Study of specific power input and mass transfer coefficient in aeration of volatile organic compounds

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The aeration of volatile organic compounds (VOC) is based on the mass transfer rate of VOCs from the liquid phase to the gaseous phase. Principle of air stripping involves the mass transfer of volatile organic contaminant from water to air. The system can be easily upgraded to strip greater amount of VOCs with relatively small increase in capital cost. Aeration tanks strip volatile compounds by bubbling air into tank through which contaminated water flows. The present study shows power input in VOC by using advanced designed gas dispersing radial impeller that is, Rushton, CD-6 and BT-6, the factors which affect the design of aeration tank baffles and the impeller used for best possible result. This study also shows the power input of VOCs at different height of submergence. A comparison of the result from experiment that shows the power input of VOCs during aeration is a function of mass transfer coefficient of air and it increases with the increase of submergence of height, by supply of air, and increase in impeller speed. Best power input result can be obtained at the 2/3rd height of the submergence of the total depth of water for impeller used.

Key words: Power input, gas dispersion impellers, Rushton impeller, CD-6 impeller, BT-6 impeller.

INTRODUCTION

Aeration is the most important and indispensable operation for the treatment of wastewater. The main purpose of aeration is to dissolve the oxygen into the water. In order to improve the dissolution of oxygen in water, the common methods include bubbling and surface aeration. For bubbling type of aeration, oxygen dissolves in the water during the rising of air bubbles in liquid phase. For surface aeration type, a vertical axis is designed to induce updraft flows through a pumping action, causing a rapid change in the air–water interface to facilitate dissolution of the air. Both types of aeration use the air–water contact to achieve oxygen dissolution (Cheng et al., 2003).

A number of volatile organic compounds (VOCs) are found in the wastewater and some of these VOCs are very harmful for the human health as well as environment. Although there are several methods which are being used for the removal of VOCs, but the air stripping process are the low energy usage, low preventive and maintenance cost and high efficiency process which can stripes VOCs from wastewater. The present study consists of aeration system for the removal of VOCs. The aeration of VOC is based on the mass transfer rate of VOCs from the liquid phase to the gaseous phase. Principle of air stripping involves the mass transfer of volatile organic contaminant from water to air (Verma and Tyagi, 2012). Aeration is the process of bringing water and air in close contact in order to remove dissolved gases, such as carbon dioxide, and to oxidize dissolved metals such as iron. It can also be
used to remove volatile organic chemicals (VOC) present in the water. Aeration is often the first major process at the treatment plant. During aeration, constituents are removed or modified before they can interfere with the treatment processes. Aeration is an important step in the treatment of sewage by bio oxidation and in much industrial fermentation (Sathiyamoorthy et al., 2012).

Bhuyar et al. (2009) found out the effect of a curved-blade-surface mechanical aerator for oxidation, which is used to treat municipal and domestic sewage. Aeration experiments were conducted to study the design characteristics of curved blade surface mechanical aerator. The paper critically examines six different configurations of aerators, which were developed, fabricated and tested in the laboratory for its various dynamic parameters, such as diameter of aerators (D), speed (N) and immersion depth (h).

Oxygen transfer rate and the corresponding power requirement to operate the rotor are vital for design and scale-up of surface aerators. It has been demonstrated that energy can be saved substantially if the aeration tanks are run at relatively higher input powers. It is also demonstrated that smaller sized tanks are more energy conservative and economical when compared to big sized tanks, while aerating the same volume of water, and at the same time by maintaining a constant input power in all the tanks irrespective of their size. Oxygen transfer characteristics for three sizes of equipment correlate well and permit scaling of fermentation systems in size were studied (John, 2003).

Oxygen transfer, the process by which oxygen is transferred from gaseous to liquid phase is a vital part of the waste-water treatment process (Metcalf and Eddy, 2001). Due to low solubility of oxygen and consequent low rate of oxygen transfer, sufficient oxygen to meet the requirement of aerobic waste does not enter through normal surface air-water interface. To transfer the large quantities of oxygen that is needed, additional interfaces are created by employing aeration process. The creation of additional interfaces enhances the rate of oxygen transfer so that the dissolved oxygen level gets raised.

The three basic categories of aeration methods (Thakre et al., 2008) are:

1) Surface or mechanical aeration method, which increases interfacial area by spraying water droplet into the air.
2) Diffused aeration method, which release air bubbles beneath the surface of water.
3) Combined and turbine aeration methods, which introduced large air bubble into water and reduce their sizes mechanically

Out of these three, the mechanical surface aerators are widely used because they offer better efficiency as well as convenience in operation and maintenance (Rao and Kumar, 2007). Further, oxygen transfer rate from gas to liquid phase is dependent on various factors for given method of aeration such as dynamic variables like speed, mixing intensity and turbulence, geometrical parameters like size and number of blades, depth of flow etc and physicochemical properties of the liquid.

Objective

Objective of present work is to show specific power input required for the different types of impellers at different speed of rotation and at different height of submerge. This work also shows that mass transfer coefficient depends upon specific power input.

EXPERIMENTAL PROCEDURE

Experimental procedure and setup used are the same as mentioned in Verma and Tyagi (2012) which consist of cylindrical tank with a diameter of 30 cm and height of 35 cm with total working volume of 24.74 L, and working volume of water is 16 L with water height in tank is 22.6 cm. Verma and Tyagi (2012) described in detail VOC’s for combination of impellers and height of submergence and the result shows removal rate of different VOC’s used. This article intend to specify power input and mass transfer coefficient for different impellers at different height of submergence.

Estimation of $K_{La}$

In aeration, open vessel were used that allows the sufficient air volume to avoid significant gas phase saturation above the liquid surface, which allow us to assume $C_a = 0$ (Chu-Chin et al., 1993). Therefore from the equation (Bhuyar, 2009), the liquid concentration changes over time were used to estimate the mass transfer coefficient $K_{La}$ using the equation below.

$$\ln \left( \frac{C_t}{C_o} \right) = -K_{La}(t - t_0)$$ (1)

Estimation of specific power input

$$P/V = 2.05E-06 \ (N)^{3.11}$$

Materials used

Chemical used in this study are acetone and dichloromethane. Table 1 shows some physical and chemical properties of these chemicals:

Impeller used in the study

In this study, gas dispersion impellers that is, Rushton or D-6 and hollow blade impellers that is, CD-6 and BT-6 are used which is shown in Table 2 and Figure 1 (Verma and Tyagi, 2012).

RESULTS

Relation between specific power input (P/V) versus mass
Table 1. Physical and chemical properties of VOCs used.

<table>
<thead>
<tr>
<th>Property</th>
<th>Value (Dichloromethane)</th>
<th>Value (Acetone)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Molecular weight</td>
<td>84.9 g</td>
<td>58.08 g</td>
</tr>
<tr>
<td>Aspect</td>
<td>Liquid</td>
<td>Liquid</td>
</tr>
<tr>
<td>Melting point</td>
<td>- 94.9°C</td>
<td>-95.35°C</td>
</tr>
<tr>
<td>Boiling point</td>
<td>39 - 40°C at 1.013 Pa</td>
<td>-94.7°C at 1 Pa</td>
</tr>
<tr>
<td>Density</td>
<td>1.33 g/ml at 20°C</td>
<td>0.78996 g/ml at 20°C</td>
</tr>
<tr>
<td>Vapor pressure</td>
<td>475 mm of Hg at 20°C</td>
<td>181.72 mm of Hg at 20°C</td>
</tr>
<tr>
<td>Water solubility</td>
<td>13.7 g/L at 20°C</td>
<td>11.7 g/L at 20°C</td>
</tr>
</tbody>
</table>

Table 2. Description of the impeller used.

<table>
<thead>
<tr>
<th>Impeller</th>
<th>Geometrical characteristic of the impeller</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>D (m)</td>
</tr>
<tr>
<td>D-6</td>
<td>0.1</td>
</tr>
<tr>
<td>CD-6</td>
<td>0.1</td>
</tr>
<tr>
<td>BT-6</td>
<td>0.11</td>
</tr>
</tbody>
</table>

Transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when Rushton impeller was used. The maximum value is 0.185 at 350 rpm and VOC1, minimum value is 0.118 at 250 rpm and VOC2 Rushton impeller at height H1 (Figure 2).

Relation between specific power input (P/V) versus mass transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when CD6 impeller was used. The maximum value is 0.220 at 350 rpm and VOC2, minimum value is 0.154 at 250 rpm and VOC1 CD6 impeller at height H1 (Figure 3).

Relation between specific power input (P/V) versus mass transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when BT6 impeller was used. The maximum value is 0.323 at 350 rpm and VOC1, minimum value is 0.246 at 250 rpm and VOC1 BT6 impeller at height H1 (Figure 4).

Relation between specific power input (P/V) versus mass transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when Rushton impeller was used. The maximum value is 0.187 at 350 rpm and VOC1, minimum value is 0.132 at 250 rpm and VOC2 Rushton impeller at height H2 (Figure 5).

Relation between specific power input (P/V) versus mass transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when CD6 impeller was used. The maximum value is 0.246 at 350 rpm and VOC1, minimum value is 0.192 at 250 rpm and VOC1 CD6 impeller at height H2 (Figure 6).

Relation between specific power input (P/V) versus mass transfer co-efficient (KLa) at 250, 300, and 350 rpm for VOC1 and VOC2 when BT6 impeller was used. The maximum value is 0.346 at 350 rpm and VOC1, minimum

Figure 1. Impeller used in the study.

Figure 2. Plot of mass transfer co-efficient (KLa) versus specific power input (P/V) by Rushton impeller at height H1.
DISCUSSION

Mass transfer coefficient depends upon specific power input (as specific power input proportional to impeller speed) graph clearly shows that it increases with the increase in specific power input at both height of submergence H1 and H2. These graph shows that mass transfer coefficient increases with the increase in specific power input, and its value changes more frequently for
Figure 8. Plot of Specific power input (P/V) versus rotation in RPM for Rushton, CD6 and BT6 impeller.

BT-impeller, and it's having lower value for Rushton impeller. The value of $K_La$ changes with increase in height of submergence. The result obtained from model is fairly new, which was calculated experimentally. The result found are based on prototype model and the value of parameters such as specific power input, mass transfer coefficient are within the range of literature cited in this research article.

REFERENCES


NOMENCLATURE

$H$, Height of the tank; $H_1=H/3$; $H_2=2H/3$; $C_s$, gas phase concentration in equilibrium; $C_L$, liquid phase concentration in equilibrium; $K_La$, mass transfer coefficient, 1/h; $B$, tank baffle width, (m); $T$, tank diameter, (m); $C_{Ss}$, Sparger clearance, (m); $D$, impeller diameter, (m); $D_{D}$, impeller central disk diameter, (m); $W$, impeller blade width, (m); $L$, impeller blade length, (m).