Liquid-phase dispersion in an airlift reactor with a net draft tube

W.-T. Wu, J.-Z. Jong

Abstract  Liquid-phase dispersion in an airlift reactor with a net draft tube was considered. Four net tubes with different ratios of draft tube to reactor diameters and superficial air velocities ranged from zero to 6.05 cm/s were investigated. The sparger was a porous plate. The parameter of the dispersion effect, axial dispersion coefficient, was characterized by measuring the residence time distribution in the liquid phase with single-pulse tracer input. The values of the dispersion coefficient of the proposed airlift reactor were much higher than those of the bubble column under the same operating conditions.

1 Introduction
Most bioreactors require a thorough mixing behavior that can achieve a rapid and homogeneous distribution of added medium and dissolved oxygen in the bulk fluid. Dead zones, where possible damage or inhibition to cultivation may arise, should be avoided. For characterization of the performance of bioreactors [1-5], mixing is an important factor.

Agitated reactors are frequently used for a variety of gas-liquid operations with or without solid particles. However, there are several shortcomings of using agitated reactors, such as, high agitation power requirement, difficulties in maintenance, and high operating costs. The bubble column has some advantages, such as, low shear stress for microorganisms, ease of construction and maintenance. However, a bubble column is not so flexible as an agitated reactor in mass transfer and liquid mixing. Modified bubble columns have been proposed [6-8]. The airlift reactor is one of the modified bubble columns. Airlift reactors have high liquid circulation rates and thorough liquid mixing [9-11]. Nevertheless, the gas-liquid mass transfer rate of airlift reactors is usually lower than that of bubble columns under the same operating conditions. Bando et al. [12] introduced the bubble column with perforated draft tube and observed the flow characteristics [13, 14].

Wu and Wu [15] proposed an airlift reactor with a net draft tube. The mass transfer coefficients of the reactor with a mesh-24 draft tube were higher than those of the bubble column and conventional airlift reactor. Wu et al. [16] also found that the ratio of the draft tube to reactor diameter was an important factor for mass transfer. The reactor has been successfully used for cultivation of baker's yeast [17] and production of glutamic acid [18] without the problem that the net might be covered by microorganisms.

There are many investigations on the mixing characteristics of bubble columns [19-21] and airlift reactors [22-24]. Since the axial mixing is an important characteristic factor of tubular reactors, many research works have been focused on it [6, 25-26]. The axial dispersion model [5, 27-28] and the tanks-in-series model [6, 29-30] are widely used for description of the axial mixing in bubble columns. Determination of axial dispersion coefficient depends on the equipment and operating conditions. In a conventional airlift reactor, Weiland [31] examined the effect of the ratio of the draft tube to reactor diameter on process parameters: gas holdup, oxygen transfer, liquid circulation, and mixing time. He pointed out that the diameter ratios of 0.8 and 0.9 would give efficient mixing. In the present study, evaluation of the axial dispersion coefficient in the airlift reactor with the net draft tube for different ratios of draft tube to reactor diameters is investigated.

2 Equipment and materials

2.1 Equipment
The experimental equipment was the same as that described by Wu et al. [16]. The schematic diagram is shown in Fig. 1. The reactor which was made of acrylic, 13 cm in diameter and 200 cm high, contained a concentric draft tube of 100 cm height. Four different draft tubes were tested. They were 6.5, 8.0, 9.0, 10.4 cm in diameter, respectively. The mesh number of the net draft tube was 24. Without the net draft tube, the reactor became the bubble column. The working volume of the liquid in the reactor was 15 dm³. The sparger was porous with pore size of 40 to 50 μm. Its location was at the bottom of the draft tube. The superficial gas velocity was in the range of zero to 6.05 cm/s. The 3.4 N of NaCl solution was used as the tracer which was injected from the top of the reactor center. The injected volume of the tracer was 5 ml. The conductivity sensor (Jenco, model 3101) was located at a position of 30 cm from the bottom of the reactor. The reactor was coupled with a computer data acquisition system. The computer was an IBM PC/AT which was interfaced with an HP-3456A digital voltmeter and an HP-3497A data acquisition unit (Hewlett-Packard).
2.2 Methods
Several methods for measuring mixing operation have been reviewed by Ford et al. [32]. The basic approach of the methods was the pulse response technique. The characteristic parameter of mixing was determined by matching a mathematical model and experimental data. In a tubular reactor, the mixing effect was frequently characterized by dispersion coefficient.

The axial dispersion model was usually applied to determine the dispersion coefficient in the loop reactor [25, 28]. On the other hand, for batch operation of bubble columns, the diffusion model was used [26, 33-34]. Since the RTD (residence time distribution) curve of our proposed airlift reactor was similar to that of the bubble column, determination of the dispersion coefficient in the present study was closely related to that of Ohki and Inoue [33].

The axial dispersion coefficient was given by [26, 33-34]:

$$D_l = \left( \frac{h_f}{\pi} \right)^3 \Delta \theta,$$

where $D_l$ was the axial dispersion coefficient, $h_f$ was the height of liquid with aeration; $\Delta t$ was the time interval between 0.7 and 0.3 of the normalized RTD curve with respect to time; $\Delta \theta$ was directly measured from the normalized RTD curve with respect to $(\pi h_f)^2 D_l t$ as shown in Fig. 2, where $Z$ denoted the sensor position from the top of the column. In the present study, the curve fitting was carried out by using a computer program.

3 Results and discussion

3.1 The RTD curves of the bubble column and the proposed airlift reactor

Figure 3 gives a typical RTD curve of the proposed airlift reactor. It shows that the tracer response curve of the proposed reactor is similar to that of a bubble column and unlike that of a conventional airlift reactor. The pulse response curve of the conventional airlift reactor is oscillatory [10]. Michell and Furzer [35] and Shah [2] report that estimation of the axial dispersion coefficient depended on the close match of the observed RTD curve and the solution of the axial dispersion model. Since the RTD curve of the proposed airlift reactor was similar to that of the bubble column, the diffusion model was applied. The close match between the model and experimental data from our experiments showed that application of the diffusion model was suitable.