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Transfer Characteristics in Mechanically Stirred Airlift Loop Reactors with or without Static Mixers

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Abstract The mechanically stirred internal loop airlift reactors equipped with or without static mixers are devised for intensification of gas-liquid mass transfer rate. The influences of superficial gas velocity, agitation or static mixers on gas hold-up, mixing time, liquid circulating velocity and volumetric mass transfer coefficient have been investigated with tap water and carboxymethyl cellulose (CMC) aqueous solution. The experimental results indicate that mechanical agitation is more efficacious than static mixer in highly viscous media for improving mass transfer in airlift reactors. The empirical correlation of volumetric mass transfer coefficient with apparent viscosity, and energy consumption for mechanical agitation and aeration is developed.
Keywords airlift loop reactor, static mixer, stirrer, hydrodynamics, mass transfer

1 INTRODUCTION

Airlift reactors have received much attention for application in biochemical and chemical industries because of their simple geometry, uniform mixing and low power consumption. However, it has been generally recognized that the gas-liquid mass transfer rate in conventional internal airlift loop reactors is lower than that in bubble columns. On the other hand, viscous media are frequently encountered in chemical or biochemical processes. High viscosity induces bubble coalescence, leading to deterioration of interphase mass transfer. Therefore, improvement of mass transfer in airlift reactors is desired. Employing a stirrer and/or a static mixer may be useful for intensification of the performance of mass transfer in an airlift reactor[1—5]. However, only a few investigations of airlift reactors employing static mixers or mechanical agitation are available[6,7]. In this work, gas holdup, liquid circulating velocity, mixing time, energy dissipation and the overall volumetric oxygen transfer coefficient are investigated with tap water and non-Newtonian aqueous CMC solution systems (5, 16 and 24 $g{\cdot}L^{-1}$). The flow index K is equal to 0.0096, 0.3325 and 1.304 $Pa{\cdot}s^n$ and the flow consistency n equal to 0.9723, 0.809 and 0.7363 respectively in the power law model.

2 EXPERIMENTAL

The experimental apparatus is outlined in Fig. 1. The reactor ($D = 0.14\,m$, $H = 1.4\,m$, $V_r = 0.02m^3$) was made of plexiglass. The diameter of riser was 0.1 m. The cross-sectional area ratio of downcomer to riser was 1.086 for reducing flow resistance, and H_C was 1.04 m. Two SMV-12 static mixer elements[8] were mounted in the upper riser. The mechanical impeller was placed inside of the lower part of riser above the gas ring sparger over the reactor bottom. The impeller was a pitched disk turbine with 4 blades with a diameter of 0.085 m. Four baffles were placed above and below the impeller respectively to avoid the formation of vortex.. The gas and liquid flow upward in the riser. The average gas hold-up value is obtained by the volume expansion method. The overall liquid-side volumetric mass transfer coefficient K_La was determined with an oxygen meter by means of the dynamic gas dissolution method. The liquid flow characteristics (liquid circulating velocity and mixing time) were measured with two conductometers in tracer experiments. The mixing time was defined as the time required to achieve a specific percentage of concentration homogeneity (95% of its final value) within the reactor after the tracer (KCl Solution) was injected[9].

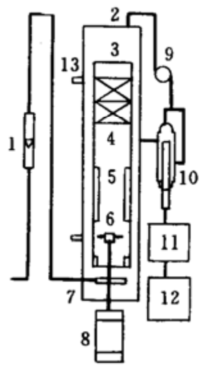

Figure 1 Schematic diagram of internal airlift loop reactor with static mixers
1—rotameter; 2—external column; 3—draft tube; 4—static mixers; 5—baffle; 6—impeller; 7—gas ring sparger; 8—electromotor; 9—pump; 10—oxygen electrode; 11—data card; 12—computer; 13—conductometer

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The total energy consumption rate P_T was assumed to be the sum of the individual contributions from aeration and propeller operation. The energy dissipation due to aeration P_A was calculated by Eq. (1) proposed by Chisti[10]. The energy dissipated by propeller operation P_P was estimated by Eq. (2) suggested by Onken[11].

$$P_A = \frac{\rho_L g U_{gr}}{1 + A_d/A_r} \tag{1}$$

$$P_p = \frac{2\pi N M_R}{V_L} \tag{2}$$

3 RESULTS AND DISCUSSION

3.1 Gas hold-up

The ε_g increases with the increase of N and gas superficial velocity U_g with/without static mixers (Figs. 2 and 3). It also generally decreases with an increase of fluid viscosity due to bubble coalescence (Fig. 3). Larger bubbles rise faster in the riser and make ε_g reduced. The static mixers reduce bubble diameter owing to the shear rate enhanced by static mixers. On the other hand, static mixers reduce liquid circulation velocity. These two factors increase ε_g. The effect of static mixers on ε_g in low viscosity liquid (waterlike) is larger than in highly viscous liquid. So static mixers are more efficient in low viscosity fluids.

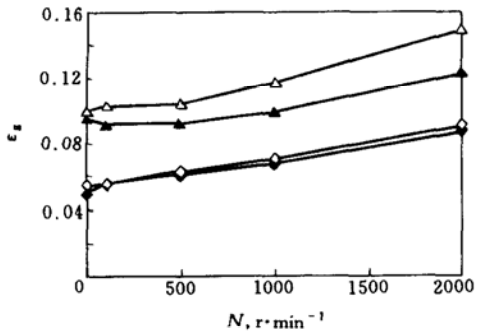

Figure 2 Effect of viscosity, impeller speed and static mixer on gas hold-up in tap water and 24 g·L^{-1} aqueous CMC solution ($U_g = 0.055\,\mathrm{m{\cdot}s^{-1}}$)

c, g·L^{-1}: ▲ 0; △ 0, m; ◆ 24; ◇ 24, m

m: with static mixers

3.2 Liquid circulating velocity

In this study, U_L increases with the increase of superficial gas velocity U_g and impeller speed N as shown in Fig. 4 when no static mixer installed. In the presence of static mixers, U_L is lower than that without static mixers, because the increased resistance to fluid flow. When there are static mixers in the riser of the airlift reactor, the variation tendency of U_L presents two different aspects. When the impeller speed is moderate (0 to 500 r·min^{-1}), U_L increases with the increase of U_g, and when N is higher (1000 to 2000 r·min^{-1}), U_L decreases with the increase of U_g instead. It was observed in the experiment that blocking gas pockets appeared around the impeller, and disturbed the flow of liquid. When U_g is bigger than 0.05 m·s^{-1}, U_L does not decrease any longer (Fig. 4). A suitable impeller speed must be chosen for the operation of an impeller airlift reactor.

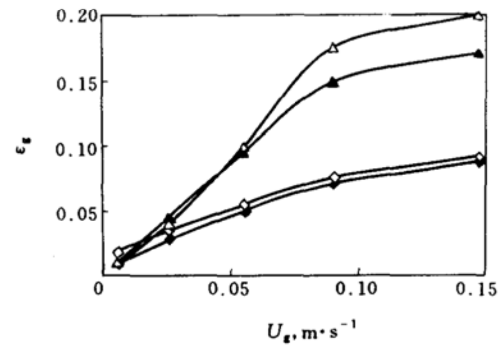

Figure 3 Effect of viscosity, U_g and static mixer on gas hold-up in tap water and 24 g·L^{-1} aqueous CMC solution ($N = 0$)

c, g·L^{-1}: ▲ 0, m; △ 0; ◆ 24; ◇ 24, m

m: with static mixers

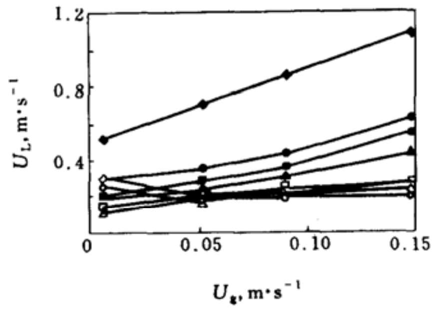

Figure 4 Effect of static mixers and of impeller speed on liquid circulating velocity in 16 g·L^{-1} aqueous CMC solution

N, r·min^{-1}: ▲ 0; ■ 500; ● 1000; ◆ 2000;

△ 0, m; □ 500, m; ○ 1000, m; ◇ 2000, m

m: with static mixers

3.3 Mixing time

As drawn in Fig. 5, T_m decreases with increase of U_g and N. The effect of U_L is larger when no stirring is used. Static mixer reduces the circulation velocity and leads always to longer T_m. This result is similar to that in an external loop airlift reactor[9]. The variation tendency of mixing time without agitation is different from that of mixing with agitation. The variation of mixing time without static mixers is in a manner similar to that of mixing time with static mixers.

3.4 Volumetric mass transfer coefficient

Fig. 6 illustrates that K_La decreases with the increase of liquid viscosity and increases with U_g and N, that is, with the increase of power input. At the same operating condition, K_La is higher with static mixers than without static mixers[12]. The effect of static mixer decreases with the increase of the liquid viscosity, though the K_La value with static mixers is always slightly higher than that without static mixers. In more viscous media, the effect of mechanical agitation is larger than that of static mixers. There is no necessity for using static mixers in internal airlift reactors in highly viscous fluid system, but they can be used together with impeller for improving mass transfer.

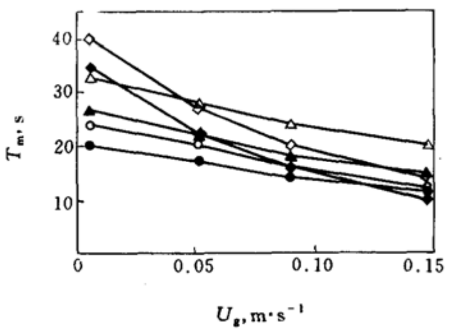

Figure 5 Effect of static mixers and of impeller speed on mixing time in 16 g·L^{-1} aqueous CMC solution
N, r·min^{-1}: ◆ 0; ▲ 1000; ● 2000;
◇ 0, m; △ 1000, m; ○ 2000, m
m: with static mixers

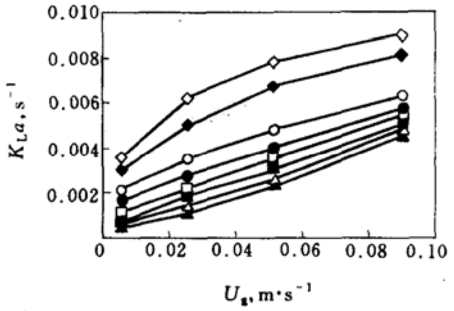

Figure 6 Effect of static mixers and of impeller speed on mass transfer coefficient in 24 g·L^{-1} aqueous CMC solution
N, r·min^{-1}: ▲ 0; ■ 500; ● 1000; ◆ 2000;
△ 0, m; □ 500, m; ○ 1000, m; ◇ 2000,m
m: with static mixers

4 CORRELATIONS OF VOLUMETRIC MASS TRANSFER COEFFICIENT WITH/WITHOUT STATIC MIXERS

Two correlations were developed in terms of three important variables (μ_a, P_A, P_P):

$$K_La = 0.0003\mu_a^{-0.348}(P_A^{0.388} + P_P^{0.293})$$

for the case without static mixers with the standard deviation 0.8975;

$$K_La = 0.0003\mu_a^{-0.316}(P_A^{0.413} + P_P^{0.308})$$

for the case with static mixers installed with the standard deviation 0.9417.

It can be seen the difference between the corresponding parameters in two correlations mentioned above is small. At the same operation conditions, the K_La values with static mixers are slightly higher than that without static mixers. It appears that the effect of static mixers is only moderate.

5 CONCLUSIONS

It is found that the gas hold-up increases with the increase of impeller speed N and gas superficial velocity no matter static mixers are installed or not, and decreases with increase of fluid viscosity. Static mixers are more efficient for increasing gas hold-up in less viscous fluid.

The liquid circulating velocity increases with the increase of superficial gas velocity and impeller speed. U_L with static mixers is lower than that without static mixers, and it also varies with the operating conditions in distinctly different ways.

The mixing time decreases with increase of U_g and N. Static mixers reduce the circulating velocity and lead to longer T_m.

The mass transfer coefficient K_La is lower in liquid with higher viscosity and increases with the increase of U_g and N. The gas-liquid mass transfer in airlift loop reactor can be intensified by static mixer or mechanical agitation. In highly viscous media, the application of mechanical agitation is more efficient than static mixers.

The empirical equations for evaluation of K_La with/without static mixers take into account the energy dissipation rate and apparent viscosity. The effect of P_A is more significant than that of P_P.

NOMENCLATURE

A_d	downcomer cross-sectional area, m^2
A_r	riser cross-sectional area, m^2
c	concentration of aqueous CMC solution, g·L^{-1}
D	diameter of airlift reactor, m
g	gravitational acceleration, 9.812 m·s^{-2}
H	height of airlift reactor, m
H_C	static height of liquid, m
K_La	volumetric mass transfer coefficient, s^{-1}
M_R	torque or impeller shaft N·m
N	stirring speed, r·min^{-1}
P_A	energy dissipation rate for airlift aeration, W·m^{-3}
P_P	energy dissipation rate for mechanical agitation, W·m^{-3}
P_T	total energy dissipation rate, W·m^{-3}
U_g	superficial gas velocity, m·s^{-1}

U_L liquid circulating velocity, $m \cdot s^{-1}$
U_{gr} superficial gas velocity in the riser, $m \cdot s^{-1}$
V_r volume of reactor, m^3
ε_g gas hold-up
μ_a apparent viscosity, Pa·s
ρ_L density of liquid, $kg \cdot m^{-3}$

REFERENCES

1 Ruffer, H. M., Broring, S., Schugerl, K., "Fluid dynamic characterisation of airlift tower loop bioreactors with and without motionless mixtures", *Bioprocess Eng.*, **12** (3), 119 (1995).

2 Pollard, D. J., Ison, A. P., Ayazi Shamlou, P., Lilly, M. D., "Influence of a propeller on Saccharomyces cerevisiae fermentations in a pilot scale airlift bioreactor", *Bioprocess Eng.*, **16** (5), 273 (1997).

3 Zhou, W., Holzhauer-Reiger, K., Bayer, T., Schugerl, K., "Cephalosporin C, production by highly productive Cephalosporium acremonium strain in an airlift tower reactor with static mixers", *J. Biotechnol.*, **28** (2-3), 165 (1993).

4 Chisti, Y., Moo-young, M., "Bioprocess intensification though bioreactor engineering", *Trans. Instn. Chem. Eng.*, **74A**, 575 (1996).

5 Xu, P., Lin, J. Q., Jiang, B. Y., "Xanthan gun production with pumping static mixing loop fermentor (PS-loop fermentor)", *Biotech. Let.*, **18** (5), 523 (1994).

6 Okada, K., Nagata, Y., Akagi, Y., "Effect of packed bed on mass transfer in external-loop airlift bubble column", *J. Chem. Eng. Japan*, **29** (4), 582 (1996).

7 Garvrilescu, M., Roman, R. V., Tudose, R. Z., "Hydrodynamics in external-loop airlift bioreactors with static mixers", *Bioprocess Eng.*, **16** (2), 93 (1997).

8 Chisti, Y., Kasper, M., Moo-Young, M., "Mass transfer in external-loop airlift bioreactors using static mixers", *Can. J. Chem. Eng.*, **68** (1), 45 (1990).

9 Garvrilescu, M., Roman, R. V., "Mixing time in an external-loop airlift bioreactor with static mixers", *Acta Biotechnology*, **16** (2-3), 145 (1996).

10 Chisti, M. Y., Airlift Bioreactors. Elsevier Applied Science, U. K.,(1989)

11 Keitel, G. ,Onken, U., "Gas-liquid mass transfer in a stirred loop reactor", *Ger. Chem. Eng.*, **4**, 250 (1981).

12 Ujhidy, A., Jr, Bucsky, G., "Influence of static mixers on operation behaviour of arlift reactors", *Hung. J. Ind. Chem.*, **25** (1), 7 (1997).