DESIGN AND SCALE-UP OF BIOREACTORS FOR DENSE SUSPENSION BROTHS

Y. KAWASE, T. KUMAGAI AND S. UENO
Center for Biotechnology Research
Kanazawa Institute of Technology
Nonoichi, Ishikawa
Japan 921

ABSTRACT. The effects of rheological complexity of dense suspension broths on the design and scale-up of bioreactors are discussed. On the basis of the surface renewal concept, a theoretical model for liquid-phase mass transfer coefficient, is developed. The validity of the proposed model is examined using a wide range of experimental results. The scale-up strategy for bioreactors is also discussed.

1. Introduction

There is increasing interest in dense suspension broths because of the incentive for higher productivity per unit reactor volume. Such suspensions, which become very viscous and behave as non-Newtonian fluids with an increase of the biomass concentration, present challenging problems in the design and scale-up of bioreactors.

In this work, the oxygen transfer in bioreactors is discussed. A theoretical model for liquid-phase mass transfer coefficient in bioreactors is developed. It is compared with the present data and the available correlations and experimental data. Furthermore, the scale-up strategy for bioreactors is also discussed.

2. Oxygen Transfer

2.1. VOLUMETRIC MASS TRANSFER COEFFICIENTS

The volumetric mass transfer coefficient ($k_{La}$) is one of the most important parameters which govern the performance of bioreactors. Therefore, an extensive effort has been directed to the estimation of $k_{La}$. However, only little systematic effort has been made. In order to elucidate the mechanism of mass transfer, theoretical development of correlation for $k_{La}$ is required.

Kawase et al. (1987, 1988) developed theoretical correlations for $k_{La}$ using a combination of Higbie's penetration theory and Kolmogoroff's theory.
of isotropic turbulence.

For bubble column reactors (Kawase et al. (1987))

\[
\mathrm{Sh} = 0.452 n^{11/6} \mathrm{Sc}^{1/2} \mathrm{Re}^{(2+n)/(1+n)} \mathrm{Fr}^{((11n-4)/(1+n))} / 30 (1+n) \mathrm{Bo}^{3/5} 
\]

\[
\mathrm{Sh} = \frac{k_L a D_R^2}{\rho} , \quad \mathrm{Sc} = \frac{(K/\rho) D_R^{1-n}}{U_{*e}^{1-n}} , \quad \mathrm{Re} = \frac{D_R n U_{*e}^{2-n}}{K/\rho} 
\]

\[
\mathrm{Bo} = \frac{\varepsilon D_R^2 \rho}{\omega} 
\]

and for stirred tank reactors (Kawase and Moo-Young (1988))

\[
k_L a = 0.875 \sqrt{\varepsilon / \pi} a^{3/5} \frac{\varepsilon^{(9+4n)/(1+n)}}{K/\rho} a^{1/2} \left( \frac{\mu_s}{\mu_w} \right)^{1/2} - 0.25 
\]

It should be mentioned that non-Newtonian flow behavior of dense suspension broths is assumed to be represented by a power-law model \((\tau = K\eta^n)\).

### 2.2. Liquid-Phase Mass Transfer Coefficients

The volumetric mass transfer coefficient \((k_L a)\) is the product of the specific surface area \((a)\) and the liquid-phase mass transfer coefficient \((k_L)\). There are a number of factors which affect the \(k_L a\) coefficient. They influence \(k_L\) and \(a\) in different fashions. Therefore, the constituent parameters of the volumetric mass transfer coefficient, \(k_L\) and \(a\), should be determined separately.

A theoretical correlation for \(k_L\) is developed on the basis of the surface renewal concept. In the correlations presented in Section 2.1., the validity of the Higbie equation, in which an exposure time was evaluated by Kolmogoroff's theory of isotropic turbulence, was not verified. We apply the surface renewal concept to estimate the exposure time \(t_e\).

Higbie's penetration theory is written as

\[
k_L = 2 (a / \pi t_e)^{1/2} 
\]

A periodic transitional sublayer model, which is based on the surface renewal concept, gives the following expression for the exposure time

\[
t_e = \left( T^* + 2/4 \right) 2^{-2/n} \left( K/\rho \right)^{1/(1+n)} \varepsilon^{-1/(1+n)} 
\]

where a dimensionless bursting time period \(T^*\) is a function of the flow index \(n\) (Kawase and Ullbrecht (1983)). It should be noted that the exposure time for free surfaces is considered to be one quarter of that for rigid surfaces.

Substitution of Eq. (4) into Eq. (3) yields

\[
k_L = (4/\sqrt{\pi}) \left( T^* + 1/2 \right) T^* -1/2 \left( (1+n) \varepsilon^{1/2} \right) 
\]