Determination of mass transfer coefficient for the waste water from a centrifuge rubber latex concentration unit

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During the concentration of natural rubber latex by centrifuging, considerable quantity of waste water is generated. Mass transfer coefficient is an important parameter in the design of a biological waste water treatment system based on aeration. This paper deals with the experimental determination of mass transfer coefficient for the waste water generated during the concentration of natural rubber latex by centrifuging. The determination of alpha, the ratio of mass oxygen transfer coefficient in waste water to that in clean tap water under identical conditions is also discussed in the paper. The effects of various parameters on the alpha value are also discussed.

The supply of oxygen to an aerobic biological treatment system has been studied by several investigators in the past1. The type of aerating device, the system under consideration (whether plug flow or completely mixed), the characteristics of the waste water under aeration and system configuration are some of the factors which determine the transfer of oxygen. Interphase gas transfer has been found to play an important role in transferring the required amount of oxygen to the aerobic treatment system. Alpha (α) is defined as the ratio of mass oxygen transfer coefficient in waste water to mass oxygen transfer coefficient in clean tap water under identical conditions. Alpha value is an important variable in the evaluation of aerator performance and it should be found out for each waste under similar set of conditions to be encountered in the field2.

The alpha values for sewage as well as many industrial waste waters have been found out by previous investigators3,4. In the present work, an attempt has been made to determine experimentally the alpha value for the waste water generated in centrifuge rubber latex concentration units. The effect of various parameters like concentration of waste water, MLSS, speed of the aerator and temperature on alpha has also been studied.

Transfer of Oxygen

In surface aeration, which is commonly employed in activated sludge process, the oxygen molecules are transferred from air to the liquid interface establishing a saturated oxygen layer at the interface. The shearing action of the surface aeration impeller creates new interfaces with generally high degree of induced turbulence and mass transfer of oxygen is governed by the phenomenon of surface renewal.

The total amount of oxygen transferred will depend on the interfacial surface exposed and on the total volume of liquid pumped. When the liquid strikes the tank surface, the turbulent mixing and air entrainment result in additional oxygen transfer.

The oxygenation capacity of the aerator under field conditions and standard conditions can be correlated by the following expressions4.

\[
OC_f = \frac{OC_r (C_{sw} - C)_{20}^{1024}}{C_s} \quad \text{... (1)}
\]

\[
OC = (K_{La})_{20}^{V} C \quad \text{... (2)}
\]

where

\[ OC_f, OC = \text{oxygen transferred (oxygenation capacity)} \]

under field and standard conditions (1 atmosphere pressure and 20°C) respectively, kg/h.

\[ C_{sw}, C_s = \text{dissolved oxygen saturation concentration for waste water and clean tap water respectively at 20°C and 1 atmosphere, mg/L} \]

\[ C = \text{the minimum dissolved oxygen concentration which needs to be maintained in the aeration basin, mg/L} \]

(This depends on whether nitrification is required or not)

\[ \alpha = \text{ratio of mass transfer coefficients} \]

\[ = \frac{(K_{Lw})_{\text{waste water}}}{(K_{La})_{\text{clean tap water}}} \]

\[ V = \text{volume of aeration basin, L} \]

\[ \text{where} \]

\[ OC_r = \text{oxygen transferred under field conditions} \]

\[ (K_{Lw}) = \text{mass oxygen transfer coefficient for waste water} \]

\[ (K_{La}) = \text{mass oxygen transfer coefficient for clean tap water} \]
\[ T = \text{temperature, } ^\circ\text{C} \]
\[ (K_{\text{La}20}) = \text{overall mass transfer coefficient at } 20^\circ\text{C}, \text{ h}^{-1} \]

As alpha value is the ratio of overall mass transfer coefficient in waste water to that in tap water, the objective reduces to the determination of mass transfer coefficients in tap water as well as waste water under identical conditions.

Experimental Procedure

The composite waste water samples used for the study were collected from a natural rubber latex concentration unit situated in Central Kerala of South India. The sources of effluents are washings from drums, bowls and tanks of the centrifuging machine and the serum from the skim latex coagulation section where the latex content is separated out using sulphuric acid. The characteristic of the waste water samples were determined by standard methods.

The experimental set-up used in this study consisted of a plexi glass aeration tank measuring 0.70 m \( \times \) 0.70 m and 1 m depth. In order to fill the tank with waste water and to facilitate its removal, inlet and outlet connections were provided. The waste water level in the tank was maintained constant at 0.8 m throughout the study. A plate type surface aerator (0.15 m diameter) as shown in Fig. 1 was fixed at the centre of the aeration basin. The surface aerator was fabricated by welding two blades to a plate of 0.15 m diameter and 3 mm thickness. The size of the blade was 20 mm \( \times \) 20 mm. A mild steel rod, 0.4 m long and 20 mm diameter was fixed vertically at the centre of the plate to act as the shaft. The aerator was rotated at a maximum speed of 1425 rpm with the help of a 0.746 kW motor. The submergepce of aerator was maintained at 0.15 m below the liquid surface during the study.

To estimate the oxygen transfer coefficient, the non-steady state aeration procedure was adopted. The aeration basin was first filled with clean tap water up to the desired level and the water temperature was noted. The dissolved oxygen content of the water was measured by Winkler's modified method. The dissolved oxygen content of tap water in the aeration basin was then removed by adding 10 mg/L sodium sulphite and 1 mg/L cobalt chloride catalyst per mg/L of dissolved oxygen. After deoxygenation of dissolved oxygen, the surface aerator unit was started. Samples of water were collected from the aeration basin at regular intervals and the dissolved oxygen content of the samples were determined by Winkler's method. The aerator was stopped when the D.O level was observed to be more than 90 per cent of saturation value. The water temperature was noted after stopping the aerator.

The above procedure was repeated for the latex concentration waste water. Experiments were also conducted at various temperatures. In order to avoid heating or cooling of water / waste water, the experimental runs were conducted at different periods of the year when the temperature of water was different. The experimental runs were also conducted at different speeds of the surface aerator.

BOD, COD and sludge solid concentration were measured before and after aeration using standard methods.

Determination of DO saturation

The saturation concentration of dissolved oxygen corresponding to a specific temperature was obtained from standard tables. The saturation dissolved oxygen values above 30°C was obtained using the Eq. (3) given below.

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Fig. 1 — Surface aerator details
$$C_s = 14.652 - 4.1022 \times 10^{-1} (T) + 7.991 \times 10^{-3} (T)^2 - 7.7774 \times 10^{-3} (T)^{-3} \quad \ldots \quad (3)$$

**Determination of alpha**

The general equation of oxygen transfer in aqueous media is

$$\frac{dc}{dt} = K_{La} (C_s - C) \quad \ldots \quad (4)$$

where $\frac{dc}{dt}$ = rate of change of dissolved oxygen concentration with time

$C_s$ = saturation concentration of oxygen

$C$ = dissolved oxygen concentration at any time $t$.

On integration, Eq. (3) gives

$$\log (C_s - C) = K_{La} t + \text{constant.}$$

Plotting $\log (C_s - C)$ against time will yield a straight line, the slope of which gives the value of $K_{La}$.

The value of alpha is obtained by dividing $K_{La}$ for waste water by that for clean tap water.

**Results and Discussion**

**Characteristics of the waste water samples**

The characteristics of the waste water samples are given in Table 1. The $pH$ values of the waste water samples used for the study were in the range of 3.5 - 4.2 indicating the acidic nature of the waste water from a latex centrifuging unit. The COD and BOD values of the waste samples show that they are highly organic in nature.

**Estimation of alpha value**

A plot of $\log (C_s - C)$ versus time for tap water as well as latex concentration waste water samples are shown in Fig. 2. The slope of the line gives the value of $K_{La}$. From the $K_{La}$ values, the value of $\alpha$ was found out. The value of $\alpha$ obtained for latex concentration waste water is in the range of 0.74 - 0.78.

<table>
<thead>
<tr>
<th>Parameter</th>
<th>Sample-1</th>
<th>Sample-2</th>
<th>Sample-3</th>
<th>Sample-4</th>
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</thead>
<tbody>
<tr>
<td>pH</td>
<td>3.5</td>
<td>4.0</td>
<td>3.8</td>
<td>4.2</td>
</tr>
<tr>
<td>Turbidity, NTU</td>
<td>1200</td>
<td>850</td>
<td>2200</td>
<td>2000</td>
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<tr>
<td>COD, mg/L</td>
<td>9500</td>
<td>8500</td>
<td>8000</td>
<td>10400</td>
</tr>
<tr>
<td>BOD, mg/L</td>
<td>5700</td>
<td>5500</td>
<td>5000</td>
<td>6100</td>
</tr>
<tr>
<td>Total solids, mg/L</td>
<td>15420</td>
<td>10700</td>
<td>12200</td>
<td>11100</td>
</tr>
<tr>
<td>Dissolved solids, mg/L</td>
<td>11100</td>
<td>10200</td>
<td>9100</td>
<td>9200</td>
</tr>
<tr>
<td>Suspended solids, mg/L</td>
<td>4320</td>
<td>6500</td>
<td>3100</td>
<td>1900</td>
</tr>
</tbody>
</table>

**Effect of aerator speed on alpha value**

Fig. 3 shows alpha values plotted against various rotational speeds of the surface aerator. It is observed that alpha value increases with speed. Initially the rate of increase in alpha value is high which becomes moderate subsequently. This phenomenon should be due to the increased oxygen transfer resulting from liquid spray and turbulence and entrainment caused by the rotation of the surface aerator. As oxygen concentration in the waste water approaches the saturation value, the value of alpha comes down. This observation is in line with the conclusions made by Downing\(^9\) and Kaul \(et \, al\).\(^7\)

**Effect of BOD on alpha value**

In Fig. 4, alpha values are plotted against BOD concentration of centrifuge latex concentration waste water. Alpha value is found to decrease linearly with the BOD concentration of waste water. This can be explained by the fact that the more the BOD concentration of the waste water, the more will be the quantity of oxygen utilised for aerobic degradation of
organic matter. This will result in decline of \( K_{La} \) and hence alpha value.

**Effect of MLSS on alpha value**

A plot of alpha versus Mixed Liquor Suspended Solids (MLSS) concentration in the aeration basin is given in Fig. 5. It seems that value of alpha decreases with sludge solids concentration. This should be due to the fact that sludge solids act as a physical barrier for oxygen transfer and thereby decreasing \( K_{La} \) and hence alpha².

**Effect of temperature on alpha value**

Fig. 6 shows a plot of alpha versus temperature. It is observed that alpha does not change with variation in temperature.

The effect of temperature on oxygen transfer is usually described in terms of temperature characteristic \( \psi \) as shown in the Eq. (5) given below.

\[
K_{La}(T) = K_{La}(20) \psi(T-20) \quad \ldots (5)
\]

As the temperature characteristic \( \psi \) is the same for latex concentration waste water and tap water, it is quite reasonable that the alpha value does not vary with increase or decrease in temperature.

**Conclusion**

The present study reveals that the alpha value for the waste water from a centrifuge latex concentration unit is in the range of 0.74 – 0.78 for an average BOD concentration of 5500 mg/L. The study leads to the conclusion that alpha value increases with increase in speed of rotation of the surface aerator. Moreover, the alpha value of latex concentration waste water is found to decrease with increase in BOD concentration of waste water and sludge solids concentration. The alpha value does not vary with changes in temperature.

**References**

6. APHA, Standard methods for the examination of water and waste water, 16th edn, 1985