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Biodegradation of organic content in wastewater in fluidized bed bioreactor using low-density biosupport

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ABSTRACT

In this study, a new biocarrier made up of low-density polypropylene of surface area 524 mm^2 per particle and of density 870 kg/m^3 was used in the treatment of wastewater using fluidized bed reactor. Holdup studies were performed for various bed heights (0.2–0.8 m) to predict the operating conditions. The effect of bed height (0.6, 0.8, and 1 m), hydraulic retention time (6.25, 8.33, 12.5, and 24 h), superficial gas velocity (0.0016, 0.00212, 0.00265, and 0.00318 m/s), and concentration (910, 1,820, 2,840, and 3,940 mg/l) on the percentage of COD reduction were studied. For bed height of 0.8 m, optimum holdup and maximum COD reduction was obtained. From the results, it was observed that percentage of COD reduction was increased with the increase in superficial gas velocity but it was decreased with the decrease in initial concentration. A maximum COD reduction of 96.7% at a superficial gas velocity of 0.00318 m/s was obtained for a wastewater of concentration of 910 mg/l and HRT of 24 h.

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 is less than liquid, is a very efficient system for the biological treatment of wastewater when compared with an up-flow fluidized bed reactor because the control of biofilm thickness is achieved within a very narrow range [2]. Several studies like hydrodynamics [3–5], mass transfer [6–9], anaerobic wastewater treatment [10–14], and aerobic wastewater treatment [15–18] have been performed in the recent years. An important 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 [19]. 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].

The aim of this work was to evaluate the efficiency for treating domestic wastewater with a new bio carrier of density 870 kg/m^3 and surface area 524 mm^2 per particle. Hydrodynamics and biofilm growth on

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the particles were 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.

2. Methods and materials

2.1. Experimental set-up

The experimental setup of three-phase inverse fluidized bed reactor is shown in Fig. 1. The column of 0.1 m 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 m^3. The column consisted of three sections, namely, liquid distribution section, test section, and liquid discharge section. Liquid and gas were supplied from the bottom of the reactor in a concurrent manner. The wastewater 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.

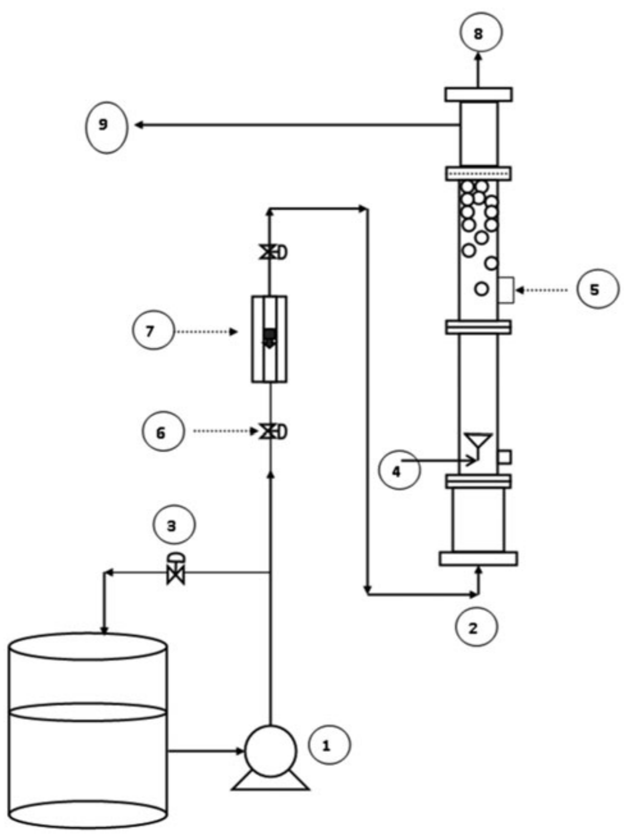

Fig. 1. Schematic diagram of experimental set-up. (1) Pump, (2) wastewater inlet, (3) bypass valve, (4) air inlet, (5) solids inlet, (6) control valve, (7) rotameter, (8) air outlet, and (9) effluent.

2.2. Phase holdup

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

Air holdup

$$\varepsilon_g = \frac{H - H_0}{H} \quad (1)$$

Solid holdup

$$\varepsilon_s = \frac{M}{AH_\rho} \quad (2)$$

$$\varepsilon_s + \varepsilon_l + \varepsilon_g = 1 \quad (3)$$

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:

$$\varepsilon_g = AU_g^n \quad (4)$$

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

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 wastewater. The wastewater was enriched with mineral salts by adding the following (mg/l):

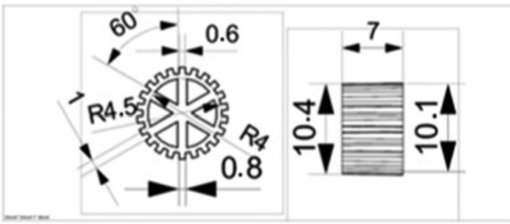

Fig. 2. Dimensions of bio carrier.

(NH4)$_2$SO$_4$—500; KH_2PO_4—200; $MgCl_2$—30; NaCl—30; $CaCl_2$—20; and $FeCl_3$—7 as recommended by Sokol et al. [16]. The inoculum was prepared from the sludge collected from the domestic wastewater pit. Inoculum of 1.25 l 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 micro-organisms. The system was left for two weeks time after which a thin layer of biofilm on the particle was observed. At the end of 14 d, 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, 0.8, and 1 m), hydraulic retention time (6.25, 8.33, 12.5, and 24 h), superficial gas velocity (0.0016, 0.00212, 0.00265, and 0.00318 m/s), and concentration (910, 1,820, 2,840, and 3,940 mg/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 and discussion

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 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 increased 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 0.2 to 0.8 m. Higher the value of U_g lower will be n [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 ε_g and U_g [12,15]. For a bed height of 0.8 m, optimum gas hold up of 0.4849 at a superficial gas velocity 0.002548 m/s which is maximum when compared to the biocarrier used in the treatment [15,16].

3.3. 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, 0.8, and 1.0 m) at a superficial gas velocity of 0.00265 m/s. From Fig. 4, 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 was much higher than 0.6 and 1.0 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.

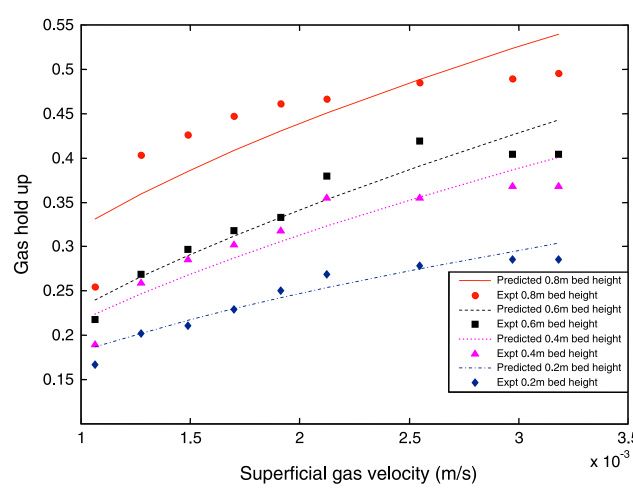

Fig. 3. Relation between experimental and predicted gas holdup and superficial velocity.

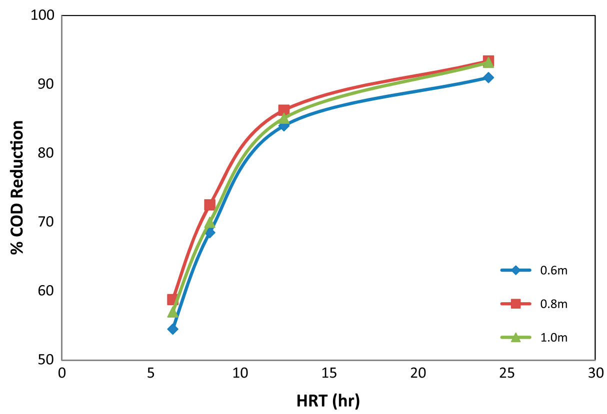

Fig. 4. Effect of bed height on percentage of COD reduction.

Table 1
Gas holdup correlations

U_g (m/s)	ε_g	Correlation	Bed height (m)
0.001–0.0032	0.16–0.29	$\varepsilon_g = 3.899U_g^{0.444}$	0.2
0.001–0.0032	0.19–0.37	$\varepsilon_g = 8.428U_g^{0.5308}$	0.4
0.001–0.0032	0.21–0.40	$\varepsilon_g = 11.03U_g^{0.5599}$	0.6
0.001–0.0032	0.25–0.50	$\varepsilon_g = 6.9344U_g^{0.444}$	0.8

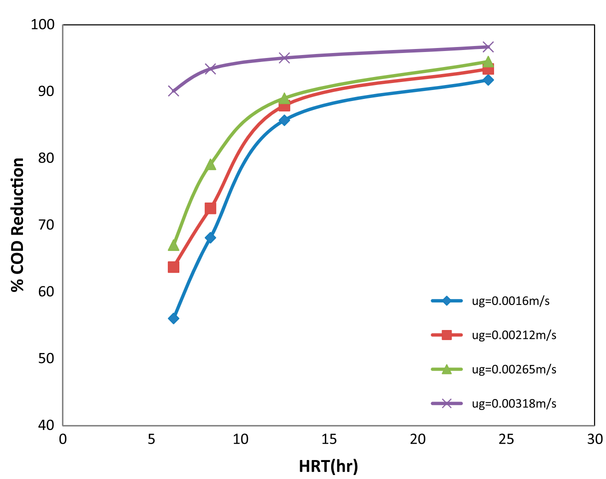

Fig. 5. Percentage of COD reduction vs. HRT (initial concentration = 910 mg/l).

For the initial concentration of 1,820 mg/l, the optimum COD reduction was found to be 93.4% at a bed height of 0.8 m. Hence, all the experiments were performed at a bed height of 0.8 m.

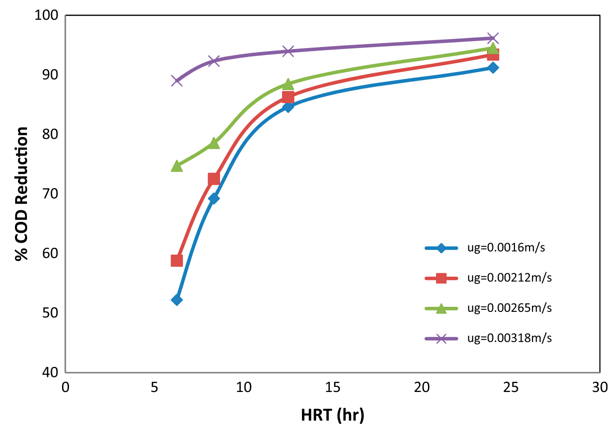

Fig. 6. Percentage of COD reduction vs. HRT (initial concentration = 1,820 mg/l).

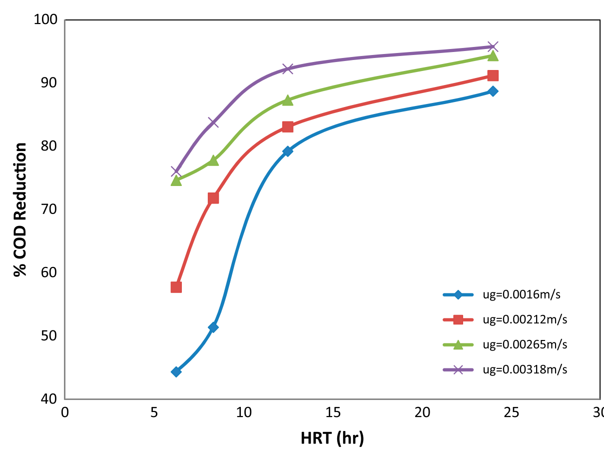

Fig. 7. Percentage of COD reduction vs. HRT (initial concentration = 2,840 mg/l).

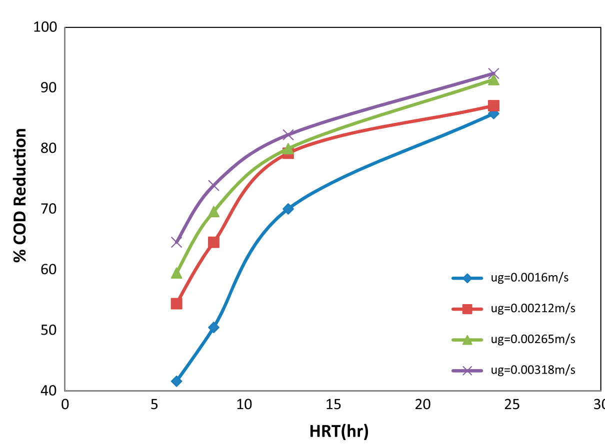

Fig. 8. Percentage of COD reduction vs. HRT (initial concentration = 3,940 mg/l).

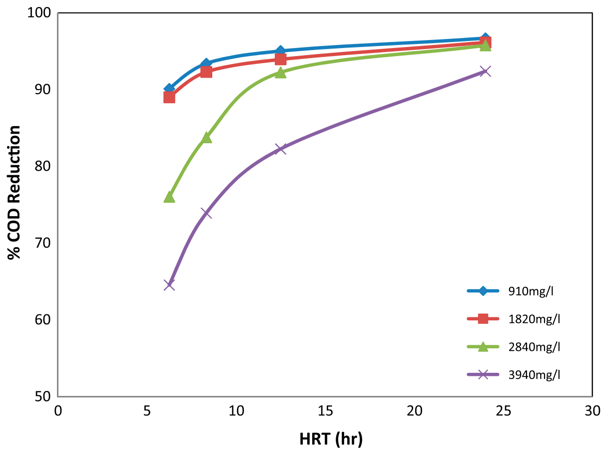

Fig. 9. Effect of initial concentration on percentage of COD reduction.

3.4. Hydraulic retention time

Figs. 5–8 shows the results of percentage of COD reduction for various hydraulic retention time and air velocities. For an initial concentration of 910 and 3,940 mg/l, the maximum COD removal of 96.7 and 92.40%, respectively. Percentage of COD reduction increases as there is an increase in the HRT due to the increase in the residence time of the organics in the reactor providing more time for the micro-organisms to degrade the organics. As the air velocity increases the percentage reduction increases due to the increase in the holdup. The COD permissible level is 100 mg/l according to Central Pollution control Board of India. At a HRT of 24 h, the COD level is maintained within the permissible level for all initial concentration levels discussed here.

3.5. Effect of initial concentration

Percentage COD reduction decreases as the initial concentration of wastewater increases due to the increase in organics as the concentration increases which offers a resistance for the degradation rate. From Fig. 9, it is clear that for an initial concentration of 910 and 1,840 mg/l the degradation rate is much higher whereas it reduces as the concentration increases because the wastewater becomes more viscous at high HRT decreasing the air holdup. A maximum removal of 96.7% at a superficial gas velocity was obtained for a wastewater of concentration of 910 mg/l and HRT of 24 h.

4. Conclusion

(1) The minimum fluidization velocity—0.00148 m/s, which is less when compared to the support materials so far used for IFBR studies.
(2) 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.
(3) A maximum COD reduction of 96.7% was achieved with the operating conditions of 0.8 m bed height and 0.00318 m/s superficial gas velocity.
(4) 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 0.8 m.
(5) Percentage of COD reduction decreases as the initial concentration of the wastewater increases.
(6) The efficiency of the system was high with the new bio carrier of—Effective method for biological waste water treatment.

Nomenclature

IFBR	—	inverse fluidized bed reactor
H	—	expanded bed height (m)
H_0	—	initial bed height (m)
M	—	mass of the particle (kg)
A	—	cross sectional area of the column (m^2)
U_g	—	superficial gas velocity (m/s)
U_{mf}	—	minimum fluidization velocity (m/s)
V_b	—	volume of the bed (m^3)
V_r	—	volume of the reactor (m^3)
ρ	—	density of particle (kg/m^3)
C_i	—	initial concentration of substrate (g/l)
HRT	—	hydraulic retention time (h)
ε_g	—	gas holdup
ε_s	—	solid holdup
ε_l	—	liquid holdup

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