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Treatment of Wastewater in Fluidized Bed Bioreactor Using Low Density Biosupport

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Abstract

In this study, a biocarrier made up of low density polypropylene of surface area 524 mm² per particle and of density 870 kg/m³ was used in the treatment of wastewater using fluidized bed reactor. Holdup studies are performed for bed heights (0.2 m to 0.8 m) to predict the operating conditions. The effect of Bed height (0.6 m to 1 m), Hydraulic retention time (6 hr to 40 hr), and superficial gas velocity (0.00106 m/s, 0.00159 m/s, 0.00212 m/s), Concentration (2 g/l – 7.5 g/l) on the percentage of COD reduction were studied. For bed height of 0.8m, optimum holdup and maximum COD reduction was obtained. From the results, it was observed that percentage of COD reduction increases as the superficial gas velocity increases and decreases as the initial concentration decreases. A COD reduction of 97.5% was achieved at an initial concentration of 2 g/l and for a superficial gas velocity of 0.00212 m/s at hydraulic retention time of 40 hr.

Keywords: Fluidized bed reactor; Bio carrier; holdup; wastewater; chemical oxygen demand.

1. Introduction

Fluidized bed reactors have proved their versatility for carrying out aerobic fermentation process, catalytic reaction and biological treatment of wastewater [1]. Inverse fluidization, in which density of solid particles are less than liquid is a very efficient system for the biological treatment of wastewater when compared with an up-flow fluidized bed reactor because in an inverse fluidized bed reactor the control of biofilm thickness is achieved within a very narrow range [2]. Several studies like hydrodynamics [3, 4, 5], mass transfer [6-9], anaerobic wastewater [10-14], aerobic wastewater treatment [15, 16, 17] have been performed in the recent years. An important

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biotechnological process, ferrous iron oxidation by thiobacillus ferrooxidans was also carried out with very high efficiency in an inverse fluidized bed biofilm reactor [7]. In anaerobic systems pre-aeration of the liquid is done for providing oxygen to microorganisms to live and perform their metabolic activities. This process is eliminated in the aerobic system [18]. Three phase fluidized bed reactor has been successfully employed in treating wastewaters like starch, refinery, phenol, and high strength industrial wastewater and have been found efficient in treating the wastewater [15, 18, 19].

The aim of this work was to evaluate the efficiency of IFBR for treating domestic wastewater with a new bio carrier of density 870 kg/m³ and surface area 524 mm² per particle. Hydrodynamics study and biofilm growth on the particles are studied. The continuous studies were performed at different superficial gas velocities, initial concentration of wastewater, bed heights and hydraulic retention time for the removal of organic matters by analyzing the chemical oxygen demand of the wastewater.

**Nomenclature**

<table>
<thead>
<tr>
<th>Symbol</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>H</td>
<td>Expanded bed height (m)</td>
</tr>
<tr>
<td>H₀</td>
<td>Initial bed height (m)</td>
</tr>
<tr>
<td>M</td>
<td>Mass of the particle (kg)</td>
</tr>
<tr>
<td>A</td>
<td>Cross sectional area of the column (m²)</td>
</tr>
<tr>
<td>Uₙ</td>
<td>Superficial gas velocity (m/s)</td>
</tr>
<tr>
<td>Uₘf</td>
<td>Minimum fluidization velocity (m/s)</td>
</tr>
<tr>
<td>V₉</td>
<td>Volume of the bed (m³)</td>
</tr>
<tr>
<td>Vᵣ</td>
<td>Volume of the reactor (m³)</td>
</tr>
<tr>
<td>ρ</td>
<td>Density of particle (kg/m³)</td>
</tr>
<tr>
<td>Ci</td>
<td>Initial concentration of substrate (g/l)</td>
</tr>
<tr>
<td>HRT</td>
<td>Hydraulic retention time (hr)</td>
</tr>
<tr>
<td>εₙ</td>
<td>Gas holdup</td>
</tr>
<tr>
<td>εₛ</td>
<td>Solid holdup</td>
</tr>
<tr>
<td>εᵢ</td>
<td>Liquid holdup</td>
</tr>
</tbody>
</table>

2. Methods and materials

2.1. Experimental Setup

The experimental setup of three-phase inverse fluidized bed reactor is shown in Fig.1. The column of 0.1m diameter was made up of Perspex with a maximum height of 1.8 m, wall thickness of 0.003 m and a working volume of 0.0125 m³. The column consisted of three sections, namely liquid distribution section, test section and liquid discharge section. Liquid and gas was supplied in a co current manner, which were supplied from the bottom of the reactor. The water flow to the column was controlled by a peristaltic pump (10-80 ml/min). An air vent was also provided at the top of the column. The test section consists of a wire mesh provided both at the top and the bottom to prevent the elutriation of the particles. A gas sparger (diameter of hole – 0.001 m; triangular pitch – 0.005 m) was provided for air flow above the liquid distribution section. The airline was connected to a compressor through a calibrated flow meter. All runs were made at room temperature.

2.2 Phase Hold up

Phase Holdup is one of the most significant parameter that determines the effectiveness of the fluidization process. Phase holdup were estimated from the bed height correlation and they can be calculated [20]

\[
\text{Air holdup, } \varepsilon_n = \frac{H - H_0}{H} \quad (1)
\]

\[
\text{Solid holdup } \varepsilon_s = \frac{M}{A H \rho} \quad (2)
\]
$$
\varepsilon_g + \varepsilon_l + \varepsilon_g = 1
$$

(3)

Gas holdup governs the gas-phase residence time and it is also crucial for mass transfer between liquid and gas. Gas holdup depends on gas flow rate, but also to a great extent on the gas-liquid system involved [20]. Gas flow rate contributes to the operating cost of a reactor and a correlation between gas hold up and flow rate, given by

$$
\varepsilon_g = A U^n_g
$$

(4)

Where A and n are constants and the value of constant n slightly varies from unity [12].


Fig 2. Dimensions of Bio carrier

2.3 Biofilm growth on biocarrier

Biocarriers used in this study have been designed in our lab with the dimensions as shown in Fig.2. It has a horizontal dividing plaque of 0.8 mm to obtain a larger surface. The idea was to create “recipients” full of bacteria. The growing medium was the synthetic waste water. The wastewater was enriched with mineral salts by adding the following (mg/l): (NH4)2SO4—500; KH2PO4—200; MgCl2—30; NaCl—30; CaCl2—20; and FeCl3—7 as recommended by Sokol and Migiro[16]. The inoculum was prepared from the sludge collected from the domestic wastewater pit. Inoculum of 1.25 litres was transferred to the reactor along with the bio carrier and the growing medium. Oxygen required for the system was supplied at an air velocity of 0.00106 m/s. pH was maintained at 6 - 7 for the optimum growth of microorganisms. The system was left for two weeks time after which a thin layer of biofilm on the particle was observed. At the end of 21 days, growth of biofilm was significant.
2.4 Experimental Procedure

The performance of the IFBR was studied by the reduction in COD of the domestic wastewater with hydraulic retention time. The chemical oxygen demand of the wastewater was measured by Lovibond COD photometer. Experiments were performed to find the effect of Bed height (0.6 m, 0.8 m, 1 m), Hydraulic retention time (6 hr to 40 hr), and superficial gas velocity (0.01768 m/s, 0.02652 m/s, 0.03536 m/s), Concentration (2 g/l – 7.5 g/l) on the percentage of COD reduction. After the growth of biomass in the particle, the liquid inside the reactor was drained and fresh feed is injected into the reactor. COD measurements were taken after reaching a steady state. The cycle is repeated for further experiments.

3. Results & Discussions

3.1 Minimum fluidization velocity

The minimum fluidization velocity \( (U_{mf}) \) quantifies the drag force needed to attain solid suspension in the fluid phase. The onset of the fluidization occurred when the superficial velocity was 0.000148 m/s. The experiment was carried out at bed heights ranging from 0.2 m to 1 m. Bed height has no effect on minimum fluidization velocity [13, 21].

3.2 Phase holdup

From the experiments conducted, it was observed that the gas holdup was increasing with increase in superficial gas velocity up to 0.0032 m/s after which it remained as constant. This was in good correlation with earlier studies [12]. From Fig. 3 it is evident that the gas holdup was increasing as the bed height was varied from 0.2m to 0.8m. Higher the value of \( \varepsilon_g \), lower will be \( \varepsilon_l \) [13]. Many correlations were proposed based up on the range of operated gas velocity in literature. Gas hold up correlations used in this work is reported in the Table.1. From the Fig.3 it is evident that there is an almost a linear relation exists between \( \varepsilon_g \) and \( U_g \) [12, 15]. For a bed height of 0.8m, optimum gas hold up of 0.4849 at a superficial gas velocity 0.002548 m/s

Table 1. Gas holdup correlations

<table>
<thead>
<tr>
<th>( U_g ) (m/s)</th>
<th>( \varepsilon_g )</th>
<th>Correlation</th>
<th>Bed Height (m)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.001 – 0.0032</td>
<td>0.16 – 0.29</td>
<td>( \varepsilon_g = 3.899 U_g^{0.444} )</td>
<td>0.2</td>
</tr>
<tr>
<td>0.001 – 0.0032</td>
<td>0.19 – 0.37</td>
<td>( \varepsilon_g = 8.428 U_g^{0.5308} )</td>
<td>0.4</td>
</tr>
<tr>
<td>0.001 – 0.0032</td>
<td>0.21 – 0.40</td>
<td>( \varepsilon_g = 11.03 U_g^{0.5599} )</td>
<td>0.6</td>
</tr>
<tr>
<td>0.001 – 0.0032</td>
<td>0.25 – 0.50</td>
<td>( \varepsilon_g = 6.934 U_g^{0.444} )</td>
<td>0.8</td>
</tr>
</tbody>
</table>
3.3 Effect of Initial concentration.

Percentage of COD reduction was studied for various initial concentrations of wastewater and hydraulic retention time. Fig 4 shows that as the initial concentration increases the percentage of COD reduction decreases. This is due to the presence of organics in the wastewater which inhibits the degradation rate. The gas hold up is consistent in the reactor for wastewater of concentration 2g/l and 3.75 g/l, leading to the decrease of COD. The rate of reduction of COD is less for the wastewater of concentration 7.5g/l. This may be due to the increase of organics which leads to the growth of biomass in the reactor making the wastewater more viscous and providing a less air holdup. An optimum COD reduction of 96.8% at a superficial gas velocity of 0.00106 m/s was obtained for a wastewater of concentration 2 g/l and 35 hr of HRT.
3.4 Effect of Bed height

The optimum operating condition for an IFBR was determined by measuring the reduction in COD of the effluent for various bed heights (0.6 m, 0.8 m, 1.0 m) at a superficial gas velocity of 0.00106 m/s. From Fig. 5, it was observed that the percentage COD reduction increases with increase in bed height. Among the three bed heights, the optimum bed height is 0.8 m because the COD reduction at 0.8 m bed height was much higher than that of 0.6 m. It may be due to the fact that by increasing the bed height, more biomass participated in degradation of the constituents of waste water. For a bed height of 1 m there is a decrease in the percentage of COD reduction due to lesser gas holdup which also affects phase mixing and mass transfer characteristics. For the initial concentration of 2 g/l, the optimum COD reduction was found to be 96.8% at a bed height of 0.8 m. Hence all the experiments were performed at a bed height of 0.8 m.

![Fig 5. Effect of bed height on % COD reduction](image)

3.5 Effect of superficial gas velocity

Superficial gas velocity is an important parameter in the degradation of wastewater. Fig. 6 shows that an increase in superficial gas velocity increases the percentage of COD reduction. It is evident that increase in COD reduction rate is due to increase in holdup which improves the mass transfer rate. An optimum COD reduction of 97.5% was obtained for an initial concentration of 2 g/l, at a superficial gas velocity of 0.00212 m/s.

![Fig 6. Effect of superficial gas velocity on % COD reduction](image)
4. Conclusion

From the experimental results, the minimum fluidization velocity required for the bio carrier was 0.00148 m/s, which is less when compared to the support materials so far used for IFBR studies. A maximum gas holdup of 0.4849 was achieved at a bed height of 0.8 m for a superficial gas velocity of 0.002548 m/s. An optimum COD reduction of 97.5% was achieved with the operating conditions of 0.8m bed height and 0.00212 m/s superficial gas velocity. Percentage of COD reduction increases as the superficial gas velocity and HRT increases but decreases as the initial concentration increases for a fixed bed height of 0.8m. The efficiency of the system was high with the new bio carrier of density 870 kg/m³. It can be offered as an effective method for biological waste water treatment.

References