Scientia Iranica, Vol. 9, No. 1, pp 47–52

SCIENTIA
IRANICA

Studies on Treatment of Carbonaceous Wastewater by Fixed Film Aeration Tank

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In this paper, a modified activated sludge process using a Fixed Film Aeration Tank (FFAT) was investigated as an improvement for the usual activated sludge or trickling filtration processes. The aeration tank of the system was arranged with fixed parallel saran nets, which were set vertically as supporting media for microbial growth. A carbonaceous solution was brought into contact with microorganisms in the media and was oxidized aerobically. Filamentous microorganisms predominantly grew on the films and the COD removal increased with the increase in accumulated biomass in the system. Simulation of treatment performance in the system was carried out using mathematical models. The biological coefficients needed for the computation were obtained from flow reactor experiments. The results showed that the dissolved COD in the FFAT effluent was not affected by the organic loading due to total oxidation in this system, but the accumulated biomass in the fixed film was influenced by the organic loading. Experimental data confirmed the theoretical values. It was concluded that this new modified activated sludge process could be applied to the treatment of carbonaceous wastewater, without sludge bulking problem and the mathematical models used by the author might be useful in practical operations.

INTRODUCTION

Activated sludge and trickling filtration are commonly used processes in the secondary treatment of wastewater containing biodegradable organic matter [1]. The former is a suspension process and the latter a fixed bed process [1-3]. However, caution is needed in the daily operations of both processes. For example, in the activated sludge process, there are often problems with sludge return, sludge disposal and sludge bulking; whereas, in trickling filtration, problems of odor, fly nuisance etc. are encountered. Several attempts have been made to simplify the operational problems of these conventional devices [4-7].

In order to establish a treatment system with less need for close control, a biooxidation process was investigated using a new type of aeration tank in which synthetic fiber nets were set vertically as a supporting medium on which microorganisms could grow.

Basic studies are necessary to obtain data for the possible design and operation of wastewater treatment plants. The data is required to elucidate the relationship between organic loading, the accumulation of microorganisms in the aeration tank and COD removal.

As a preliminary study, a comparison was made between wastewater treatment using the new modified system (FFAT) and treatment using the conventional system of Activated Sludge Aeration Tank (ASAT), with the same dimensions.

MATERIALS AND METHODS

Experimental Setup

A simplified schematic diagram of the experimental setup is shown in Figure 1. The FFAT was constructed with a 20 liter aeration tank in which parallel saran nets were placed vertically. The surface area of the nets per unit volume was 60 m^2/m^3, for a total of 1.2 m^2 in a 20 liter tank. ASAT was constructed with a 5 liter settling tank and a 20 liter aeration tank. The settling tank with a height and area of 0.5 m and 0.01 m^2, was recycled manually 3 to 4 times/day.

Air supply in both tanks was provided by sintered glass diffusers inserted in the side walls. The diffusers were below the nets in the FFAT. The diffused air not only supplied the oxygen necessary for the respiration of the microorganisms (above 2 mg/l), but also provided turbulent mixing of the liquid to ensure

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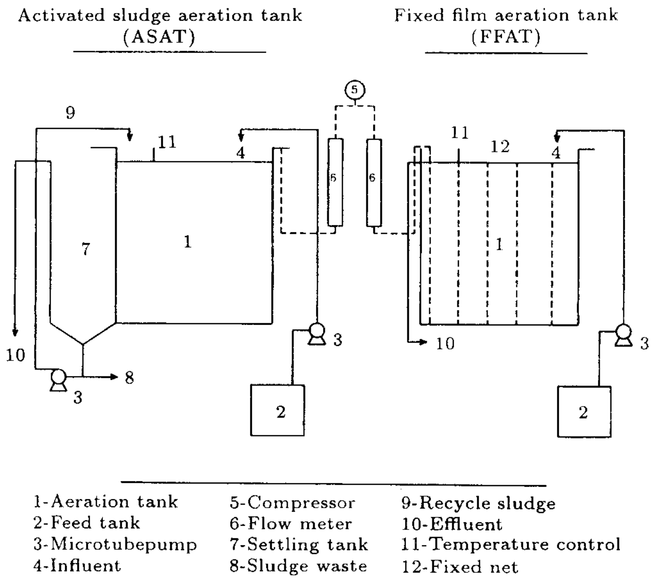

Figure 1. Schematic presentation of experimental setup.

that adequate substrate and oxygen were available throughout the vessels. The wastewater temperature was controlled at 25°C throughout the aeration tanks. Retention time of both systems was maintained at 6.6 hrs by constant feeding of wastewater with microtube pumps.

Wastewater

In order to have carbonaceous wastewater with uniform physical and chemical characteristics throughout the experimental studies, synthetic wastewater was prepared by dissolving known amounts of glucose in tap water. To provide balanced food for the growth of microorganisms responsible for the biodegradation of organic matter in the wastewater, ammonium diphosphate was added in appropriate quantities to get BOD/N/P ratio equal to 100/5/1. The feed was prepared on daily bases.

Seed Cultural Preparation

A mixed culture developed from municipal wastewater was used. The synthetic waste for the seed culture was prepared by dissolving glucose (1.5% by weight) and 1% ammonium diphosphate in tap water. 100 ml of the filtered wastewater was mixed with 900 ml of the synthetic wastewater.

The contents were incubated for 48 hrs at 25-30°C with intermittent mixing. The incubated broth was mixed with fresh wastewater with the ratio of 1:5 and was incubated again. The process was repeated until a sufficient culture volume for starting the system was obtained.

Hydrodynamic Flow Characteristics

Residence Time Distribution (RTD) studies were carried out to analyze the hydrodynamics of each aeration tank by adding a pulse of inert tracer to the aeration tanks under the normal operating conditions [8].

The concentration of the tracer in the effluent was measured for at least 3 HRTs (Hydraulic Residence Times) after the addition of the pulse.

In this way, the variance could be calculated by the discrete form [8]:

$$\delta^2 = \frac{\sum t_i^2 c_i \Delta t_i}{\sum c_i \Delta t_i} - \bar{t}^{\,2}, \tag{1}$$

$$\bar{t} = \frac{\sum t_i c_i \Delta t_i}{\sum c_i \Delta t_i}. \tag{2}$$

The variance represents the square of the spread of the distribution and has the unit of $(\text{time})^2$.

Kinetic Constants of Flow Reactor Studies

It is necessary to evaluate kinetic parameters for simulating waste-treatment processes.

The flow reactor has been widely used for kinetic studies. In the case of Monod kinetics in a completely mixed reactor under the steady-state condition, the material balance becomes [9]:

$$\frac{\theta X}{S^o - S} = \frac{K_s Y}{\mu_m}\left(\frac{1}{S}\right) + \frac{Y}{\mu_m}, \tag{3}$$

$$\frac{S^o - S}{X} = \frac{k_d \theta}{Y} + \frac{1}{Y}. \tag{4}$$

In this way, at several steady-state residence times, θ, within the reactor, the inlet and outlet substrate and biomass concentrations (S, S^o, X) were measured.

By plotting $\frac{\theta X}{S^o - S}$ against $\frac{1}{S}$, the slope and intercept are $\frac{K_s Y}{\mu_m}$ and $\frac{Y}{\mu_m}$ and by plotting $\frac{S^o - S}{X}$ against θ the slope and intercept are $\frac{k_d}{Y}, \frac{1}{Y}$. Therefore, the four kinetic parameters required for simulation, K_s, k_d, μ_m and Y were obtained.

Analysis

Dissolved Chemical Oxygen Demand (COD) was an index of the concentration of substrate. Mixed Liquor Suspended Solids (MLSS) and Sludge Volume Index (SVI) were measured by the standard methods [10].

Results and Discussion

It is known that the sludge bulking often occurs under increased organic loading conditions in the activated sludge process, especially when the wastewater contains a large quantity of carbohydrates. In this study, in order to investigate the treatment capacity of the two systems, the organic loading was gradually increased during the experiment for 25 days (Figure 2).

The comparison between performance of the Fixed Film Aeration Tank (FFAT) and Activated Sludge Aeration Tank (ASAT) during these days is shown in Figures 3 and 4. In ASAT, SVI increased with an increase in the organic loading and sludge bulking occurred when the organic loading exceeded 0.5 kg COD/m^3/day (Figure 3). On the other hand, in FFAT, COD removal was rather low in the initial period due to the low microbial concentration. However, after sufficient microbial growth, it attained the same COD removal as ASAT (Figure 4).

The activated sludge from the two systems was observed under microscope from time to time during the increasing of organic loading, and the presence of filamentous microorganisms were noticed. The problem of sludge bulking is caused by a prolific growth of this kind of microorganisms in the suspension process [11,12].

In the FFAT, the attachment of the microorganisms to the bed was very stable under the aeration from the bottom of the bed and the amount of microorganisms sloughed off the bed was negligible. Consequently, in recent development of the proper modification of the activated sludge process (FFAT), an attempt has been made to eliminate or at least minimize the sludge bulking problem due to adherence of the filamentous microorganisms to the fixed film instead of suspending in the aeration tank.

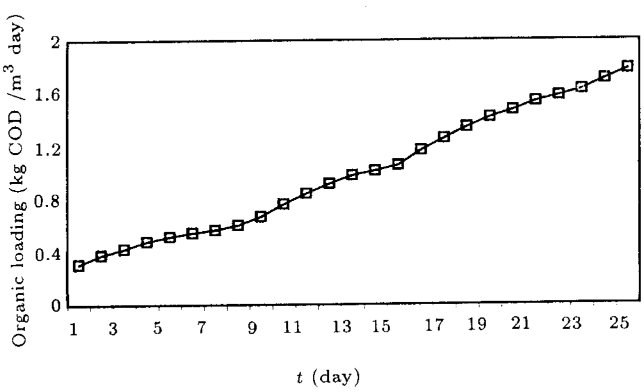

Figure 2. Increasing COD loading during the experiment (treatment period).

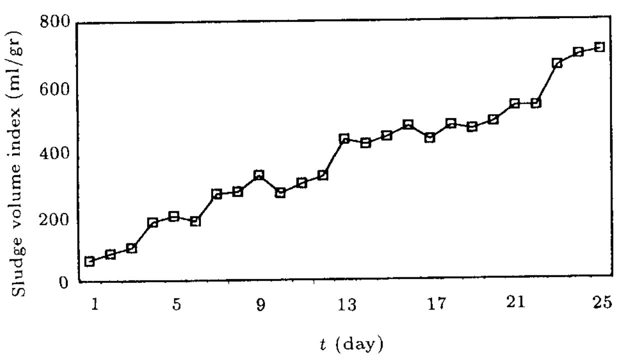

Figure 3. Sludge Volume Index (SVI) in ASAT during the treatment period.

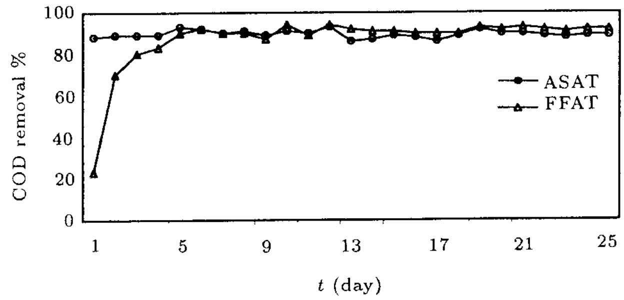

Figure 4. Comparison of COD removal during the treatment period.

Furthermore, to characterize the hydrodynamic flow in the tanks, the Residence Time Distribution (RTD) studies were carried out, as mentioned previously.

Figure 5 illustrates that when an impulse of tracer was added under normal operating conditions, tracer immediately appeared in the output of stream of each tank at its peak value and then decayed away exponentially.

The variance for each tank was calculated by measuring tracer concentration at each time (Equations 1 and 2). This parameter was approximately equal for the two systems. Therefore, if the ASAT is considered as a complete mixed tank, the FFAT could be considered a complete mixed type as well [8].

Now, it is assumed that: (1) All attached microorganisms were active, (2) Non-active microorganisms were stripped off the nets, (3) The aeration tank is considered a complete mixed type, (4) The rate equation can be represented by Monod model.

Material balances for active mass of microorgan-

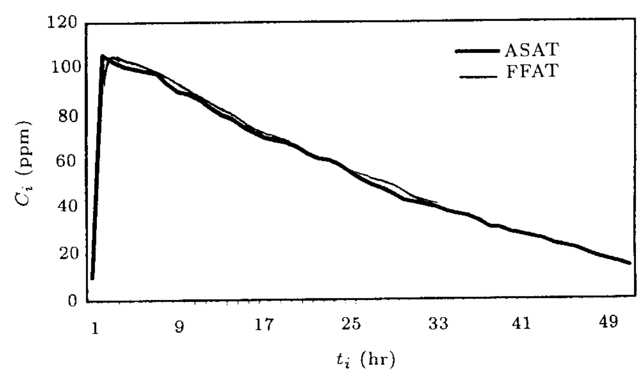

Figure 5. Comparison of hydrodynamic flow (pulse tracer experiment).

isms attached to the nets per unit area, X_a, and endogenous mass concentration suspended in the aeration tank, X_e, are expressed as:

$$nA\frac{dX_a}{dt} = nA\frac{\mu_m X_a S}{K_s + S} - nAk_d X_a, \tag{5}$$

$$V\frac{dX_e}{dt} = nAk_d(1 - f_d)X_a - FX_e. \tag{6}$$

Material balance for substrate, S, provides:

$$V\frac{dS}{dt} = (S^o - S)F - \frac{1}{Y}\frac{\mu_m S}{K_s + S}(nAX_a). \tag{7}$$

Initially all microorganisms were attached to the fixed nets, therefore, initial conditions regarding X_a and X_e can be written as:

$$X_a = X_{ao}, \tag{8}$$

$$X_e = 0. \tag{9}$$

X_a, X_e and S were simulated using Equations 5 to 9 with the aid of a computer [13]. The values of μ_m, K_s, Y, and k_d used for calculation were separately determined from flow reactor studies as mentioned previously (Figures 6 and 7). The values were μ_m = 1.25 1/hr, K_s = 376 mg/l, Y = 0.45, k_d = 0.0073 1/hr and f_d was assumed to be 0.5.

Figures 8 and 9 illustrate the computed results for the endogenous mass concentration in the tank and

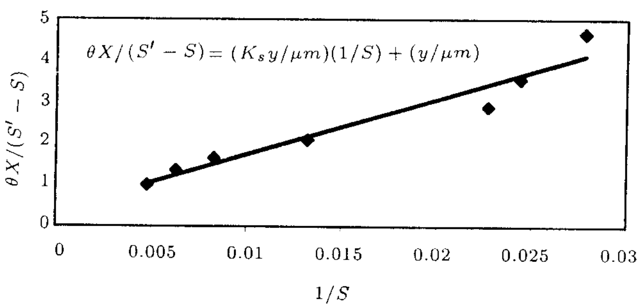

Figure 6. Estimation of kinetic constants, Equation 3 (K_s, μ_m).

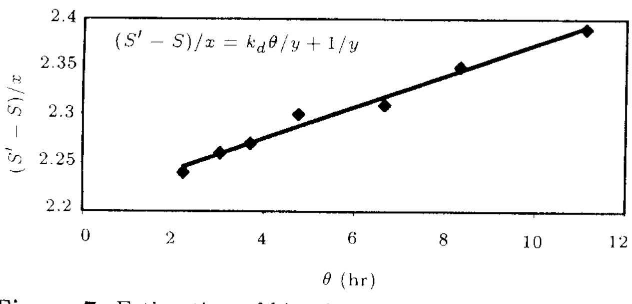

Figure 7. Estimation of kinetic constants, Equation 4 (k_d, Y).

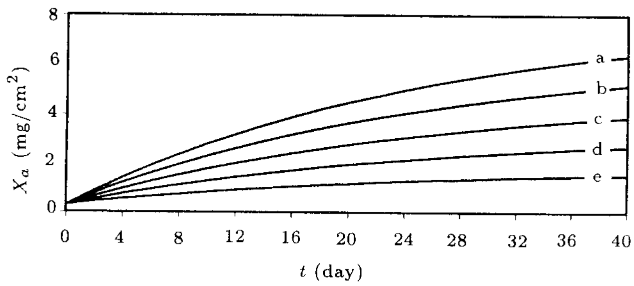

Figure 8. Simulation curves of active mass concentration of microorganisms attached to the nets; influent COD (mg/l): a: 500, b: 400, c: 300, d: 200, e: 100.

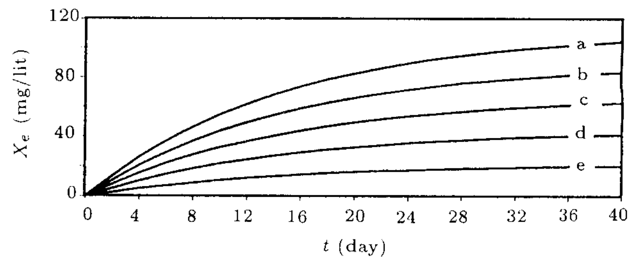

Figure 9. Simulation curves of endogenous mass concentration in the tank; influent COD (mg/l): a: 500, b: 400, c: 300, d: 200, e: 100.

active mass of microorganisms attached to the nets for values of influenced COD in the range of 100-500 mg/l at flow rate of 3 l/hr.

Figure 10 shows the computed results of the effluent dissolved COD as a function of COD.

For steady-state conditions, Equations 5 to 7 can be rewritten as:

$$X_a = \frac{FY}{nAk_d}\left(S^o - \frac{k_d K_s}{\mu_m - k_d}\right), \tag{10}$$

$$X_e = Y\left(S^o - \frac{k_d K_s}{\mu_m - k_d}\right)(1 - f_d), \tag{11}$$

$$S = \frac{k_d K_s}{\mu_m - k_d}. \tag{12}$$

The steady-state values of X_a estimated by using Equation 10 were 1.5, 3, 4.5, 6.1 and 7.6 mg/cm^2.

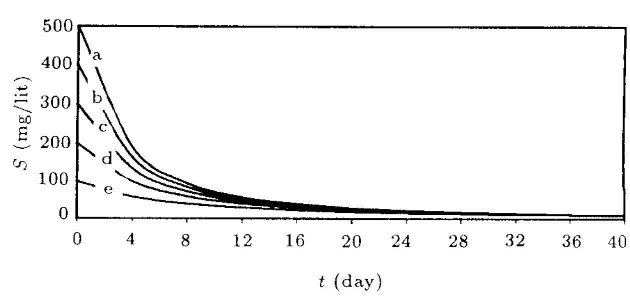

Figure 10. Simulation curves of effluent dissolved COD concentration; influent COD (mg/l): a: 500, b: 400, c: 300, d: 200, e: 100.

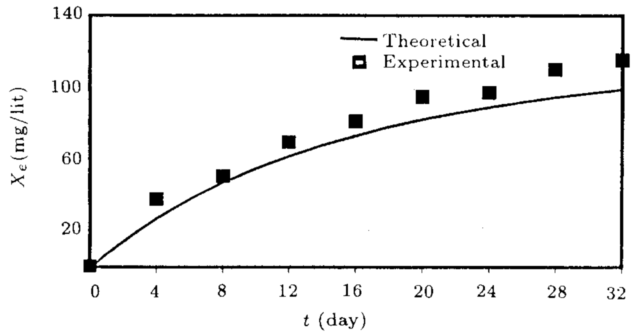

Figure 11. Comparison between the experimentally obtained data and the theoretical curve for endogenous mass concentration; influent COD (mg/l): 500.

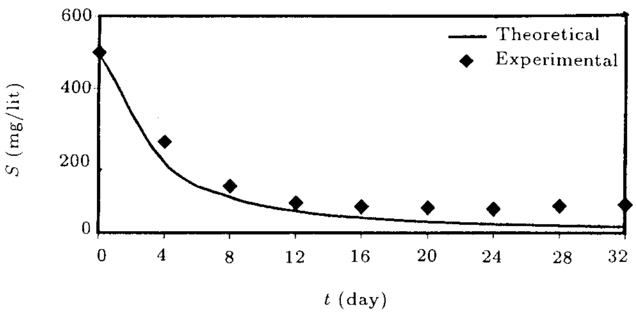

Figure 12. Comparison between the experimentally obtained data and the theoretical curve for effluent dissolved COD; influent COD (mg/l): 500.

Also, the steady-state values of X_e calculated from Equation 11 were 22, 44.5, 67, 89.5 and 112 mg/l. These values correspond to an influent concentration of 100, 200, 300, 400 and 500 mg/l, respectively. It should be mentioned that because the endogenous mass was non-active, it could form flocculated mass and be settled easily. Therefore, by setting a settling tank after FFAT at an industrial scale, the endogenous mass could be separated easily and there is no problem. However, the effluent dissolved COD was found to be independent of the influent concentration and its constant value was calculated as 2.2 mg/l.

Figures 11 and 12 show the experimental results for the endogenous mass concentration and effluent dissolved COD concentration with an influent COD of 500 mg/l.

The computed results for the same influent concentration are appended for comparison with the experimental results in both figures. These experimental data were in relatively good agreement with the simulation curves, although lower values of these were obtained by calculation.

CONCLUSION

The Fixed Film Aeration Tank (FFAT) promises a potential replacement for activated sludge and trickling filter processes in secondary wastewater treatment. It is expected to need less close control than either of the older types of the system due to its ability to maintain effective processing while adapting to high and variable organic loadings, as demonstrated in the present study.

In this preliminary laboratory study, comparing bench-scale activated sludge and FFAT reactors processing a synthetic wastewater, consisting of glucose and ammonium diphosphate, the sludge volume index in the activated sludge reactor increased in proportion with the organic loading, but microorganisms like those that cause sludge bulking were observed in the fixed film.

A mathematical model based on Monod kinetics predicts the FFAT behavior well.

Additional research remains to be done to develop this technology to the point where it will be operationally useful, including:

1. More realistic feeds,
2. Longer studies to reach steady-state demonstrating long-term stability,
3. Assessment of the need for removal of biomass in endogenous metabolism from effluent.

NOMENCLATURE

A	effective surface area of the nets, cm^2
F	flow rate, l/day
f_d	biodegradable fraction of active mass concentration, dimensionless
k_d	endogenous oxidation rate, 1/day
K_s	saturation coefficient, mg/l
n	number of fixed nets
S	effluent dissolved COD, mg/l
S^o	influent COD, mg/l
t	treatment period, day
V	volume of aeration tank, lit
X_a	active mass of microorganisms attached to a unit area of net, mg/cm^2
X_e	endogenous mass concentration in aeration tank, mg/l
Y	cell yield for COD, dimensionless
μ_m	maximum specific growth rate, 1/day
θ	residence time, day
C_i	tracer concentration, mg/l
t_i	time for tracer measuring, min

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