AEROBIC FILTER TREATMENT OF PHARMACEUTICAL WASTE

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ABSTRACT

The success of both the conventional, aerobic and anaerobic contact processes depends on the ability of each to bring the waste with an aerobic microbial mass for a sufficient length of time to convert the waste to stable compounds. This objective is achieved in the conventional process through a trickling filter contact process. Important operating parameters in this system are the hydraulic loading, recycle ratio and bed height. Investigating these parameters can be established sufficient microbial mass for efficient treatment. Through this investigation the responses of waste equalization tank and aerobic trickling filter were studied. The process was operated under various conditions of hydraulic loading, recycle ratio, bed height. Wastewater discharges from pharmaceutical facility were subjected and a 90 % removal of chemical oxygen demand (COD) was achieved. From the experimental investigation, it has shown that the aerobic trickling filter process is highly efficient in treating wastewater discharges from pharmaceutical facilities.

INTRODUCTION

Fixed-growth biological systems are those that contact wastewater with microbial growths attached to the surfaces of supporting media. Where the wastewater is sprayed over a bed of crushed rock, the unit is commonly referred to as a trickling filter. The concept of biological growth retention on a support medium or packing material is not new to the field of waste treatment. The aerobic trickling filter uses the fixed bed principle as a basis of its operation. Its importance is reflected in the many trickling filters in use and in the considerable research that has been conducted toward the process improvement and the definition of its mode of operation. Aerobic filters (also known as 'trickling filters' or 'percolating filters') have been in use for the treatment of organic wastewaters since the first decade of 20th century. The development of high-rate types has added to the adaptability of this method of treatment to many needs and conditions and has greatly increased its popularity [1].

Domestic wastewater sprinkled over fixed media produces biological slimes that coat the surface. The films consist primarily of bacteria, protozoa and fungi that feed on waste organics. As the wastewater flows over the slime layer, organic matter and dissolved oxygen are extracted, and metabolic end products such as carbon dioxide are released. Dissolved oxygen in the liquid is replenished by absorption from the air in the voids surrounding the filter media. Therefore, although biological filtration is commonly referred to an aerobic treatment, it is in fact a facultative incorporating both aerobic and anaerobic activity. Organisms attached to the media in the upper layer of a bed grow rapidly, feeding on the abundant food supply. As the wastewater trickles downward, the organic content decreases to the point where microorganisms in the lower zone are in state of starvation [2].

The most common media in the existing filters are crushed rock, slug, or fieldstone that are durable, insoluble and resistant to spalling. The size range preferred for stone media is 75-225 mm diameter. Although smaller stone provides greater surface area for biological growth, the voids tend to plug and limit passage of liquid and air. Stone-media filters in the treatment of municipal wastewaters are always proceeded by primary settling to remove larger suspended solids [7].

The removal of organic colloids in suspension and dissolved substances occurs by 'biosorption' and coagulation from that portion of the flow that passes through rapidly, and by the usual processes of synthesis and respiration from the part of the flow with long residence time. This residence time is primarily related to the hydraulic loading, so it seems reasonable that the greater the hydraulic loading the more the process will depend upon biosorption and the less it will depend upon the synthesis and respiration [7].

EXPERIMENTAL WORK

Pilot-Scale Biofilter

Aerobic biofilters are categorized as low-rate or high-rate, depending on the applied hydraulic and organic loading rates. In high-rate filters, recirculation of filter effluent permits the use of higher organic and hydraulic loading rate (7). Biofilters are typically used at high hydraulic and organic loading rates to achieve a 40-70% COD reduction (1). For a single-stage filter process with recirculation, the clarified effluent from an equalization tank is discharged to a primary clarifier, from where it is pumped to the filter distribution system. Where recirculation being applied, recycled effluent is also discharged to this primary clarifier from a secondary clarifier tank. The distribution system was consists of a fixed distributor manifold of two arms; each arm is designed as a distribution manifold with discharge points (nozzles) so spaced as to secure a uniform irrigation of clarified wastewater over the entire bed area. A clearance of 0.2 m is allowed between the underside of the distribution arm and the top of the bed. The essential requirements for a filter medium are that it should be inert and posses within its bulk an extensive area of exposed surfaces over which the liquid to be treated can be passed. Also, adequate void spaces must exist between adjacent surfaces to allow for some accumulation of biological film, for free passage of liquid and suspended matter, and for access of air. A compromise between the conflicting requirements for large specific surface and adequate void space results in the use of gravel of about 75 mm to 120 mm in natural aggregate as a filter media. This filter media was contained in a carbon steel drum of 0.75-m diameter. The floor of the drum was graded to provide under drainage to a central collector channel. A schematic diagram of the pilot-scale biofilter used in this investigation was shown in Fig (1). The experiments were carried out according to pre-designed values of variables under study, which accommodate the most dominant parameters on the performance of the trickling filter against the chemical loading and suspended solid of the pharmaceutical wastewater.

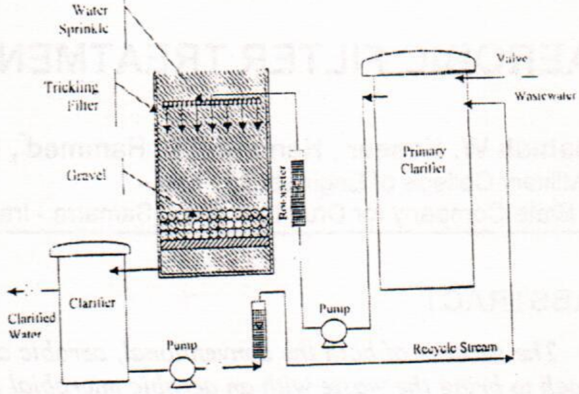

Fig. (1) Schematic drawing of the boiler assembly

In order to carry out a comprehensive investigation based on lab scale experimentation, it is necessary to investigate the parameters, that considerably affect the system behavior, or the factors that influence the system responses. So one must ensued a systematic method, which follow the response function that relates the dependent variables with the independent one with minimum number of experiments. Hence an experimental design technique was followed in order to determine the most important factor among the variables under study, how these variables influence the response of the simulation model, and why certain results occur as they do in the simulation experiments (4).

In chemical industry, experimental designs are particularly applied to the study of process variables and how they affect the product. For an example, in reactor problem, the effect of operating temperature on yield was characterized by a regression analysis, which is developing of mathematical models to represent physical situations. Similarly additional variables such as catalyst age, flow rate, and pressure could have been included in the regression analysis, that is, their quantitative effect on yield are estimated by the regression coefficients (3).

A systematic method, which follows the response function, relates the dependent variables with the independent one with minimum number of experiments was followed. Besides, their quantitative effects are estimated by the regression coefficients (6).

A response surface can be most efficient fitted if proper attention is given to the choice of experimental design. The application of experimental design for planning the experiments required to examine the system will extract the information from pre-existing data by using a statistical method to interpret the results in a regular form with the minimum number of observations (4).

Box-Wilson composite rotatable design, which has been used in this investigation, is a common type of statistical experimental technique especially applicable to optimization analysis. The experimental results of these tests serve as a function to represent the relationships between the variables and the response (6).

These designs consists of a 2k fractional (i.e. coded to the usual ± 1 notation) augmented by 2k axial points, i.e. (±α, 0, 0, …, 0), (0, ±α, 0,…, 0), (0, 0, ±α, …, 0), ….., (0, 0, …, ±α,) and center points (0, 0, 0, …, 0).

A preliminary step is to set up the relationships between the coded levels and the corresponding real variables. This relationship is as follow (5):

$$X_{coded} = \frac{[X_{actual} - X_{center}]}{\left[\frac{X_{center} - X_{min}}{\sqrt{k}}\right]} \qquad (1)$$

Experimental Trials

The study was devoted to test the effect of process variables on percent of COD reduction relative to the initial value. The experimental work was designed in the following experimental ranges:

1. Hydraulic loading ranged from 18.70 to 56.12 m3/ m2.day, coded as X1.
2. Recycle ratio ranged from 0.3 to 0.7, coded as X2.
3. Height of filter media ranged from 0.2 to 0.6 m, coded as X3.

The coded levels were related to real values according to Eq. (1) as follows:

$$X_1 = \frac{L - 37.41}{10.7965} \qquad (2)$$

$$X_2 = \frac{R - 0.5}{0.1155} \qquad (3)$$

$$X_3 = \frac{H - 0.4}{0.1155} \qquad (4)$$

Where L is the hydraulic loading in m3/m2day, R is the recycle ratio and H is the height of filter media in m. The working ranges of coded and corresponding real variables are listed in Table (1). According to experimental design there are fifteen experiments carried out in a sequence shown in Table (2) where the coded values +1.732, -1.732, and 0 represent the maximum, minimum and center values respectively.

The representation of the response space takes into account the effect generated by each variable, as well as the interaction effect of the variables reflected on the response.

Using the coded data of the central composite design, the coefficients of 2rd order polynomial were estimated. The number of iterations according to Hookes and Jeeves pattern move method was terminated when the proportion of variance was equal to 0.899 and the correlation coefficient was equal to 0.944. Thus, the proposed model was as follows:

$$\begin{aligned} Y = {} & 0.81388 - 0.035896X_1 - 0.028389X_2 \\ & - 0.078972X_3 - 0.007045X_1^2 \\ & + 0.01423X_2^2 - 0.030321X_3^2 - 0.015966X_1X_2 \\ & - 0.018621X_1X_3 - 0.024263X_2X_3 \end{aligned} \qquad (5)$$

Results and Discussion

A series of experiments were conducted with pharmaceutical waste from an equalization tank to study the effect of the most affective variables (i.e. hydraulic loading, recycle ratio, and height of filter media) on the performance of trickling filter towards decreasing the chemical loading. These variables had been correlated with removal percent of COD. Optimum conditions were predicted to ensue the best performance for biofilter pilot scale unit subjected to a high rate of hydraulic loading and high chemical loading rate pharmaceutical waste.

Table (3) listed the predicted and the experimental data. The predicted values were obtained through best formal postulation of 2nd order polynomial, Eq. (5).

Figures (3) to (5) show the interaction effect of two variables (hydraulic loading, and recycle ratio; hydraulic loading and filter bed height; and recycle ratio and filter bed height respectively) on performance of trickling filter in terms of removal of COD matter.

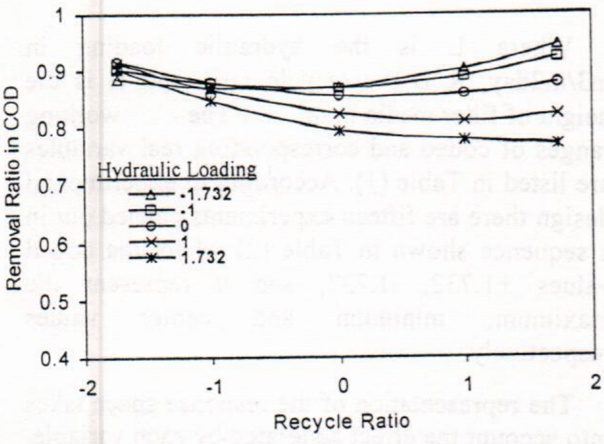

Fig (2) Effect of recycle ratio and hydraulic loading on the COD loading of effluent at optimum filter bed height (H = -0.723)

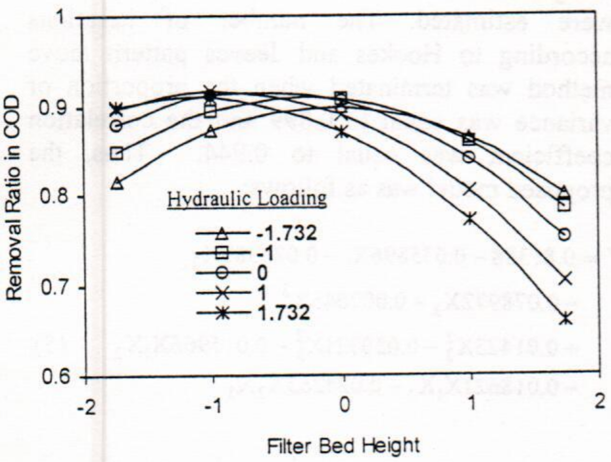

Fig (3) Effect of filter bed height and hydraulic loading on COD loading at optimum recycle ratio (R = -1.732)

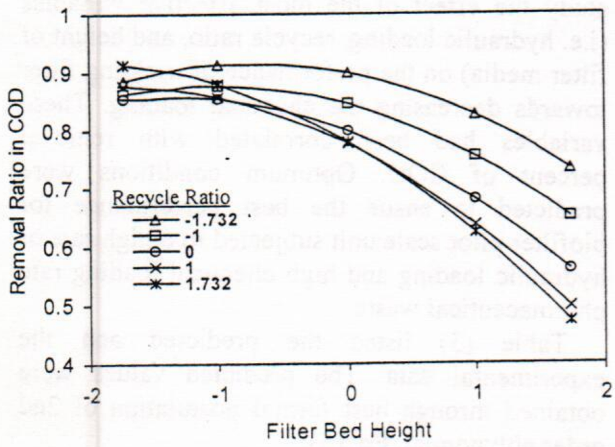

Fig (4) Effect of filter bed height and recycle ratio on COD loading at optimum hydraulic loading (L = 0.372)

Optimum conditions are found equal to 0.372 hydraulic loading, -1.732 recycle ratio and –0.723 bed height.

Examine Eq. (5), it was found that the three interaction terms have significant effects on the objective variable, in addition they posse interference effect on each other. Great tendency for the curves to change their trends was noticed in Figs (2), (3) and (4). The three figures had shown higher than 90 % reduction in COD materials. As shown in Fig (2), optimum filter-bed height was maintained where not less than 75 % reduction in COD whatsoever, the other conditions are. Furthermore, Fig (2) show suitable performances at the extreme limits of the two variables (hydraulic loading and recycle ratio). In addition, at low values of hydraulic loading (-1.732 and –1) the performance of the trickling filter was noticed to decrease with decreasing the values of recycle ratio that was contributed to longer residence time in the biofilter reactor. In contrary, higher values of hydraulic loading (0, 1, and 1.732) shows higher performance with corresponding lesser values of recycle ratio. Whatsoever the values of hydraulic loading are, 90 % reduction in COD materials was attained at –1.732 recycle ratio. Whereas in Fig (3) the best performance conditions was sponsored at low filter bed height values and high hydraulic loading values. Customarily, Fig (4) shows optimum conditions at -1.732 recycle ratio and 1.732 filter bed height whereas, at the lower limit of filter bed height (i.e., -1.732), higher performance (i.e., higher COD reduction) was observed at 1.732 recycle ratio. This means that the contributions are submitted by these two variables in opposite direction to each other (high degree of mixedness with lower residence time and vice versa). In general, these findings for the best optimum conditions in the three figures are matched. Therefore, the optimum condition would match in coded values to 0.372 hydraulic loading, -1.732 recycle ratio and -0.723 filter bed height. These optimum conditions were coincided with previously determined optimum conditions.

In general, the three figures had showed significant interaction between the three variables as the curves had reversed its trends or its courses.

At highest values of the recycle ratio (i.e., 1.732) the increasing in performance with increasing hydraulic loading was contributed to the higher values of mass transfer coefficients that was endued as the aerobic layer becomes thinner in the course of higher velocities. Also higher values of recycle ratio with higher hydraulic loading would increase the growth rate of the microorganisms inside the aerobic film since the filter medium was aerated vigorously that consequently increases the flow resistance inside the biofilter reactor. Whereas, lower values of recycle ratio (i.e. 0, -1 and –1.732), with higher hydraulic loading had lowered the performance of trickling filter as attributed to the scouring effect of the microorganisms. Customarily, increasing the velocities will match lesser residence times inside the biological reactor. Whereas, lower values of filter bed height that corresponding to higher performance was attributed to the fact that 90 % reduction in the COD matter may occur in the upper region of the bed. In these two events, the removal of organic colloids in suspension and dissolved substances occurs by biosorption and coagulation from that portion of the flow that passes through rapidly (e.g. high hydraulic loading with lower filter bed height), and by the usual processes of synthesis and respiration from the part of the flow with long residence time (low hydraulic loading and high filter bed height).

Figure (2), (3) and (4) show that hydraulic loading, recycle ratio and filter bed height have nonlinear dependence with chemical loading (i.e., COD) of the effluent stream from trickling filter. Figure (2) shows minimal performance point, whereas, Fig (3) and (4) shows negative dependence of the three variables and maximal performance point.

Figure (5), (6) and (7) show the effect of each variable on the performance of the trickling filter. It seems that filter height had the most significant nonlinear dependence in comparison to hydraulic loading and recycle ratio. Figure (5) shows that the hydraulic loading increased the reduction of COD matter in the effluent in according to higher values of mass transfer rates inside the biofilter whereas lower COD matter reduction with hydraulic loading was attributed to scouring effect. Figure (6) postulated the dependence of COD reduction with recycle ratio. It shows that increasing the recycle ratio decrease the reduction of COD in according to higher flow resistance inside the biofilter whereas an increasing performance at recycle ratio higher than 0.5 was attributed to higher residence time and higher degree of mixedness inside the biofilter reactor. Figure (7) shows the effect of filter bed height on COD matter reduction. As outlined above, lower values of filter height that corresponding to higher performance was attributed to the fact that 90 % reduction of the COD matter may occur in the upper region of the bed whereas, lower performance was attributed to higher resistance inside the biofilter reactor. Besides, organisms attached to the media in the upper layer of a bed grow rapidly, feeding on the abundant food supply. As the wastewater trickles downward, the organic content decreases to the point where microorganisms in the lower zone are in state of starvation.

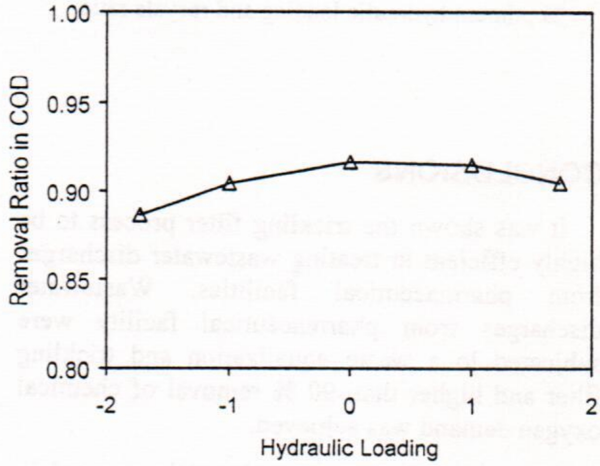

Fig (5) Effect of hydraulic loading on COD removal at optimum recycle ratio and filter bed height

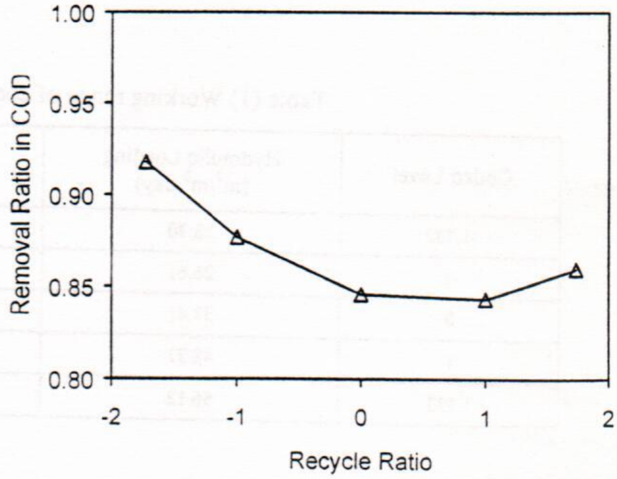

Fig (6) Effect of recycle ratio on COD removal at optimum hydraulic loading and filter bed height

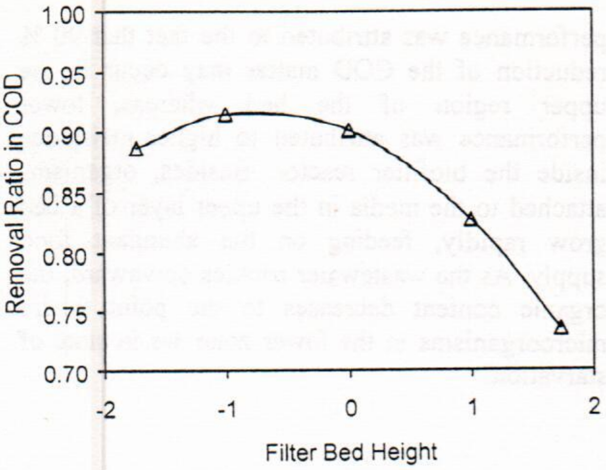

Fig (7) Effect of filter bed height on COD removal at optimum hydraulic loading and recycle ratio

CONCLUSIONS

It was shown the trickling filter process to be highly efficient in treating wastewater discharges from pharmaceutical facilities. Wastewater discharges from pharmaceutical facility were subjected to a waste equalization and trickling filter and higher than 90 % removal of chemical oxygen demand was achieved.

Typical data are presented and interpreted in terms of various conditions. The process was operated under various conditions of hydraulic loading, recycle ratio and filter bed height, which have showed significant interaction between these three variables besides nonlinear dependence was observed in terms of the objective variable (i.e. removal ratio of chemical oxygen demand).

NOMENCLATURE

COD	Chemical Oxygen Demand
e_i	Residual of the i^{th} experiment: $e_i = y_i - \acute{y}_i$
H	Filter bed height, Eq (4)
L	Hydraulic loading, Eq. (2)
R	Recycle Ratio, Eq (3)
X_k	Coded variable X for element k
y_i	Response for the i^{th} experiment
$\acute{y}_i$	Estimated response for the i^{th} experiment

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Table (1) Working range of coded and corresponding real variables

Coded Level	Hydraulic Loading (m^3/m^2.day)	Recycle Ratio	Media Thickness (cm)
-1.732	18.70	0.3	0.2
-1	26.61	0.4	0.3
0	37.41	0.5	0.4
1	48.21	0.6	0.5
1.732	56.12	0.7	0.6

Table (2) Sequence of experiments according to central composite design

Exp. No.	Coded Variable			Real Variable		
	X_1	X_2	X_3	Hydraulic Loding ($m^3/m^2.day$)	Recycle Ratio	Media Thickness (cm)
1	-1	-1	-1	26.61	0.4	30
2	-1	-1	1	26.61	0.4	50
3	-1	1	-1	26.61	0.6	30
4	1	-1	-1	48.21	0.4	30
5	-1	1	1	26.61	0.6	50
6	1	-1	1	48.21	0.4	50
7	1	1	-1	48.21	0.6	30
8	1	1	1	48.21	0.6	50
9	-1.732	0	0	18.70	0.5	40
10	1.732	0	0	56.12	0.5	40
11	0	-1.732	0	37.41	0.3	40
12	0	1.732	0	37.41	0.7	40
13	0	0	-1.732	37.41	0.5	20
14	0	0	1.732	37.41	0.5	60
15	0	0	0	37.41	0.5	40

Table (3) Percent of the experimental COD loading (ppm) and the predicted values in the effluent stream

Exp. No.	Coded Variable			COD Reduction xperimental (%)	COD Reduction Predicted (%)	Error $e = y_{Exp} - \acute{y}_{Pred.}$
	X_1	X_2	X_3			
1	-1	-1	-1	0.744680	0.730162	0.014518
2	-1	-1	1	0.893617	0.854676	0.038941
3	-1	1	-1	0.845745	0.806884	0.038861
4	1	-1	-1	0.920213	0.905441	0.014772
5	-1	1	1	0.618351	0.585618	0.032733
6	1	-1	1	0.880319	0.859588	0.020731
7	1	1	-1	0.598667	0.587873	0.010794
8	1	1	1	0.781333	0.832065	-0.05073
9	-1.732	0	0	0.680000	0.725516	-0.04552
10	1.732	0	0	0.898667	0.872339	0.026328
11	0	-1.732	0	0.662667	0.729145	-0.06648
12	0	1.732	0	0.904000	0.898685	0.005315
13	0	0	-1.732	0.813333	0.802677	0.010656
14	0	0	1.732	0.824000	0.874848	-0.05085
15	0	0	0	0.813330	0.813761	-0.00043