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Effect of Palm Oil on Oxygen Transfer in a Stirred Tank Bioreactor

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Abstract: In many industrial bioprocesses, the key parameter is the oxygen mass transfer capability of the bioreactor. The bottleneck in such processes is the low solubility of oxygen in aqueous media (8-10 ppm). This decreases the Oxygen Transfer Rate (OTR). Literature showed that the addition of organic liquids to the bioreactor as the second liquid phase could enhance OTR, if the oxygen solubility in the second liquid phase is higher than that in aqueous media. In this study, palm oil was chosen as the organic phase, because it is abundantly available in Malaysia. Experiments were carried out in two model media viz., xanthan gum solution and distilled water with the addition of palm oil to evaluate the effect on oxygen transfer. OTR was measured in terms of the volumetric mass transfer coefficient, k_La. Results indicated that the addition of the palm oil in the medium decreased the oxygen transfer coefficient.

Key words: Palm-oil, oxygen transfer rate, k_La, stirred tank bioreactors, second immiscible liquid phase

INTRODUCTION

In many aerobic industrial bioprocesses, oxygen is an important nutrient that is used by microbes for growth, maintenance and metabolite production (Garcia-Ochoa and Gomez, 2008). Oxygen is a soluble substrate, but its solubility in aqueous media is very low (8-10 ppm) (Doran, 1995). Consequently, actively growing cells can consume all the dissolved oxygen very fast. Therefore, oxygen has to be supplied continuously by mass transfer from air to the growth medium.

Many studies indicate that the oxygen mass transfer can be enhanced with the addition of a second liquid phase in which oxygen solubility is high. Compounds such as hydrocarbons (Galaction *et al*., 2004; Clarke *et al*., 2005), PFC (Elibol, 1998; Amaral *et al*., 2008) and vegetable oil (Rols and Goma, 1991), which are non-toxic to microorganisms, were used as the second liquid phase. The advantage of using these organic phases in the system is that they can increase the oxygen transfer rate from gas phase to the microorganism without the need of extra energy supply (Amaral *et al*., 2008). In contrast to these studies, it is also known that addition of antifoam (normally are also organic phase) can reduce the oxygen transfer rate.

In this research, palm oil (type RBD palm olein) which is available abundantly in Malaysia was used as the second liquid phase. It has high oxygen solubility (47.7 mg L^{-1} at 30°C) (Allen and Hamilton, 1994). Palm oil is non-toxic towards the microorganisms and it has very low solubility in water (below 100 mg dm^{-3} at 28°C) (Ahmad *et al*., 1996). Palm oil can also be used as an antifoam agent. This study has been done in order to evaluate the effect of palm oil on the oxygen transfer rate, in view of the conflicting reports on the use of organic phase in the media.

MATERIALS AND METHODS

Experiments were carried out in a computer-coupled 5 L bench top scale bioreactor (Biostat B, Sartorius BBI Systems) with a working volume of 4 L. The glass vessel has a height/diameter ratio of about 2:1. Two types of impeller were used, Rushton turbine and InterMIG impeller. A ring sparger was situated below the bottom impeller. The system was agitated at two different speeds viz., 200 and 400 rpm. The effect of aeration rate was studied at 0.25, 0.75 and 1.25 vvm. The experiments were performed at atmospheric pressure and the temperature was controlled at 30°C.

The model media used were distilled water and xanthan gum solution, in order to represent aqueous solutions of different viscosities. Food grade xanthan gum was used in these studies. Xanthan gum solutions were prepared at two different viscosities, viz 140 cP and 290 cP and were measured by Brookfield viscometer (model LVDV-II+Pro, using SC25 spindle at 100 rpm). In order to study the effect of palm oil dosage, experiments were carried out at different volumetric fractions of palm oil in the media viz., 0.05, 0.1, 0.15 and 0.2.

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Dissolved oxygen in the liquid was measured by using a polarographic dissolved oxygen probe (InPro 6820 Series, Mettler Toledo). For k_La value determination, unsteady state, i.e., dynamic method has been used (Clarke *et al.*, 2005). This method was performed by first sparging the nitrogen gas through the system until the dissolved oxygen falls to zero. Then, continue with aeration at different operating conditions of aeration and agitation and monitor the dissolved oxygen concentration (C_L) until it reaches a steady value. The following Eq. 1 is used to determine the k_La value:

$$\frac{dC_L}{dt} = k_L a (C_L^* - C_L) \tag{1}$$

which on integrations yields:

$$\ln\left(1 - \frac{C}{C^*}\right) = -k_L a.t \tag{2}$$

The k_La value can be determined from the slope of $\ln(1\text{-}C_L/C_L^*)$ versus t graph where C_L^* is the equilibrium dissolved oxygen concentration.

RESULTS AND DISCUSSION

Experiments with palm oil in water: The experimental data shows that at an agitation speed of 200 rpm using Rushton impeller, the k_La values in the presence of palm oil in the system are very much lower compared to those without oil. As shown in Fig. 1, k_La at 5% oil fraction dropped more than 2 times compared to those without oil and it went on decreasing as palm oil fraction was increased. At the time these experiments were carried out, it was observed that the diameters of air bubbles and oil droplets were higher than those at higher agitation rate. This observation was also reported by Clark *et al.* (2005) in their study with alkane. It was also observed that some of the oil tends to stick at the glass wall of the bioreactor than to disperse with water. This event might be due to poor mixing at low agitation rate (200 rpm).

Experiments were also carried out at an agitation speed of 400 rpm using Rushton impeller. The results obtained are shown in Fig. 2 and they indicate similar behavior as seen at an agitation speed of 200 rpm using Rushton impeller. The Nevertheless, the k_La values did not drop as much as at 200 rpm with the addition of oil. This time, air bubbles and oil droplets size were smaller than those at 200 rpm and less oil was found to stick to the glass wall of the bioreactor. Even though there was a slight increase of k_La values at 15% of palm oil addition, it was not high enough to enhance the oxygen transfer as much as without oil condition.

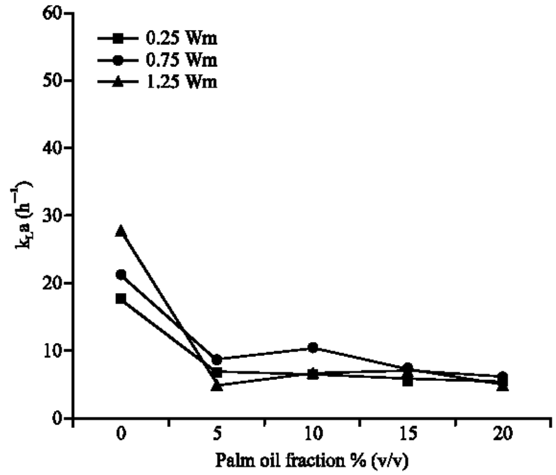

Fig. 1: Effect of palm oil on k_L a for water at 200 rpm at different aeration rate

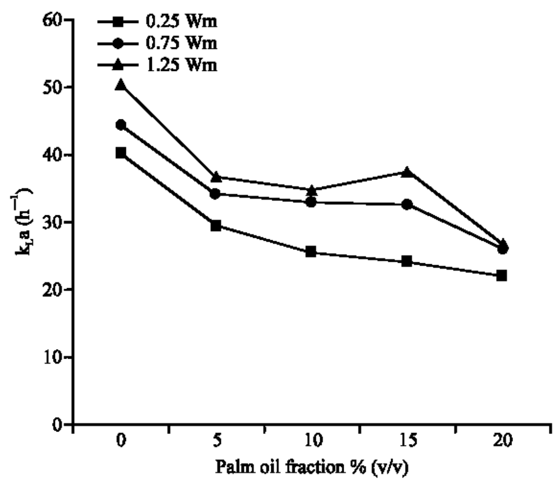

Fig. 2: Effect of palm oil on k_L a for water at 400 rpm at different aeration rate

Amaral *et al.* (2008) observed similar effect of oil on the oxygen transfer in the medium when they used olive oil as second organic phase in their study. They reasoned that the decrease of k_La by using olive oil was due to poor dispersion of oil. This could be caused by the properties of olive oil, such as higher viscosity and lesser density than water. They suggested that operation at higher agitation rates could enhance the dispersion. This might explain the steep decrease in oxygen transfer with palm oil addition at low speed of agitation in this study.

Experiments with palm oil in xanthan: For xanthan gum solution, experiments were carried out at 400 rpm and 0.75 vvm with different palm oil fractions. For 140 cP viscosity of xanthan gum solution, experiments were

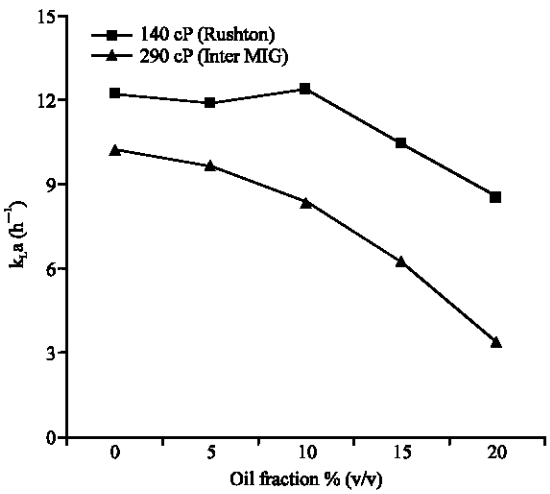

Fig. 3: Effect of palm oil on k_L a for xanthan gum solution at different aeration rate

carried out with Rushton turbine and for 290 cP, InterMIG impeller was used, as it is more suitable for high viscosity solution. Result in Fig. 3 showed that k_La values decreased as the oil fraction is increased for both impellers. However, it can be seen that k_La values were higher for high viscosity (290 cP) xanthan gum solution when using InterMIG impeller compared to low viscosity of xanthan gum solution using Rushton turbine. This in contrast to the findings of Garcia-Ochoa and Gomez (1997), who found that k_La values decreases as the viscosity of liquid increasing, which happened due to decrease in the degree of liquid flow turbulence. It could be due to the use of a more effective impeller i.e., InterMIG.

CONCLUSIONS

Oxygen transfer in bioprocesses is one of the major parameters that determine the productivity. There have been many studies to increase the oxygen transfer rate in the process adopting various strategies. One of the strategies is to add an organic phase, which has higher oxygen solubility to the system. But, in these studies, it has been found that the addition of an organic phase like palm oil decreased the oxygen transfer rate. Nevertheless, oxygen transfer rate was found to be higher even in higher viscosity solutions if an InterMIG impeller is used.

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