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Mass transfer, gas hold-up and cell cultivation studies in a bottom agitated draft tube reactor and multiple impeller Rushton turbine configuration

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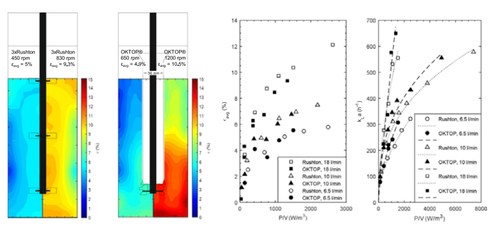
HIGHLIGHTS

- OKTOP®9000 draft tube reactor was utilized in a cell cultivation and mixing study.
- More uniform DO-profile was measured for OKTOP® reactor in cell cultivation.
- Draft tube reactor achieved higher k_La than regular STR with similar agitation power.
- EIT-measurements showed differences in local gas hold-up and gas flow regimes.

GRAPHICAL ABSTRACT



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ABSTRACT

Gas–liquid mass transfer is an important phenomenon in aerobic microbial cultivations, and the mass transfer performance of an industrial reactor strongly affects the overall process economics. Traditionally, industrial and laboratory bioreactors have been agitated with flat disc turbines (Rushton turbines) although there are many variants to this design. In addition, pneumatically agitated reactors such as bubble columns and airlift reactors have been studied and used by the industry.

In this study we utilize an agitated draft tube reactor in cell cultivation and mass transfer studies. A standard reactor geometry agitated with three Rushton turbines was compared to Outotec OKTOP®9000 reactor which is a draft tube reactor agitated with a single impeller located just below the draft tube. The experiments included cell cultivation with *Pichia pastoris* yeast, determination of overall mass transfer coefficient by dynamic gassing in method and measurement of local gas hold-up by electrical impedance tomography (EIT). In addition, agitation power was estimated from the power consumption of the DC-motor.

OKTOP®9000 reactor was found to have higher k_La values than the STR with similar agitation power and gas flowrate. The overall gas hold-up was similar in both geometries at same power inputs and gas flow rates. However, some significant differences were detected in the distribution of gas phase between the two geometries especially in the axial direction. Also changes in the gas dispersion regime can be detected from the spatial distribution of the gas hold-up measured by EIT. The cell cultivation experiments showed the applicability of this type of agitated draft tube reactor to bioprocesses although a direct comparison with Rushton geometry is not straightforward.

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Nomenclature

A	reactor cross sectional area (m^2)
B_w	baffle width (mm)
C	impeller off bottom clearance (mm)
C_l	dissolved oxygen concentration (mg/l or %)
$C_{l,p}$	dissolved oxygen probe reading (mg/l or %)
C_g	dispersed gas oxygen concentration (%)
C^*	saturation concentration of oxygen in liquid phase (mg/l or %)
D	diameter (mm)

Subscripts

I	impeller
dt	draft tube
g	gravitational acceleration (m/s^2)
H	height (mm)

Subscripts

l	liquid level
dt	draft tube
k_La	overall mass transfer coefficient (s^{-1} or h^{-1})
M	torque (Nm)
m	dimensionless partition coefficient for gas/liquid equilibrium (dimensionless)
N	impeller revolution rate (s^{-1} or min^{-1})
N_P	impeller power number (dimensionless)
P	impeller power input (W)

Subscripts

gas	gas buoyancy
tot	impeller and gas buoyancy
Q_g	volumetric gas flow rate (l/min or m^3/s)
S	impeller spacing (mm)
T	tank diameter (mm)
v_s	superficial gas velocity (m/s)
V	volume (l)
X	cell mass concentration (g/l)

Abbreviations

AL	airlift reactor
BSM	basal salt medium
CDW	cell dry weight (g/l)
DO	dissolved oxygen (%)
STR	stirred tank reactor
OD	optical density
OUR	oxygen uptake rate of cells
OTR	oxygen transfer rate of a reactor
YPD	yeast extract, peptone, dextrose medium

Greek letters

α, β, γ	parameters in k_La correlation
ε	gas hold-up (dimensionless)

Subscripts

avg	average hold-up over the reactor or measurement volume
vis	visually measured overall hold-up
θ_m	mixing time (s)
σ	conductivity (mS/cm)

Subscripts

l	liquid phase
m	measured
ρ	density (kg/m^3)
τ_r	DO-probe response time (s)

1. Introduction

Micro-organisms are used to produce different chemicals, enzymes and medicines. A majority of these production processes are aerobic. In aerobic processes, the cells utilize oxygen, dissolved in the liquid medium, in their metabolism as the final electron acceptor. In addition, there are so-called gas-fermentation processes in which carbon and/or energy is provided through the gas phase (Munasinghe and Khanal, 2010). Therefore, the most common reactors are gas–liquid contactors. The microbial cells can be considered as a solid phase. However, their density is near to that of water, reducing the terminal settling velocity, and they are often neglected when considering only the hydrodynamics of bioreactors. Especially in bulk enzyme and chemical production, the reactor volumes may be several hundred cubic meters, and the efficiency of gas–liquid mass transfer and bulk mixing becomes an important design parameter. Stirred tank reactors (STR) with height to diameter ratio (H/T) above 2 are common in large scale industrial processes and, therefore, they are often equipped with multiple impellers. Alternatives for STR include pneumatically agitated bubble column and airlift reactors. In the latter, a draft tube or other internal structure is constructed to enhance recirculation.

For STR, various impeller configurations have been proposed and tested. The traditional approach is to use several Rushton turbines for gas dispersion and mixing. Other options include concave disc turbines for better gas handling capacity and axial impellers to enhance liquid circulation. The axial impellers have been used both in up and down pumping modes (Moucha et al., 2003).

Gas flow regimes in a conventional STR are often characterized based on gas flow number ($Fl_g = Q_g N^{-1} D^{-3}$) and Froude number ($Fr = N^2 D g^{-1}$) to flooding, loading and complete dispersion. Impeller flooding should be avoided in all cases. In addition, superficial gas velocity ($v_s = Q_g A^{-1}$) is often used to describe a scale independent value for gas flow. At homogeneous regime ($v_s < 0.02$–0.03 m/s), impeller controls the flow pattern and bubble size whereas at heterogeneous regime ($v_s > 0.02$–0.03 m/s) flow is controlled by the gas velocity. (Paul et al., 2004). At homogeneous regime and non-flooded conditions, a following correlation is often written for overall gas–liquid mass transfer coefficient:

$$k_L a = \alpha \left(\frac{P}{V} \right)^{\beta} v_s^{\gamma}$$

where P is agitation power, V is the liquid volume, v_s is superficial gas velocity and α, β and γ are adjustable parameters. Sometimes, overall power input due to agitation and gas buoyancy is used instead of agitation power. Pneumatic power input per liquid