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Influence of agitator speed and aeration rate on the oxygen mass transfer rate coefficient in the stirred tank bioreactor.

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Abstract

The oxygen transfer rate (OTR) is an important parameter in the aerobic fermentation process. Especially in the food industry, an impurity in the fermented product must be concerned. Due to the rate of oxygen consumption of cell culture over the critical oxygen concentration, the optimum operating condition is required to attain OTR enough or higher than the consumption rate to reach sufficient oxygen dissolved in working fluid and for preventing impurity occurred from microorganism under anaerobic condition. The OTR is dependent on the oxygen transfer rate coefficient (k_La) and oxygen concentration gradient in the working fluid in the fermenter. This study aims to evaluate the k_La of three working fluids (de-ionized water and sucrose solutions) in laboratory fermenter which two of Rushton-type turbine and ring sparger were installed. The fermenter was operated over a range of agitation speeds (100-500 RPM) and aeration rates (0.25-2VVm). The result shows that the effect of aeration rate on k_La was similarly trend for three working fluids. The k_La was increased with the increasing rate of aeration until 1 VVm then the value was not changed with the higher aeration rate. In deionized water, the maximum k_La was obtained at an agitator rotational speed higher than 300 RPM. In contrast to orange juice, increasing in agitator speed enhance the k_La value. The maximum k_La was collected at agitator speed higher than 500 RPM.

Keywords: Fermenter, Gas-liquid mass transfer, Mixing

1. Introduction

Fermentation process is commonly found in the industry. This process generally uses a stirred tank reactor with oxygen continuously flow for feeding aerobic cell cultures inside the fermenter. A fermenter is designed to well mix condition. Also, sufficient oxygen for the cells is important. The oxygen concentration in liquid phase should be always above the critical oxygen concentration to allow cell metabolism to function at fastest rate

To maintain the oxygen concentration liquid phase above the critical value, Oxygen mass transfer rate (OTR) is the key parameter and must be known or predictable if possible. The oxygen transfer rate is influenced by several physical and chemical factor in fermentation system e.g. medium liquid properties, gas phase properties, fermenter geometry, operating condition etc. Therefore, proper operating condition should be achieved for each process system.

Due to many parameters affect the oxygen transfer rate, it is hard to study all of parameters in the system. However, suitable environment condition for aerobic cell culture were optimized (Pressure, Temperature, pH). For Newtonian fluid at constant pressure and temperature, the properties, including solubility of oxygen, are not changed. By the oxygen transfer rate correlation (**Eq.2**), the maximum mass transfer rate was controlled by the overall volumetric mass transfer coefficient (k_La).

This study aims to optimized operating condition (agitator speed, and aeration rate) to reach the maximum the overall volumetric mass transfer coefficient for the laboratory scale fermentation in vary medium (de-ionized water, and sucrose solutions). The operating range is limited base on foaming condition when operated with aerobic cell culture. The optimal conditions will be used for scaling up calculation to pilot scale fermenter.

2. Material and method

Fermenter geometry

The ellipsoidal bottom fermenter which 2 of six-blade Rushton type impellers (D/T = 0.33) were installed with 4 conventional baffles. Air was fed through ring sparger under the bottom impeller. The maximum working fluid loading is 7.5 litres.

Designed Experiment

The overall volumetric oxygen transfer coefficient is tested over a range of agitator speed 100 to 500 RPM and aeration rates 0.25 to 2.0 VVm. Three type of working fluid is applied which including de-ionized water, two concentrations of sucrose solution (as sample 1 and sample 2). Volume of working fluid is 3.75 litres (H/T = 0.9). The fermenter operated under ambient pressure and 35 degree Celsius.

Oxygen mass transfer rate

Consider the process without cell culture, the oxygen is transferred from gas bubble to liquid medium which describe by two film theory (Whitman). **Fig.1** shown the oxygen concentration at the interface of gas bubble and liquid medium. the gas transfer rate can be written:

$$N=K_ga(C_G-C_{Gi})=K_La(C_{Li}-C_L) \qquad \textbf{Eq.1}$$

Where K_G, and K_L are the overall mass transfer coefficient; a is interfacial area per unit volume; C_G is concentration of gas in bulk gas phase; C_L is dissolved gas concentration in bulk liquid; subscript i is concentration at the interface (equilibrium).

In laboratory system, air was used as gas phase to feed oxygen to the system. Due to poorly soluble of oxygen, the gas phase film resistance is neglected. The overall mass transfer coefficient is equal to mass transfer coefficient of liquid. **Eq.1** can be reduce to:

$$N_{O_2}=k_La(C^*-C_L) \qquad \textbf{Eq.2}$$

Where k_L is local mass transfer coefficient; C* is saturated dissolved oxygen in liquid medium. the k_La is measured as volumetric mass transfer coefficient.

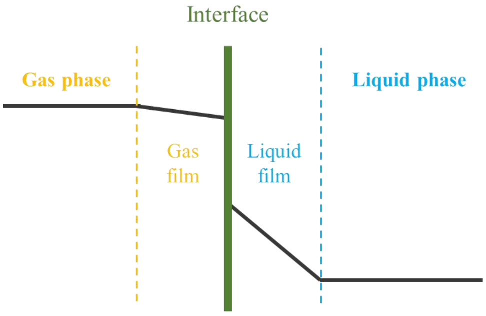

Fig. 1 Concentration gradients for gas-liquid mass transfer

Measuring overall volumetric mass transfer coefficient

There are many methods for measured k_La in the system (Suresh, Srivastava, and Mishra 2009). The method wildly used is dynamic method.

In dynamic method, by measuring change rate of dissolved oxygen concentration in liquid medium under constant rate of air inlet condition, the k_La is estimated from slope of **Eq.3** that is integration result between two different time of **Eq.2.**

$$\ln\left(\frac{C^*-C_{L1}}{C^*-C_{L2}}\right) = k_L a \cdot (t_2 - t_1) \qquad \textbf{Eq.3}$$

Fig.2 shown example of measurement dissolved oxygen concentration in the fermenter changed with time and graph is plotted from **Eq.3**. The dissolved oxygen is measured by membrane electrode probe. Response time of the probe is 21 second which is less than maximum of $1/k_La$. Thus, error from experiment are acceptable.

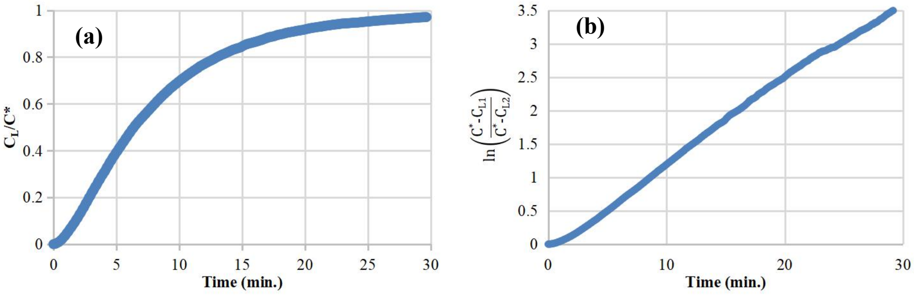

Fig. 2 Results of dynamic method: (a) Dissolved oxygen concentration profile **(b)** Data evaluating from **Eq.3**

(Doran 2013)

Gas-liquid mixing operating regime

In the fermenter, dispersion of gas phase is an important parameter on mass transfer rate. Operating regime of the fermenter operation should be concerned. Reported operating regime were studied base on air-water system in aerated stirred tank with one Rushton-type turbine (D/T = 0.4) and ring sparger were installed. Another factor that were previous studied is gas-impeller interaction which cause changing in power number of the system. The flow regime and gas-impeller interaction are combined into flow regime map . After that another correlation for completely gas dispersion is developed and summarize with the flow map . Correlation for the flow map regime is reported in dimensionless term and shown as **Eq.4** to **Eq.8.**

Line 1: An impeller has no gas-impeller interaction.

$$Fr<0.04 \qquad \textbf{Eq.4}$$

Line 2: Flow gas which cause flooding on an impeller.

$$Fl_G > 30Fr\left({}^{D}/_{T}\right)^{3.5} \qquad \textbf{Eq.5}$$

Line 3: Flow gas which cause large cavities on an impeller.

$$Fl_G > 0.025Fr\left({}^{D}/_{T}\right)^{-0.5} \qquad \textbf{Eq.6}$$

Line 4: Correlation for cause gas recirculating in the system.

$$Fl_G > 13Fr^2\left({}^{D}/_{T}\right)^{5.0} \qquad \textbf{Eq.7}$$

Line 5: The Correlation for completely gas dispersion.

$$Fl_G > 0.20Fr^{0.5}\left({}^{D}/_{T}\right)^{0.5} \qquad \textbf{Eq.8}$$

3. Results and discussion

The k_La results of three working fluid is shown in **Fig. 3** which varying agitator speed at constant aeration rate 0.5 VVm and varying aeration rate at constant agitator speed 300 RPM respectively.

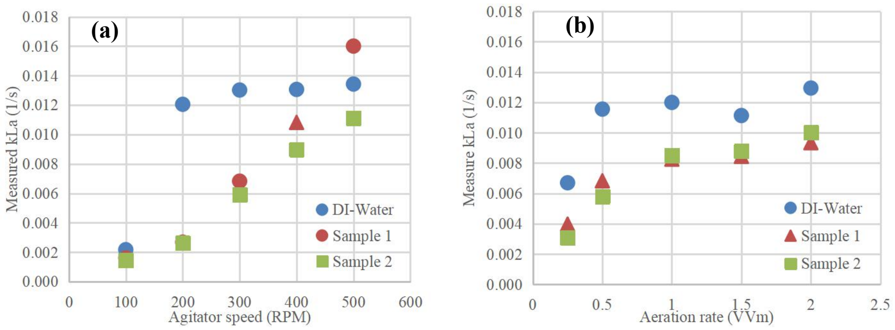

Fig. 3 Measured overall volumetric mass transfer coefficient: **(a)** Varying agitator speed at aeration rate 0.5 VVm **(b)** Varying aeration rate and agitator speed 300 RPM

From **Fig. 3(a),** k_La tend to increase at higher agitator speed. k_La was significantly increase in sucrose solution results but not in de-ionized water. k_La extremely rose when agitator speed was changed from 100 to 200 RPM and slightly change at higher speed. In theory, increasing agitator speed should enhance k_La value due to relation to power per volume in liquid phase and gas hold-up in the fermenter.

From **Fig. 3(b),** All working fluid have the same trend which k_La improved until reach the maximum value at 1 VVm and approximate the same when aeration was raised.

Considering de-ionized water results, obtained k_La value had no indeed tend when relate with reported k_La correlation(Doran 2013). However, Operating range in the experiment were not suited with reported correlation because some of operating condition was operated in transition zone or out of range in other parameter e.g.

aeration rate, power input, etc. To illustrate the results, by investigating gas-liquid flow map regime with studied operating condition, results is shown in **Fig. 4**. Operating condition was divided into 3 zone including flooding zone (regime under line 2, less than 207 RPM in **Fig. 3(a)**, more than 1.5 VVm in **Fig. 3(b)**), loading zone (over line 2 and under line 5, less than 250 RPM in **Fig. 3(a)**, more than 0.72 VVm in **Fig. 3(b)**), and after completely dispersion zone (over line 5, more than 250 RPM in **Fig. 3(a)**, less than 0.72 VVm in **Fig. 3(b)**). Then compare operating zone regime with k_La results of de-ionized water.

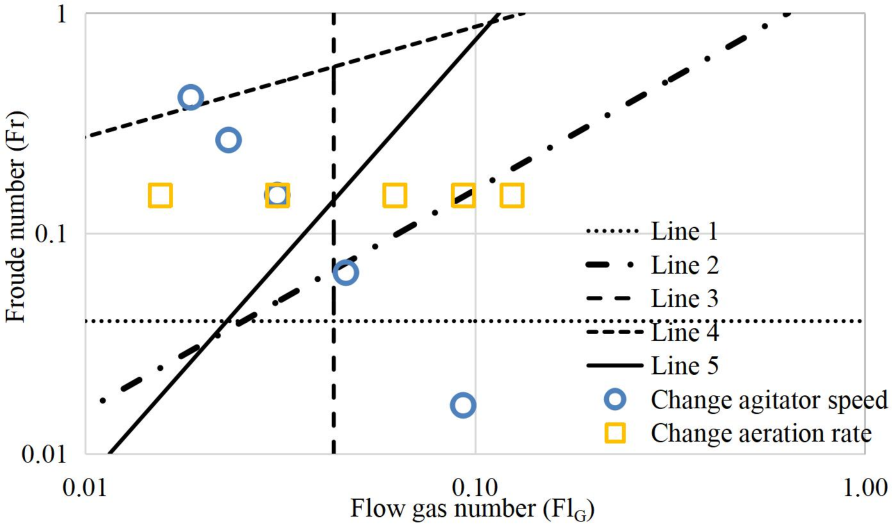

Fig. 4 Gas-liquid flow map of the fermenter

In case of different agitator speeds, k_La was enhanced when agitator speed was increased until reach speed that made completely gas dispersion and then certain value.

For k_La at different aeration rates, increasing in aeration rate affect k_La depend on flow regime. In flooding zone, k_La was improved due to among of gas in the fermenter at higher rate and responding to higher gas hold-up and gas phase interfacial area. For loading zone, operating point is shifted to near flooding zone which cause worse gas dispersion. In completely gas dispersion zone, the k_La was improved on the ground that agitator speed can handle gas to perform completely dispersion. The highest k_La was obtained at the point that attain the maximum aeration rate for completely dispersion.

None the less, the correlation of the flow map regime was developed base on air-water system and one Rushton-type turbine stirred tank reactor. So, it was not proper for investigate with the results of sucrose solutions. The primary reason is properties of liquid phase were not analyzed in the correlations. Moreover, the studied fermenter installed two of Rushton turbine which can be performed difference in gas-liquid flow in the system.

4. Conclusions

Characteristic of the overall volumetric mass transfer coefficient of de-ionized water in the fermenter can be described by gas-liquid flow map regime. The maximum k_La value is obtained at agitator speed 300 RPM for constant aeration rate 0.5 VVm and at 1.0 VVm for constant agitator speed 300 RPM. The predicted optimum point of operating condition that give maximum k_La value is on the completely gas dispersion condition which is agitator speed 250 RPM for aeration rate 0.5 VVm and aeration rate 0.72 VVm for agitator speed 300 RPM. However, there are no reported correlation or flow map regime that can illustrate other liquid system. For in depth detail must be studied for individual case or application simulation for fluid hydrodynamics to predict results of system e.g. computational fluid dynamics simulation.

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