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Influence of draft tube cross-sectional geometry on K_La and ε in jet loop bioreactors (JLB)

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Abstract

Due to their compactness, and high flexibility in operation, the new processes like jet loop bioreactors (JLB) show a large potential for high removal efficiency and significant cost reduction in particular for the biological treatment of highly polluted wastewater. The rate of oxygen delivery determines the efficiency of aerobic processes. A modified JLB with square cross-sectional draft tube was developed in this study. Experiments were performed to investigate the effects of cross-sectional geometry, liquid flow rate and gas flow rate on gas hold-up and K_La. The comparison of these parameters as well as K_La was carried out for two cross-sectional draft tubes geometry. The results indicated that K_La values were better by 11–13% in square draft tube. In this study, the mass transfer characteristics with the square draft tube configuration have also been studied and a model was developed for this configuration.

Keywords: Jet loop reactors; Draft tubes; Bioreactors; Gas–liquid mass transfer; Gas hold-up

1. Introduction

With growing industrialization and density of population, the selection of treatment processes has become more and more important because of the stringent discharge limits. In order to meet these limits, the existing treatment plants have to be modified or replaced with the novel reactors. In the aerobic bioprocesses, oxygen transfer is essential for the performance of the system. Any shortage of oxygen drastically affects the process performance negatively. The oxygen transfer also effects metabolic activity, process efficiency and energy cost. It is also the principal hydrodynamic parameter in the operation of bioprocess. Therefore, oxygen transfer is important and frequently a rate limiting step for aqueous bioprocesses [1]. The oxygen absorption capacity of a bioreactor is characterized in terms of the overall volumetric gas–liquid mass transfer coefficient, or K_La. The use of jet aeration systems for biological treatment of wastewaters is becoming more common by means of combining efficient oxygen transfer with high turbulent. Jet aerator systems have been used successfully to upgrade biological treatment plants to meet increased loads and ever tightened legislations [2].

There are various types of loop bioreactors such as air lift bioreactor, propeller loop bioreactor and jet loop bioreactor. The jet loop bioreactors (JLB) are reactors with high performance and extensively used in fermentation, biotechnology and wastewater treatment plants. The JLBs have many advantages such as simple construction and operation, low investment and operational costs, definitely directed circulation flow, fine gas dispersion, high mixing and mass transfer performance and relatively lower power requirements [2–4]. In addition, absence of moving parts in the bioreactor, the efficient primary dispersion of gas in gas–liquid system and efficient redispersion of gas phase during recirculation, JLBs provide high performance at the biological treatment of industrial wastewater with high organic contents [2,5–9].

The principle in this reactor type is the utilization of the kinetic energy of a high velocity liquid jet to entrain the gas phase and to create a fine dispersion of two phases. The high shear rates from the liquid jet produce very fine gas bubbles and thus very high interfacial areas and volumetric gas transfer rates are generated in this equipment. The most important parameter in multiphase systems is the generation of interfacial area, the extent of which is directly related to the gas hold-up

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Nomenclature

A_b	bioreactor area (cm^2)
A_d	draft tube area (cm^2)
C	oxygen concentration in liquid (mg/L)
C_i	initial oxygen concentration in liquid (mg/L)
C_s^*	saturation oxygen concentration in liquid (mg/L)
D_b	bioreactor column diameter (m)
D_c	draft tube diameter (cm)
D_i	smaller diameter in liquid annular hole in the nozzle (cm)
D_G	air hole diameter in nozzle (mm)
D_L	diffusion coefficient (m^2/s)
E/V	energy dissipation rate per unit volume ($\rho_l A_D U_L^3/2V$) (kW/m^3)
g	gravitational constant (m/s^2)
h_L	level of the clear liquid (cm)
h_D	level of the two phase dispersion (cm)
H_b	bioreactor height (m)
JLB	jet loop bioreactor
K_La	volumetric mass transfer coefficient (1/h)
L_d	height of the draft tube (cm)
ΔP	pressure drop
Q_g	gas flow rate (L/min)
Q_L	liquid flow rate (L/min)
u	linear liquid velocity based on A_D (m/s)
V	liquid volume in the bioreactor (m^3)

Greek letters

ε	gas hold-up
μ_L	liquid viscosity (mPa s)
ρ_L	liquid density (kg/m^3)

(ε). The gas hold-up in turn depends upon the physical properties of the liquid, the flow regime and bioreactor efficiency [10]. JLBs in comparison with other types of gas–liquid bioreactors produce higher surface area between the gas and liquid phases.

There are a lot of parameters that affect K_La and ε in the JLBs. Investigations of the fundamental hydrodynamic features and mass transfer characteristics in JLBs have been reported by various authors in literature [3,4,10–13]. However, no work has been reported for the effect of draft tube cross-sectional geometry on K_La and ε so far. In the present investigation, the experiments were performed to obtain the effect of draft tube cross-sectional geometry on K_La and ε in the JLBs.

2. Materials and methods

2.1. Equipment and operational procedure

A schematic diagram of experimental set-up is shown in Fig. 1. JLB consisted of a cylindrical vessel (height 140 cm, inner diameter 15 cm) with a height to diameter ratio of 10:1 and carried inside a draft tube open at both ends and a degassing tank. The apparatus was made of a Perspex flex glass tube. Other dimensions of the experimental system are given in Table 1.

Table 1
Experimental parameters for jet-loop bioreactor investigation

Description	Notation	Value
Bioreactor height (cm)	H_b	140
Bioreactor diameter (cm)	D_b	15
Draft tube diameters/length		
Circular (cm)	D_c	6.2
Square (cm)	D_s	5.5
Draft tube to bioreactor cross-section area ratio	A_d/A_b	0.19
Draft tube length (cm)	L_d	100
Distance between the lower edge of the draft tube and the impact plate (cm)	H_p	7
Distance between the impact plate and the lower edge of the bioreactor (cm)		7
Air hole diameter in nozzle (cm)	D_G	0.64
Liquid annular hole inside diameter in nozzle (cm)	D_i	1.2
Unaerated liquid height (cm)	h_L	124
Liquid height above draft-tube (cm)		10
Working volume (L)	V	35
Temperature	°C	20 ± 2
Liquid phase	Tap water	

Two-fluid nozzle consisted of two concentric tubes. The outer nozzle was made of polyester. The inner nozzle was a stainless-steel tube of 6.4 mm in diameter and 1 mm thickness. The air to the reactor was provided from an air pump through the inner stainless-steel tube via a gas flow-meter. Gas and liquid flow rates were controlled by the valves and flow-meters on their respective pipelines. The two-fluid jet nozzle located at the top of reactor created a downward directed two-phase flow inside the draft tube and at the same time dispersed the air sucked in through the gas tube located within liquid jet. The type and place of the spray nozzle has a significant effect upon the gas dispersion within the liquid phase and the extent of the jet flow momentum, which promotes the mixing of the phases. There is no contact between the liquid and gas phases within the nozzle. Due to the momentum of liquid jet, the liquid and the gas inside the draft tube were moving downwards and after reflection at the reactor bottom, rose within the annulus between the wall of the reactor and the draft tube. At the upper end of the draft tube, a part of fluid was recycled into the draft tube by sucking action of the two-phase jet resulting in a re-dispersion of the bubbles. The temperature of bioreactor content was maintained around 20 ± 2 °C by circulating tap water through a stainless steel heat exchanger immersed in the degassing tank. The recycle flow was measured by a flow-meter and air flow supplied to bioreactor was measured by an air flow-meter.

Two draft tubes with different cross-sectional geometry were used in the experiments. One was a circular and the other was square geometry. Both draft tubes had equal cross-sectional area.

All the mass transfer tests were performed with tap water while the system was running under batch mode (the broken