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Estimation of Volumetric Mass Transfer Coefficient in Bioreactor

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Abstract

This study is concentrated to investigate the effects of aeration and stirring speed on the volumetric mass transfer coefficient (KLa). A dynamic technique was used in estimating KLa values in order to achieve the aim of this study. This study was done in 10L bioreactor by using two medias:-

1. Dionized water
2. Xanthan solution (1 g /L)

Moreover, the research covered a comparison between the obtained values of KLa.

The Xanthan solution was used because of its higher viscosity in comparison with water. It behaves similarly to the cultivation medium when organisms are cultivated in a bioreactor. Growth of organisms in the reactor leads to a change in the viscosity of the medium which affects the mass transfer.

Two variables, the effect of air flow rate (3-20 L/min) and the effect of stirring speed (250-700rpm) on KLa value were studied. Other parameters such as temperature, liquid volume, and stirrer shape and stirrer position were held constant; the results demonstrated an increase in KLa – value and mass transfer with increasing stirrer speed. Thus at higher speed, better dispersion of the bubbles was obtained. Therefore, that increased the surface / volume ratio which increased the mass transfer area i.e. KLa value.

***Keywords**: Dynamic Technique, agitation and aeration, Hennery's law constant of oxygen.*

1. Introduction

The main objectives of mixing in fermentation are to disperse the air bubbles, to suspend the microorganisms or animal cells, and to enhance heat and mass transfer in the growth medium.

The solubility of oxygen in medium is very low while its demand for growth of aerobic microorganisms is high. For example, when oxygen is provided from air, the typical maximum concentration of oxygen in aqueous solution is on the order of 6 to 8 mg/L. In order to estimate the design parameters for oxygen uptake in a bioreactor, many correlations which can be applicable to wide range of gas-liquid systems in addition to the air –water system could be used.

Since the oxygen is sparingly soluble gas, the overall mass-transfer coefficient KL is equal to the individual mass-transfer coefficient KL. The main objective in bioreactor design is to maximize the oxygen transfer rate with the minimum power consumption necessary to agitate the fluid on one hand. On the other hand it is necessary to minimize air flow rate. In order to maximize the oxygen absorption rate, the term KLa (C_l^*-Cl)] should be maximize. The concentration difference is quite limited to be controlled because the value of Cl* is limited by its very low maximum solubility. Therefore, the main parameters of interest in design are the mass-transfer coefficient and the interfacial area.

Table 1 lists the solubility of oxygen at 1atm in water at various temperatures. Normally air is used to supply the oxygen demand of bioreactor. The maximum concentration of oxygen in water which is in equilibrium with air Cl* at atmospheric pressure is about one fifth of the solubility listed according to Hennery's law,

$PO_2 = Cl^* (H)$

Where Po_2 is the partial pressure of oxygen and H is Hennery's law constant of oxygen at a certain temperature.

Table 1,
(Solubility of Oxygen in Water Equilibrium with Pure Oxygen at 1atm). (International Critical Tables.Vol.3, p.271)

Temperature(C)	Mol O2/L	MgO2/ L
0	2.18	69.8
10	1.70	54.5
15	1.54	49.3
20	1.38	44.2
25	1.26	40.3
30	1.16	37.1
35	1.09	34..9

Solubility of oxygen in Xanthan was taken from Table 2, in which the oxygen solubility in different fermentation fluids was listed.

Ideally, oxygen-transfer rates should be measured in a bioreactor which contains both the nutrient and microorganisms during the actual bioreactor process. It is difficult to carry out such a task due to the complicated nature of the medium and the ever changing rheology during cell growth. A common strategy is to use a synthetic system which approximates bioreactor conditions.

Table 2,
(Solubility's of Oxygen in Different Fermentation Fluids)

	Concentration(g/ℓ)	C* 10^3(mol/ℓ)
Gluconic acid	10	1.251
	15	1.223
	20	1.213
	25	1.210
	35	1.218
	50	1.192
	100	1.121
	150	1.013
	200	0.991
	300	0.956
	400	0.889
	500	0.802
Citric acid	25	1.242
	40	1.196
	50	1.183
	75.6	1.148
	100	1.137
	150	1.083
	200	0.983
Xanthan	1	1.250
	5	1.251
Pullulan	1	1.266
	10	1.241
	20	1.240

[a]Contraspum 210, supplied by M / S Zschiemmer and Black, Lahnstein / Rhein.
[b]Values measured at 22.6 ° C

2. Dynamic Technique

By using the dynamic technique (Taguchi and Humphrey, 1966), the KLa value for the oxygen transfer during an actual fermentation process with real culture medium and microorganisms can be estimated. This technique is based on the oxygen material balance in an aerated batch fermented while microorganisms are actively growing as

$$\frac{dC_L}{dt} = k_L d(C^* - C_L) - r_{o_2} C_x \quad \ldots(1)$$

Where r_{O2} is cell respiration rate [g O2/g cell h]. While the dissolved oxygen level of the fermented is steady, and when the air supply is suddenly turn off, the oxygen concentration will be decreased, see Figure (1) with the following rate

$$\frac{dC_L}{dt} = r_{o_2} C_x \quad \ldots(2)$$

Since KLa in (Equation 1) is equal to zero. Therefore, measuring the slope of the C_L vs. t curve can estimate r_{O2} C_X. And when turning on the airflow again, the dissolved oxygen concentration will be increased according to Eq. (1) , which can be rearranged to result in a linear relationship as agitation and aeration.

$$C_L = C_L^* - \frac{1}{K_L a}\left(\frac{dC_L}{dt} r_{o_2} C_x\right)$$

…(3)

The plot of C_L versus dCL/ dt + r_{O2} C_X will result in a straight line which has the slope of 1/ (Kla) and the y-intercept of CL^{*}..

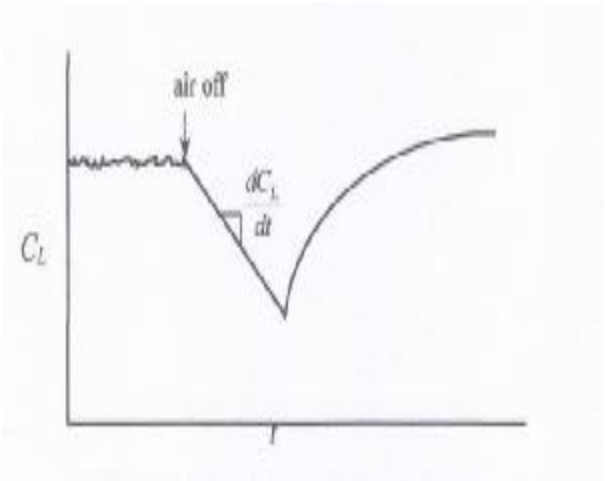

Fig. 1. Dynamic Technique for the Determination of Kla , James M. Lee .

Mathematically this means

dC_o/dt= OTR-OUR=KLa (Co^*-Co)-Ro

In this case Ro is zero because of no microorganisms.

The result of integrating is:

$$\int_{C_o^o}^{Co^{(1)}} \frac{dC_o}{C_o^* - C_o} K_L a \int_{t_o}^{1} dt$$

$$In\left(\frac{C_0^* - C_o^o}{C_0^* - C_o(t)}\right) = K_L a(t_o^* - t_o)$$

$$C_o(t) = C_o^* - (C_o^* - C_o)^{-K_L a(t - t_o^*)}$$

3. Experimental Work

3.1. List of Instruments and substances

In this work, 10L stirred bioreactor, which is connected electronically to a control board, was used. The bioreactor was supplied with dissolved oxygen meter probe, electro thermometer sensor and pH probe. Air was provided by a compressor while nitrogen gas was obtained from storage cylinder connected to pressure gauge. The gas flow rate was regulated via rotmeters. Deionized water and Xanthan solution (1g/L) were used as media. Two conditions were used:

1. Constant air flow rate at16 L / min and variable rotation speed (250, 400, 550, and 700 rpm)
2. Constant rotation speed at 325rpm and variable air flow rate (3, 7, 16 and 20 L/min)

3.2. Procedure steps

First the bioreactor vessel was filled with 6L deionized water. The temperature inside the bioreactor was held constant at 30°C. Air flow rate and stirring speed were adjusted according to experiment set. Then the oxygen electrode probe was calibrated with two points calibration i.e. zero and 100% saturation. Then the air supply was turned off and nitrogen gas was provided until reaching the zero point. At this point, nitrogen gas was stopped. Once the air was supplied again, the measurement was started by writing down the observed dissolved oxygen concentration in the

medium each five seconds until reaching 100% of saturation. The same procedure was repeated for each experiment set and for the second medium, Xanthan. The measurements were drawn between oxygen concentrations versus time. A regression was made to estimate the KLa value for each experiment by using scientific graphing software program i.e. sigma plot.

4. Results and Discussion

In Figure 2, the results show that increasing air flow rate in deionized water medium from (3L/min) to (20L/min) caused an increase in the obtained KLa from 0.011 to 0.022 1/sec respectively. The same behavior was obtained with Xanthan medium as the KLa values were increase from 0.005 to 0.012 1/sec, at the same range of air aeration. This behavior can be caused by the increased in the probability of oxygen bubbles hitting the oxygen probe on one hand. Moreover, the ratio of air volume to liquid volume was increased on the other hand. However, this direct relation between Kla and the air flow rate stopped at 16L air flow rate and started to decrease because the limitation of liquid capacity i.e. there is no space for more oxygen.

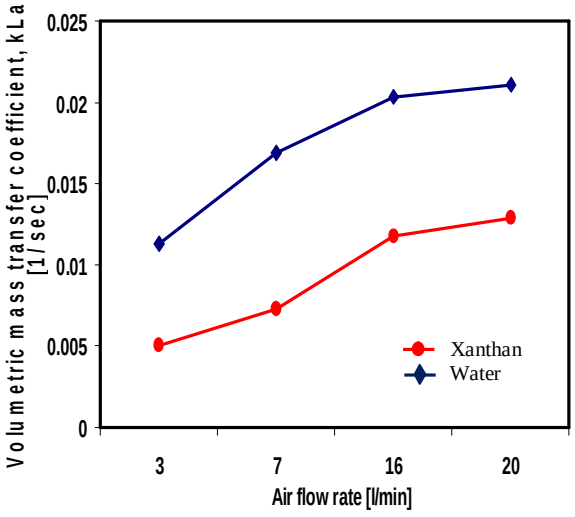

Fig. 2. Effect of Increasing Air Flow Rate on Volumetric Mass Transfer Coefficient Kla at 325rpm Constant Stirring Speed .

Also the results revealed a direct relation between Kla and stirring speed. Thus, the increase in Kla values [0.015-0.04 1/sec] for water medium and [0.006- 0.026 1/sec] for Xanthan medium were proportional to an increase in mixing speed [250-700rpm] respectively as shown in figure 3. The effect of stirring speed is by breaking down air bubbles and dispersion of air i.e. increasing the specific surface area. Therefore, the mass transfer was improved. In addition, the film built on the oxygen probe by medium is highly affected by the stirring speed. Therefore, the higher stirring speed is the thinner film. Thus, the mass transfer will be better i.e. Kla is bigger.

Furthermore, the obtained Kla values in water were much greater than those observed in Xanthan in both cases of varying aeration or mixing. Since the Xanthan is viscous compared to water, the capacity or space, for oxygen is less in its medium. Moreover, the required energy to disperse air and mixing the Xanthan is greater than water since the resistance is bigger because of the viscosity. Thus the energy was dissipated. Another effect is the film thickness on the oxygen probe. The film of Xanthan is bigger than that of water; i.e. less mass transfer.

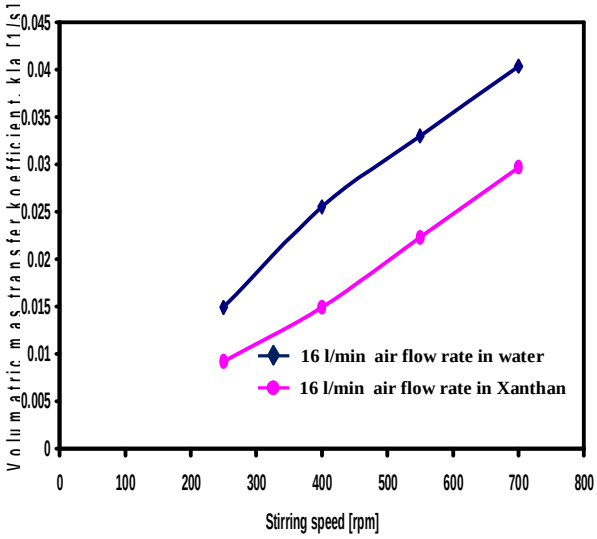

Fig. 3. Effect of Increasing Stirring Speed on Volumetric Mass Transfer Coefficient Kla at Constant Air Flow Rate 16L/min.

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حساب كفاءة الانتقال للكتلة الحجمية للمفاعل البايولوجي

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الخلاصة

لقد ركز البحث على دراسة آثار التهوية وسرعة التحريك على معامل انتقال ألكتلة ألحجمي (ثابت انتقال الكتلة), وقد استخدمت التقنية الحيوية في تقدير قيم (ثابت انتقال الكتلة) من أجل تحقيق الهدف من هذه الدراسة.
وقد استخدم في هذه الدراسة ١٠ لتر من محلولين في المفاعل الحيوي هما:-
١. ماء خالي من الايونات.
٢. محلول Xanthan (١ غرام / لتر)
إضافة إلى ذلك فان البحث قد شمل المقارنة بين القيم التي تم الحصول عليها من (ثابت انتقال الكتلة).
وقد استخدم محلول Xanthan بسبب اللزوجة العالية التي يمتاز بها مقارنة بالماء . حيث انه يمتلك سلوكا مماثلا للوسط الزراعي عندما تزرع الكائنات العضوية في مفاعل حيوي. إن نمو الكائنات العضوية في المفاعل يؤدي إلى تغيير في لزوجة الوسط مما يؤثر على انتقال الكتلة، وقد تمت دراسة متغيرين أساسيين هما تأثير معدل تدفق الهواء (٢٠-٣٠ لتر \ دقيقة) وتأثير سرعة التحريك (٢٥٠- ٧٠٠ rpm) على قيمة انتقال ألكتلة. كما أظهرت النتائج ثبات بقية المتغيرات الأخرى مثل درجة الحرارة، وحجم السائل، وشكل وموقع أداة تحريك الجهاز، مع زيادة في ثابت انتقال ألكتلة - قيمة وانتقال الكتلة مع زيادة سرعة أداة تحريك الجهاز. وبموجب هذا وعند وضع الجهاز على سرعة أعلى، فقد تم الحصول على أفضل تشتت للفقاعات. لذلك ، فان هذا سيزيد من نسبة السطح / الحجم مما أدى إلى زيادة مساحة نقل الكتلة أي قيمة ثابت انتقال ألكتلة .