics of RSR, the fact that they estimated residence time in RSR via snapshot limits the accuracy of the results presented. It is therefore necessary to employ a technique which can give more accurate and reliable results for better understanding of the hydrodynamic characteristics of RSR.

The electrical conductance and response time technique was employed to explore the hydrodynamics, mass transfer and operating characteristics of the RPB [25–27]. Therefore, this technique was used to study the hydrodynamic characteristics

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of RSR for the first time in this study. The relationship between the hydrodynamic characteristics (liquid average velocity, holdup and number of liquid droplets) and various operating conditions (number of rotor-ring layers, rotation speed and liquid volumetric flow rate) in the RSR were investigated. Additionally, correlations to predict the hydrodynamic characteristics in RSR were established.

2. Experimental section

2.1. Experimental setup and procedure

Fig. 1 shows that the RSR used in this study has an internal structure comprising 6 rotor–rings located on a rotor seat which is connected to a motor by a shaft and 5 stator–rings which comprise 5 layers of pins mounted concentrically on the cover cap. The open spaces between the pins and perforations on the rotor-rings make up liquid channels within the RSR [24]. The cover cap is semi-open in order to introduce a shielded cable into the RSR and measure the resistance surge precisely. The specifications of the RSR are given in Table 1.

Tap water was adopted as the liquid medium. The operating conditions include liquid volumetric flow rates of 300–550 L/h, rotation speeds of 200–1200 rpm, rotor-ring layers of 1–6, and inlet liquid temperature of 300 ± 2 K.

The experiments were conducted according to the following procedure. The RSR was switched on and tuned to a certain rotation speed before the liquid was introduce into the RSR as a preset volumetric flow rate. The liquid flowed through the liquid distributor and jetted onto the inlet detector before reaching the innermost layer of the rotor-ring of the RSR. The liquid then flowed radially outwards through the liquid channels in the RSR and was broken into tiny liquid droplets by the centrifugal force generated by the rotating rotor-rings. After passing through the outlet detector, the liquid droplets finally exited the RSR via the liquid outlet.

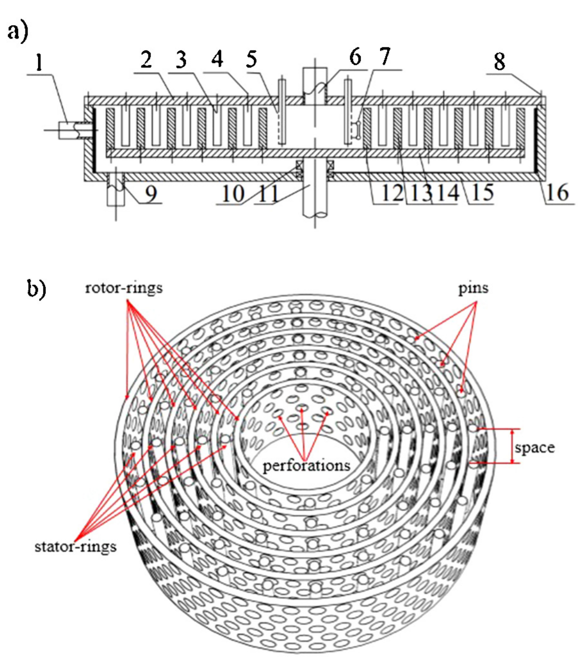

Fig. 1. (a) Structure of RSR with detectors; (b) 3D diagram of rotor-rings and stator-rings (1) gas inlet; (2) cover cap; (3) stator; (4, 8, 12) bolts; (5) liquid distributor; (6) gas outlet; (7) inlet detector; (9) liquid outlet; (10) seal; (11) shaft; (13) rotor; (14) rotor seat; and (15) casing; (16) outlet detector.

Table 1
Specifications of the RSR.

Item	unit	value
layer number of rotor-rings	–	6
layer number of stator-rings	–	5
number of perforations in rotor-rings	–	180, 240, 294, 348, 408, 462
number of pins in stator-rings	–	12, 16, 20, 24, 24
diameter of perforations in rotor-rings	mm	4
diameter of pins in stator-rings	mm	5
inner diameter of rotor-rings	mm	70, 94, 118, 142, 166, 190
inner diameter of stator-rings	mm	80, 104, 128, 152, 176
inner diameter of RSR	mm	300
axial depth of rotor-rings	mm	61
axial depth of stator-rings	mm	60
axial depth of RSR	mm	65

2.2. Description and analysis of the electrical conductance and response time technique

A metal film resistor was used as the inlet detector after the paint cover of the resistor had been removed and attached to the liquid distributor as shown in Fig. 1a. The outlet detector comprised two layers of circular metal wire mesh. The inlet and outlet detectors were placed before the liquid distributor and the inner wall of the RSR. The resistance of the metal film resistor without paint changed as soon as liquid sprayed out via the liquid distributor and contacted the inlet detector. Similarly, the resistance at the outlet detector also changed when liquid droplets passed through the two layers of the circular metal wire mesh. The change in resistance was converted into current signal by a conductivity meter and then transferred to a computer via data acquisition card. Finally, the change of resistance value at the inlet/outlet detector was expressed as the amplitude of inlet/outlet curve on the computer.

The time of the occurrence of inlet and outlet curve surges in Fig. 2 means the time of the liquid reaching the inlet and out detectors respectively. Thus the time difference between the surges means the liquid residence time in the RSR. The liquid average velocity can be obtained by dividing the liquid flow distance by the liquid residence time; the liquid holdup is the product of the liquid residence time and the liquid volumetric flow rate; the number of liquid droplets can be calculated by the liquid holdup and the average droplet diameter, which was determined by Li et al. [24].

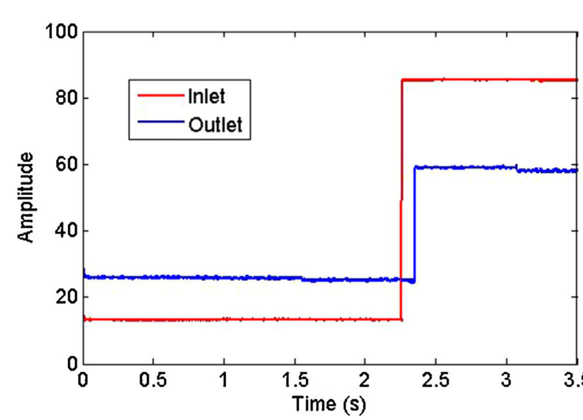

Fig. 2. Residence profile for liquid flow.