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Effects of surface active agents on hydrodynamics and mass transfer characteristics in a split-cylinder airlift bioreactor with packed bed

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ABSTRACT

The effects of three types of surface active agents (containing SDS, HCTBr and Tween 40) with various concentrations (0–5 ppm) on the hydrodynamic and oxygen mass transfer characteristics in a split-cylinder airlift bioreactor with and without packing were investigated. It was observed that in the surfactant solutions, surface tension of the liquid decreased and smaller bubbles were produced in comparison with pure water. So, surfactants presence strongly enhanced mixing time and gas hold-up although oxygen mass transfer coefficient and the liquid circulation velocity reduced. Furthermore, the packing installation enhanced the overall gas–liquid volumetric mass transfer coefficient by increasing flow turbulency and Reynolds number compared to an unpacked column. The packing increased gas hold-up and decreased bubbles size and liquid circulation velocity.

Keywords: Airlift bioreactor; Gas–liquid; Surface active agents; Packed bed; Hydrodynamics; Mass transfer coefficient

1. Introduction

Airlift bioreactors are one of the important classes of modified bubble columns (Joshi et al., 1990) which are widely used in various industrial applications such as chemical, petrochemical, biochemical fermentation and biological wastewater treatment processes (Blenke, 1979; Chisti, 1989; Saez et al., 1998).

Surface active agents (such as surfactants) are containing hydrophobic and hydrophilic groups. These materials locate their hydrophilic head groups in the aqueous phase and allow the hydrophobic hydrocarbon chains to escape from water phase. They could reduce surface tensions by accumulating at the interface of immiscible fluids. Surfactants are commonly used in the petroleum, food, and pharmaceutical industries as detergents, emulsifiers, foaming and wetting agents (Porter, 1994). These materials as most important contaminates exist in many factories wastewater (Moraveji et al., 2010).

Kalekar and Bhagwat (2006) studied the adsorption of various surfactants at gas–liquid interface. Egan (1976) investigated the critical micelles concentration (CMC) for various surfactants in different solutions. Guo et al. (1997) observed that the gas hold-up (ε) in a packed bed column linearly increased with increasing the gas superficial velocity (U_G) (for $U_G < 0.011$ m/s) although it showed a power trend for high superficial velocities (for $U_G > 0.011$ m/s).

Chisti and Moo-Young (1993) studied liquid circulation velocity (U_{LC}) in an external loop airlift bioreactor (ELAB) using spherical bead and Raschig Ring packing in the riser section. According to this research, the airlift packed bed reactor generated enough liquid flow for successful operation with some cell culture and immobilized enzyme systems.

Further, the mass transfer coefficient increased with increasing the liquid superficial velocity in the gas–liquid packed bed columns (Yuan et al., 2004; Deront et al., 1998).

Nikakhtari and Hill (2005a) increased the overall volumetric mass transfer coefficient (k_La) by inserting a few nylon meshes as packing (with 96.3% porosity) in the riser section of an external loop airlift bioreactor. They also used stainless steel meshes as packing (with 99.0% porosity) in the riser of the same reactor to increase the volumetric mass coefficient (Nikakhtari and Hill, 2005b). However stainless steel meshes

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Nomenclature

a (m^2/m^3)	gas–liquid interfacial area per unit volume of the liquid
Bo (–)	Bond number $[(\rho_L-\rho_G)gd_b^2/\sigma_L]$
C_L (kg/m^3)	concentration of dissolved oxygen at any time t
C_0 (kg/m^3)	initial concentration of dissolved oxygen
C^* (kg/m^3)	saturation concentration of dissolved oxygen
d_b (m)	bubble diameter
d_{ave} (m)	average of bubble diameter
D (m^2/s)	gas diffusivity
Fr (–)	Froud number $(U_G/\sqrt{g\cdot d_b})$
g (m/s^2)	acceleration due to gravity
Ga (–)	Galilie number $(d_b^3\cdot\rho_L{}^2\cdot g/\mu_L{}^2)$
h_R (m)	height of gas–liquid dispersion in the reactor
k_L (m/s)	liquid film mass transfer coefficient
k_La (s^{-1})	overall volumetr gas–liquid mass transfer coefficient
M_W (kg kmol^{-1})	molecular weight
Re (–)	Reynolds number $(d_b\cdot U_G\cdot\rho_L/\mu_L)$
Sh (–)	Sherwood number $(k_L\cdot d_b/D)$
Sc (–)	Schmit number $(\mu_L/\rho_L\cdot D)$
t (s)	time
t_c (s)	time interval between adjacent peaks of the tracer signal
t_E (s)	electrode response time
t_m (s)	mixing time
U_G (m/s)	superficial aeration velocity in the riser zone
U_L (m/s)	liquid superficial velocity
U_{LC} (m/s)	liquid circulation velocity
V (m^3)	volume

Greek symbols

ε (–)	overall gas holdup
μ (k/Pa s)	viscosity of phase
ρ (kg/m^3)	density of phase
σ (mN/m)	surface tension

Subscript

k phase	$k=G$: gas phase, $k=L$: liquid phase

increased the volumetric mass coefficient compared to an unpacked airlift reactor, but nylon meshes increased it more than that of the stainless steel meshes.

Mathison and Hill (1992) investigated the biodegradation enhancement of water soluble toxic organics (such as phenol and chlorophenol) using packing in an external loop airlift bioreactor (ELAB). They used seven types of packing and found that the plastic (Nylon) meshes as packing provided the maximum biodegradation.

Meng et al. (2002a) used woven nylon as packing in the riser section of an ELAB. They found that gas hold-up slightly depended on packing height. They concluded that the highest gas hold-up improved mass transfer. It also prepared large void spaces and reduced plugging and liquid frictional losses.

In this article, hydrodynamic and mass transfer characteristics of a split-cylinder airlift reactor with packing installed in the riser section were investigated when different surfactants (SDS, HCTBr and Tween 40) at various concentrations were added into the water. The effects of these surfactants on the operational characteristics in the airlift bioreactor were also considered.

2. Experiment

2.1. *Materials and methods*

Surfactants used in this study contain an anionic surfactant [sodium dodecyl sulfate (SDS)], a cationic surfactant [ammonium hexadecyltrimethyl bromide (HCTBr)] and a non-ionic surfactant [polysorbate 40 (Tween 40)] which were purchased from Acros Company (Geel, Belgium). Their various solutions with different concentrations (0–5 ppm) were locally prepared.

According to the literature, density and viscosity for surfactants diluted aqueous solutions were assumed to be equal to those values for tap water ($\rho=997$ kg/m^3 and $\mu=10^{-3}$ Pa s) (Sardeing et al., 2006). The properties of these surfactants are shown in detail in Table 1.

2.2. *Apparatus set-up*

Fig. 1 shows a schematic diagram of the split-cylinder airlift reactor with packed bed. The reactor consisted of a glass column (with 1.3 m height and 13.6 cm diameter). A rectangular Plexiglas baffle (with 0.129 m width, 1.0 m height and 0.005 m thickness) was inserted in the glass column to divide the cross section into a riser zone and a down-comer zone (the riser and down-comer areas were 86.115 and 40.299 cm^2, respectively). The baffle was located at a distance of 0.1 m from the bottom of the reactor. The ceramic Pall rings (with 38 mm in outside diameter, 34 mm in inside diameter and 38 mm in length) were used as packing (Fig. 2). The packed height in the riser zone was around 0.65 m. The packing dry factor and porosity were 356 m^{-1} and 78%, respectively. The gas-free liquid height in the reactor for each experiment was about 1.13 m. The gas sparger located at the bottom of the riser with 0.02 m in diameter made of the sintered ceramic ball.

A dissolved oxygen electrode was positioned in the riser zone at depth of 0.1 m from the surface of the gas-free liquid. The probe's tip was at an angle of 30° to the horizontal for preventing oxygen bubbles sticking to it. The conductivity electrode was positioned in the down-comer zone at depth of

Table 1 – Properties of the used materials.

Material	Formula	Type	M_W (kg kmol^{-1})	HLB	CMC (mM L^{-1})	σ (mN m^{-1})	ρ (kg/m^3)	μ (kg m^{-1} s^{-1})
SDS	$NaC_{12}H_{25}SO_4$	Anionic surfactant	288	40	–	0.035 (solution of 5 ppm)	998.2 (solution of 5 ppm)	0.001 (solution of 5 ppm)
HCTBr	$C_{19}H_{42}BrN$	Cationic surfactant	364.5	–	0.955	0.037 (solution of 5 ppm)	998.2 (solution of 5 ppm)	0.001 (solution of 5 ppm)
Tween 40	$C_{62}H_{122}O_{26}$	Nonionic surfactant	1283.8	15.5	0.027	0.038 (solution of 5 ppm)	998.2 (solution of 5 ppm)	0.001 (solution of 5 ppm)
Air	–	Gas	~29	–	–	–	1.225	2.16×10^{-5}