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EXPERIMENTAL STUDY ON THE GAS-LIQUID FLOW IN THE MEMBRANE MICROPORE AERATION BIOREACTOR

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Abstract

Particle Image Velocimetry (PIV) has been developed to measure the typical two-phase flow of various work conditions in Membrane Micropore Aeration Bioreactor (MMAB). The fluid phase is separated out using image processing techniques, which provides accurate measurements for the Bioreactor's flow field, and makes it possible for quantitative analysis of the momentum exchange, heat exchange and the process of micro-admixture. The experimental method PIV used in this paper can preferably measure the complex flow in the reactor and initiates a new approach for the bioreactor design which mainly depends on experience at present.

Keywords: PIV (Particle Image Velocimetry), MMAB, Simulation, Two-phase flow.

1. Introduction

The Membrane Micropore Aeration Bioreactor (MMAB) is a bran-new air-lift reactor [1], which produces energy by expansion of compressed air. The lift brought by density difference between the bubbly and pure liquid makes the fluid flow along special passage, while the gas and liquid phases mixed intensively make the process of mass and heat transfer accomplished perfectly [2,3]. The gas-liquid two-phase flow in the reactor is very complex [4,5]. At present it is very difficult to obtain the flow distribution in the reactor by theory analysis. So generally the internal flow is obtained indirectly by investigating the hydrodynamic character in the reactor. Through investigating these parameters, we gain a far-ranging and in-depth understanding about the gas-liquid two-phase flow in the reactor.

As an advanced whole flow field, instantaneous state and no touch measurement technology, particle image velocimetry (PIV) has been widely used in many sorts of steady and unsteady single phase flow. But in recent years, lots of researchers began to pay attention to use PIV to measure gas-liquid two-phase flow [6,7], especially using image processing techniques to separate the gas phase and liquid phase. And now the PIV measurement technology of gas-liquid two-phase flow in bioreactor is still under developing.

This paper firstly adopts the PIV technique combined with the image processing technique to measure the liquid-phase velocity under different superficial gas velocities in the reactor. The relation between the superficial gas velocity and the liquid circulation rate is qualitatively analysed.

2. Apparatus and Experimental Method

The experimental apparatus consists of MMAB subsystem and test system. The testing instrument in the experiment is purchased from TSI Company, which consists of a 120 mJ/pulse Nd:YAG laser (532 nm wavelength), laser light sheet optics, a CCD camera (resolution: 1280x1024 pixels) equipped with a 60-mm lens (Nikon), data acquisition system consisting of a PC and a frame grabber card. The laser beam is formed into a 0.2-mm thick light sheet using a combination of cylindrical and spherical lenses. The CCD camera is mounted on a 3-D traverse with a translation accuracy of 0.1 mm in each direction, and has its focal axis perpendicular to the plane of the laser light sheet to acquire flow images. Pair of single exposure image frames are required to enable cross-correlation data processing. The image pair acquisition and processing is done using the INSIGHT 5.0.

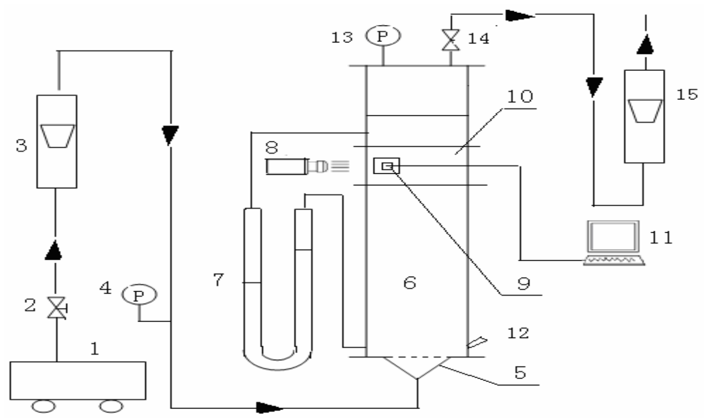
2.1. MMAB system and operation process

Following the character of gas-liquid bioreactor commonly used in ferment industry, and based on the similarity law, the experimental system is designed after simplify some auxiliary devices of bioreactor (see Fig. 1). The bioreactor is made of organic glass pipes with 1.0-m height and inner diameter of 0.3 m. The height of experimental fluid level is 0.68 m (the height ratio between fluid level and bioreactor is 2:3 in the real production process). Simultaneously in one side of the bioreactor, from bottom to the top, manometric ports are designed with 8-mm diameter every each 0.1 m. The micropore aeration distributor is fitted in the central bioreactor. Gas storage with volume of 0.2 m^3 is installed in the outlet of compressor which has the function to stabilize the gas flux. The gas is sent out from the compressor, after adjusting the gas flux by pressure steady governor valve, the gas flows to the micropore aeration distributor, arrives the bioreactor and then to the top and ejects from the outlet flowmeter. The operating pressure is controlled by adjusting the valve on the top of the bioreactor [2].

2.2. The micropore aeration distributor

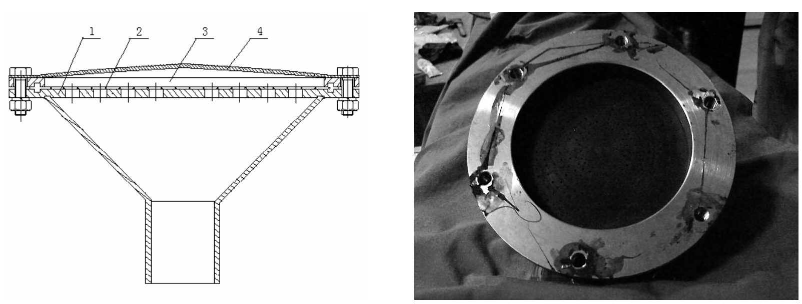
The micropore aeration distributor is a new type membrane distributor which is developed by a corporation from ChangZhou, as shown in Fig. 2. The membrane is made of high strength synthetic rubber by heating and pressurizing. Thickness of the membrane is 2 mm and with the average diameter of 10 µm. The distributor is supported by sieve plate with the thickness of 5 mm and twenty four pores of

8-mm diameter, fixed by stainless steel plate. The position-limit cover is used to restrict the height of uplifted aeration for protecting the distributor. The distributor has the valid operation diameter of 150 mm and is connected with the bioreactor by the flange.



1. Compressor, 2. Pressure stabilization valve, 3. Inlet rotameter, 4. Inlet Manometer, 5. Membrane micropore aeration gas distributor, 6. Bioreactor, 7. U-shape differential manometer, 8. YAG laser system, 9. CCD camera, 10. PIV test section (water jacketed area), 11. Computer, 12. The portable oxygenic electrode, 13. Outlet manometer, 14. Outlet valve, 15. Outlet rotameter.

Fig. 1. Experimental Apparatus.



1. Sieve plate, 2. Membrane micropore, 3. Stainless steel plate, 4. Position-limit cover.

Fig. 2. Schematic Diagram of Micropore Aeration Distributor.

2.3. Operation conditions

The working fluid of this experiment is air-water two-phase flow, and sodium oleate is used to change the liquid surface tension and the triethylene glycol is used to change the viscosity. The experiment conditions are shown in Table 1. Because temperature has a significant influence on the surface tension and viscosity, the table lists the surface tension and viscosity under normal temperature.

Table 1. Experimental Conditions.

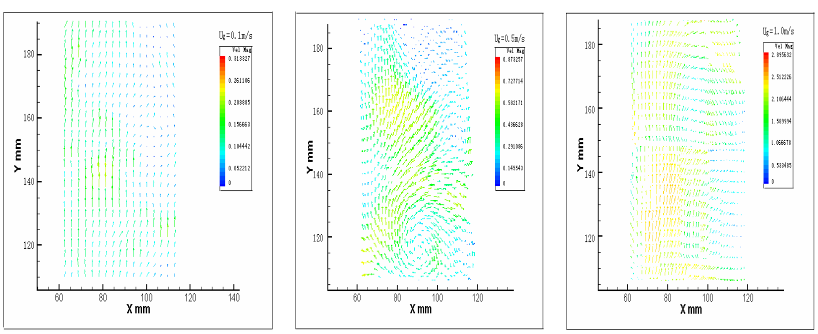
Operation Condition	Scale
Viscosity (μ)	$(1.005\text{-}8.60)\times10^{-3}$ Pa.s
Surface tension (σ)	$(51\text{-}120)\times10^{-3}$ N/m
Operation pressure (P)	(0.01-0.1) MPa
Gas flux(Q)	(5-35) m^3/h
Fluid level (H)	(0.5-0.8) m

3. Results and Discussion

3.1. Liquid velocity distribution

In the Membrane Micropore Aeration Bioreactor, different superficial gas velocity and position have different liquid velocity. This paper only shows the liquid velocity distribution on the axis plane, and then the results are compared with simulation.

It can be found from Fig. 3 that the liquid velocity has significant change with the increasing of superficial gas velocity. On the bottom of the reactor, the liquid in the rising area obtains primary velocity because of the gas motion, and then the velocity decreases under the influence of gravity and resistance. When the superficial gas velocity becomes smaller, the bubbles in liquid mainly sustain the buoyancy force, and the two-phase flow in the reactor has not reached the state of turbulent, the liquid in the rising area has been affected by the bubble motion. With the increase of superficial gas velocity, the gas-liquid phase flow reaches turbulent gradually, so the bubbles and liquid mixes intensively, and the bubbles in the rising area move to the gas-liquid separated area under the influence of buoyancy force and inlet pressure, which affects the liquid at the bottom of reactor intensively, the liquid in this area begins to move upward with the impact of the bubble movement, at the same time, the liquid in the decline area starts flow to the bottom of the reactor because of the density variation, so the liquid moves circulated . In addition, because of the scouring action of the liquid in the decline area and the shearing effect in the rising area, the vortex can be easily formed at the bottom, which reduces the static area obviously, and enhance the efficiency of the reactor. Simultaneously, because of the strong mixing of the turbulent flow, the bubble breaks up easily; this also enhances the mass transfer of oxygen.



(a) (b) (c)

Fig. 3. Liquid Velocity Distribution.

3.2. Discussion of experimental and simulation results

Figure 4 shows the simulation and experimental results of liquid velocity in radial direction. Figs. 4(a) and (b) show the liquid velocity contrast curve in central axial plane when the superficial gas velocity is 0.5 m/s and 1.0 m/s respectively. Fig. 4(c) shows the contrast curve of liquid velocity in the line of Z=50 cm under different superficial gas velocities. From these results, we can find that:

- The experiment result of velocity distribution in the radial direction corresponded with simulation. It is shown from the convexity curve distribution that in Z-direction, the velocity has the largest value in the centre and then drops sharply to zero near the wall.
- The simulation and experiment results show that the variation of the liquid velocity as a function of superficial gas velocity is also consistent. The liquid velocity increases with the increase of superficial gas velocity.

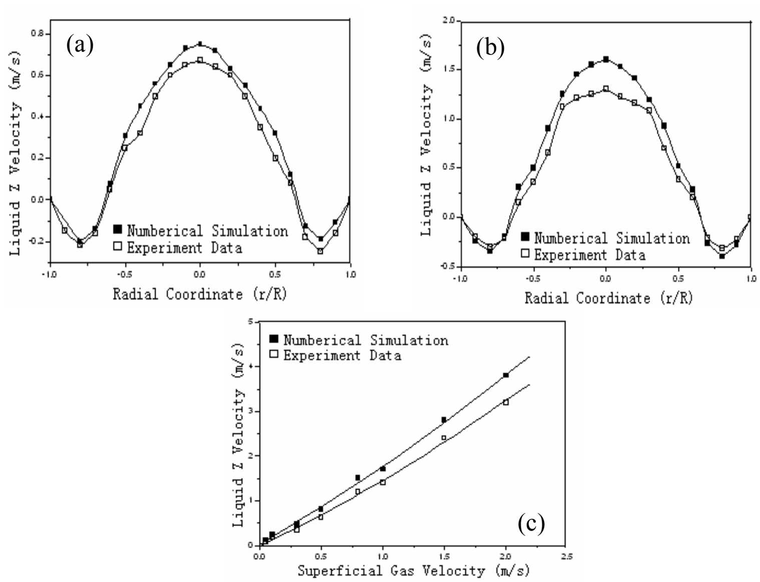


Fig. 4. Comparison between Simulation and Experimental.

4. Conclusion

Particle Image Velocimetry (PIV) is used to measure the flow field of gas-liquid two-phase turbulent flow in the bioreactor, and a contrast analysis between the result of simulation and experiment is performed. It proves that some errors exist between the simulation and experiment and the errors are from 5% to 10% in the main flow direction, but it keeps unification in the change tendency. So it is feasible to apply PIV and the image processing techniques to predict the complicated two-phase flow field in membrane micropore aeration bioreactor.

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