STUDY THE CHARACTERSTICS PERFORMANCE OF TRICKLING FILTER FOR PHARMACEUTICAL WASTE TREATMENT

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ABSTRACT

Past experience in the waste treatment field has shown the trickling filter process to be highly efficient and more capable of withstanding shock loading. For this reason it was decided to investigate the feasibility of utilizing this system type. For competent design wastewater treatment system to meet the established requirements by the water pollution control, a pilot scale plant was installed. Waste equalization and trickling filter system are studied. Wastewater discharges from pharmaceutical facility were studied and a 90 % removal of biochemical oxygen demand was achieved.

A description of pilot scale equipment is included. Typical data are presented and interpreted in terms of various conditions. The process was operated under various conditions of feed rate, recycle ratio, bed height.

The experimental investigation has showed that the trickling filter process is highly efficient in treating wastewater discharges from pharmaceutical facilities.

INTRODUCTION

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 this 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 (Steel, 1960). The removal of organics is similar to that of the activated sludge process. The greater portion of the liquid applied to the surface of the filter passes rapidly through and the remainder trickles slowly over the surface of the slime growth. 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 (Casey, 1997).

The action of a filter depends on the metabolic activity of zoogleal or filamentous bacteria or of fungi. These colonize the extensive surfaces of the support medium (most widely used is natural stone 50-100 mm size) and form the basis of the film which also contains a population protozoa as well as amorphous solids derived from the waste. The composition of the microbial population depends on the nature of the waste, its strength, the rate at which it is applied and the method of the filter.

The reduction in concentration of polluting matter occurs most rapidly in the upper regions of the filter. In a conventional filter treating sewage, about 90% of the biodegradable matter may be removed in the upper 0.6 m of the bed. The net removal rate of organic matter is a function of the immediate removal of the readily biodegradable fraction and the release of products of endogenous metabolism of the biofilm. The biological film or slime layer is inhabited by an independent microbial population, including bacteria, fungi, protozoa and a variety of macroinvertebrates (Bruce, 1969).

The thickness of the film, which can be maintained in an aerobic condition by diffusion of atmospheric oxygen through the film surface, is rather limited. Estimates of the aerobic zone in an actively respiring film vary between 0.06 mm and 2 mm, while in deeper regions of the film, aerobic conditions prevail.

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 rates (Gasey, 1997). The main elements of an aerobic biofilter system are (1) an influent feed system by gravity or pump; (2) an influent irrigation system; (3) containment for the filter medium; (4) provision for adequate ventilation of the filter medium; and (5) secondary sedimentation and recirculation of effluent, where required.

EXPERIMENTAL WORK

Pilot Scale Biofilter

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. Herein, a fixed distributor manifold was used which consists of two arms; each arm is designed as a distribution manifold with discharge points (nozzle discharges) so spaced to secure a uniform irrigation of clarified wastewater over the entire bed area. Normally, a fixed manifold distributor system is used for wastewater irrigation on deep-bed filters, so-called biotowers. Biofilters are typically used at high hydraulic and organic loading rates to achieve a 40-70% BOD reduction. A clearance 0.2 m is allowed between the distribution arm and the top of the bed. The essential requirements for a filter medium should be inert and posses within its bulk an extensive area 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 column of 0.75-m diameter. The bottom of the column was graded with gravel to provide drainage to the central collector channel. A schematic diagram of the pilot-scale biofilter used in this study was shown in Fig (1). The experiments are 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 biological loading of the pharmaceutical wastewater.

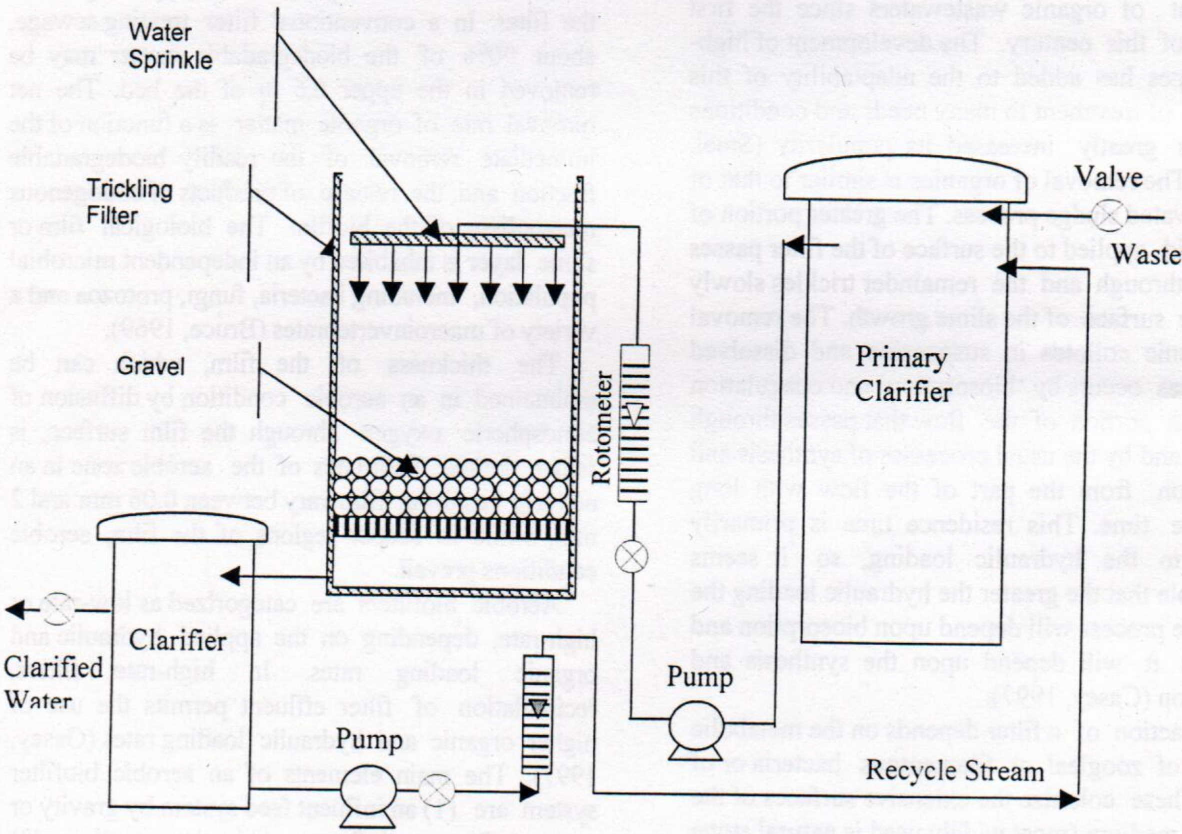

Fig (1) Schematic drawing of the biofilter assembly

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 (Phillips and Ravindan, 1980).

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 (Perry and Chilton, 1970).

Central Composite Rotatable Design

Box-Wilson composite rotatable design, which has been used in this study, is a common type of statistical experimental technique especially applicable to optimization analysis. In this technique, a special series of tests are defined. The experimental results of these tests, then serve function to represent the relationships between the variables and the response (Montgomery, 1976). These designs consists of a 2^k fractional (i.e. coded to the usual ± 1 notation) augmented by 2k axial points, i.e. $(\pm\alpha, 0, 0, \ldots, 0)$, $(0, \pm\alpha, 0, \ldots, 0)$, $(0, 0, \pm\alpha, \ldots, 0)$, ..., $(0, 0, \ldots, \pm\alpha,)$ and center points $(0, 0, 0, \ldots, 0)$. For $k = 3$ that may be subdivided into three parts:

1. The eight points (-1, -1, -1), (1, -1, -1), (-1, -1, 1), (-1, 1, -1), (-1, 1, 1), (1, -1, 1), (1, 1, -1), and (1, 1, 1) which constitute a 2^k factorial.
2. The six points $(-\sqrt{3},0, 0)$, $(\sqrt{3}, 0, 0)$, $(0, -\sqrt{3}, 0)$, $(0, \sqrt{3}, 0)$, $(0, 0, -\sqrt{3})$, and $(0, 0, \sqrt{3})$ which are extra points included to form central composite design with $\alpha = \sqrt{3}$. Five points, which are added at the center to give roughly, equal precision for the function within a circle of radius 1.

A preliminary step is to set up the relationships between the coded levels and the corresponding real variables. These relationships are as follows:

$$X_{coded} = \frac{\lfloor X_{actual} - X_{center} \rfloor}{\left[\dfrac{X_{center} - X_{min}}{\sqrt{k}}\right]} \tag{1}$$

Experimental Trials

In this study, the effects of process variables on percent of BOD reduction relative to the initial value are tested. The experimental work was designed in the following experimental ranges:

1. Flow rate of the influent ranged from 10 to 30 lit/min, coded as X_1.
2. Ratio of the effluent recycle ranged from 0.3 to 0.7, coded as X_2.
3. Thickness of filter media ranged from 0.2 to 0.6 m, coded as X_3.

The coded levels were related to real process values of these variables according to eq. (1) as follows:

$$X_1 = \frac{L - 20}{5.7740} \tag{2}$$

$$X_2 = \frac{R - 0.5}{0.1155} \tag{3}$$

$$X_3 = \frac{H - 0.4}{0.1155} \tag{4}$$

Where L is the flow rate of the influent in lit/min, R is the ratio of the recycle effluent and H is the thickness 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. Montgomery (1976) had postulated that a mathematical model of degree 2 or higher is usually required approximating the response. Because of the curvature in the true surface, a third order model of the following form be postulated to correlate the response function with the variables under study.

$$Y = B_0 + B_1X_1 + B_2X_2 + B_3X_3 + B_{11}X_1^2 + B_{22}X_2^2 + B_{33}X_3^2 + B_{12}X_1X_2 + B_{13}X_1X_3 + B_{23}X_2X_3 + B_{111}X_1^3 + B_{222}X_2^3 + B_{333}X_3^3 + B_{123}X_1X_2X_3 \quad (5)$$

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

Coded Level	Flow Rate (lit/min)	Recycle Ratio	Media Thickness (m)
-1.732	10	0.3	0.2
-1	15	0.4	0.3
0	20	0.5	0.4
1	25	0.6	0.5
1.732	30	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	Flow Rate (lit/min)	Recycle Ratio	Media Thickness (m)
1	-1	-1	-1	15	0.4	30
2	-1	-1	1	15	0.4	50
3	-1	1	-1	15	0.6	30
4	1	-1	-1	25	0.4	30
5	-1	1	1	15	0.6	50
6	1	-1	1	25	0.4	50
7	1	1	-1	25	0.6	30
8	1	1	1	25	0.6	50
9	-1.732	0	0	10	0.5	40
10	1.732	0	0	30	0.5	40
11	0	-1.732	0	20	0.3	40
12	0	1.732	0	20	0.7	40
13	0	0	-1.732	20	0.5	20
14	0	0	1.732	20	0.5	60
15	0	0	0	20	0.5	40

Using the coded data of the central composite design, the coefficients of the 3rd order polynomial, eq. (5), were estimated by implementing nonlinear regression analysis of Hookes and Jeeves pattern move via Statistica Software. The number of iterations was terminated when the proportion of variance was equal to 0.90 and the correlation coefficient was equal to 0.95. Thus, the proposed model was as follows:

$$Y = 0.322 + 0.0758X_1 + 0.0289X_2 + 0.0759X_3 - 0.0044X_1^2 - 0.0026X_2^2 + 0.0594X_3^2 - 0.02015X_1X_2 + 0.04094X_1X_3 + 0.02705X_2X_3 - 0.03063X_1^3 - 0.00324X_2^3 - 0.00018X_3^3 - 0.0493X_1X_2X_3 \quad (6)$$

RESULTS AND DISCUSSION

A series of experiments were conducted with pharmaceutical wastewater from an equalization tank to study the effect of the most affective variables (i.e. flow rate of the influent, recycle ratio, and thickness of the media) on the performance of the trickling filter towards decreasing the biological loading. These variables had been correlated with percent of BOD_5 in the out coming stream from trickling filter under study by a third order polynomial model, eq. (6). Optimum conditions were predicted to ensue the best performance of biofilter pilot scale.

Table (3) shows the predicted and measured percent of BOD_5 relative to the initial loading of BOD_5 of the incoming stream from an equalization tank. The predicted values were obtained through best formal postulation of the third order polynomial, eq. (6).

Table (3) Percent of the experimental BOD_5 loading (ppm) and the predicted values in the effluent stream

Exp. No.	Coded Variable			Experimental BOD_5 %	Predicted BOD_5 %	Error $e = y_i - \acute{y}_i$
	X_1	X_2	X_3			
1	-1	-1	-1	0.3610	0.4767	0.1157
2	-1	-1	1	0.2780	0.3936	0.1156
3	-1	1	-1	0.3000	0.4157	0.1157
4	1	-1	-1	0.3110	0.1238	-0.1872
5	-1	1	1	0.5220	0.6379	0.1159
6	1	-1	1	0.5890	0.4015	-0.1875
7	1	1	-1	0.3670	0.1793	-0.1877
8	1	1	1	0.5560	0.3681	-0.1879
9	-1.732	0	0	0.2890	0.5992	0.3102
10	1.732	0	0	0.2730	0.0185	-0.2545
11	0	-1.732	0	0.2330	0.2811	0.0481
12	0	1.732	0	0.3000	0.3476	0.0476
13	0	0	-1.732	0.3220	0.3700	0.0480
14	0	0	1.732	0.5830	0.6310	0.0480
15	0	0	0	0.3220	0.3221	0.0001

Figures (3) to (5) show the effect of each variable (flow rate, recycle ratio, and thickness of the media respectively) on the performance of the trickling filter in account to the percent of BOD_5 in the out coming stream where the other two variables was maintained at optimum conditions.

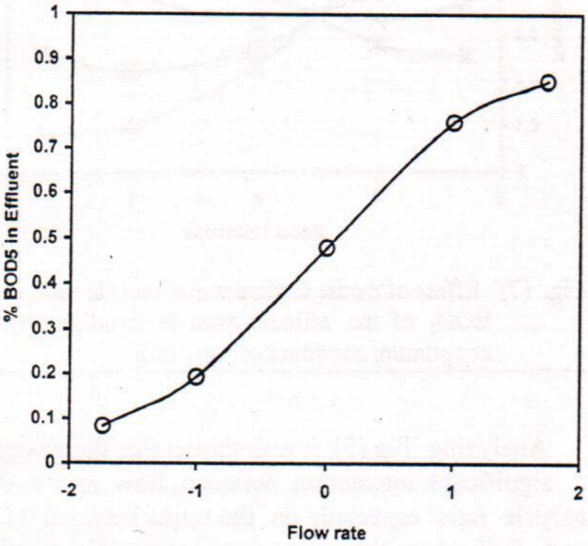

Fig. (2) Effect of flow rate of the incoming stream on the BOD_5 loading in the effluent from the trickling filter at optimum conditions of recycle ratio and media thickness

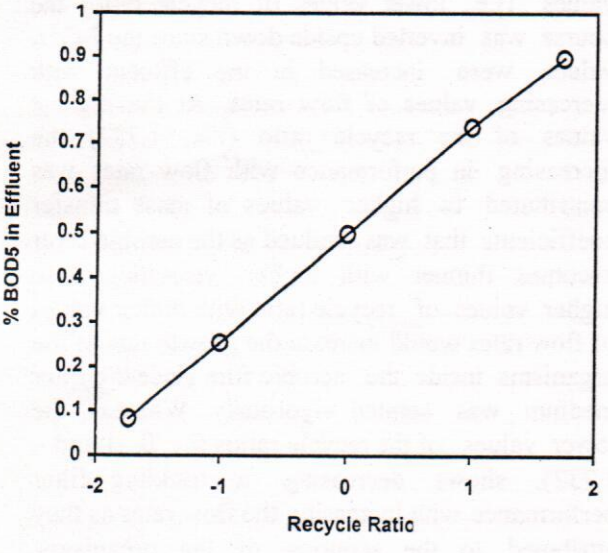

Fig. (3) Effect of recycle ratio on BOD_5 loading in the effluent from the trickling filter at optimum conditions of flow rate and media thickness

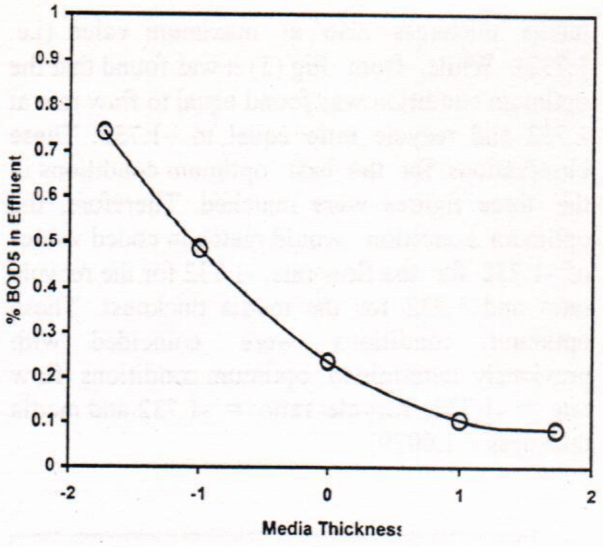

Fig. (4) Effect of media thickness on BOD_5 loading in the effluent from the trickling filter at optimum conditions of recycle ratio and media thickness

Figs (2) and (4), show that flow rate of the incoming stream and thickness of the media respectively have nonlinear dependence with loading of BOD_5 in the out coming stream from the trickling filter. Where Fig (2) shows the dependence of flow rate, of positive dependence towards decreasing the BOD_5, Fig (4), the dependence of media thickness, has shown negative dependence. Whereas, Fig (4), shows positive linear dependence of recycle ratio. Irrespective to the coefficients that are related to the linear terms in eq. (6), the coefficients that are related to nonlinear terms (i.e., X_1 and X_3) have shown significant nonlinear dependence. This was simply notified by examining the coefficients of X_2^2 and X_2^3, which means no significance was contributed. This was assured by examining Fig (3) where the dependence was found linearly.

Optimum conditions are found equal to –1.732 for the flow rate, -1.732 for the recycle ratio and 1.608 for the thickness of the media.

Once more examine eq. (6), it can be seen that all three interaction terms have significant effect on the objective variable and they posses interference effect on each other which are simply ascertained from monitoring Figs (5) to (7) where a great tendency for their curves to change their trends was noticed.

Examining Fig (7) shows the best performance was found when the media thickness was maximum (i.e. 1.732) and recycle ratio was equal to –1.732, whereas Fig (6) sponsored the best performance at flow rate equal to –1.732 and media thickness also at maximum value (i.e. 1.732). While, from Fig (5) it was found that the optimum condition was found equal to flow rate at 1.732 and recycle ratio equal to –1.732. These observations for the best optimum conditions in the three figures were matched. Therefore, the optimum condition would match in coded values of -1.732 for the flow rate, -1.732 for the recycle ratio and 1.732 for the media thickness. These optimum conditions were coincided with previously determined optimum conditions (flow rate = -1.732, recycle ratio = -1.732 and media thickness = 1.6079).

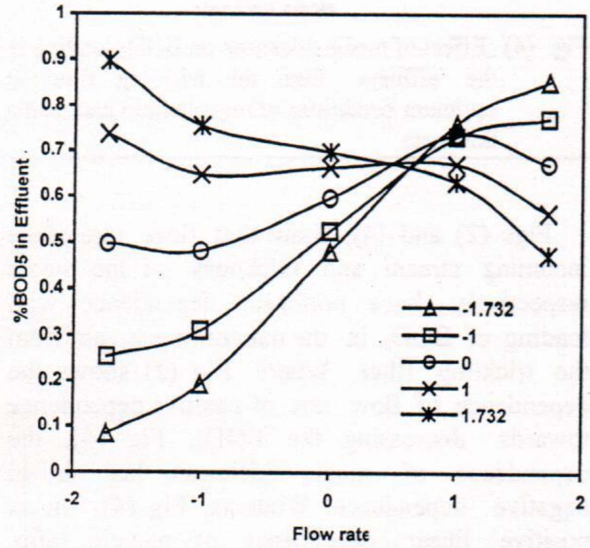

Fig. (5) Effect of flow rate and recycle ratio on BOD_5 of the effluent from the trickling filter at optimum condition of media thickness

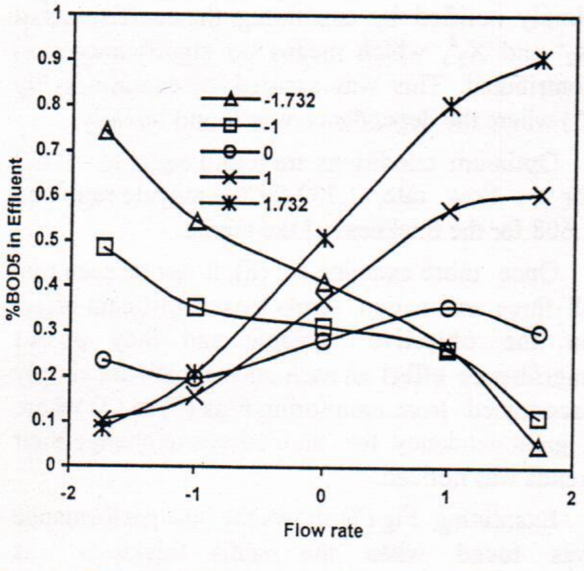

Fig. (6) Effect of flow rate and media thickness on BOD_5 of the effluent from the trickling filter at optimum condition of recycle ratio

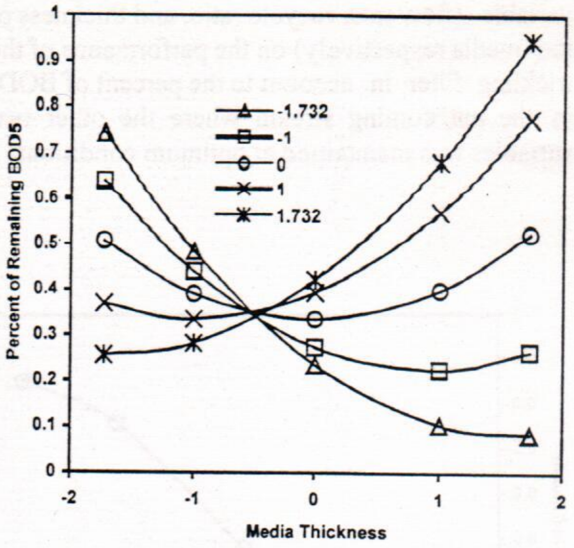

Fig. (7) Effect of media thickness and recycle ratio on BOD_5 of the effluent from the trickling filter at optimum condition of flow rate

Analyzing Fig (5), it was shown that there was a significant interaction between flow rate and recycle ratio especially in the range between 0.5 and 0.75 where the curves were reversed its trend or an inverse course was occurred. Besides different courses were noticed, these are as follows; for the recycle ratio equal to 1.732 and 1, the trend of their curves tends to decrease the BOD_5 with increasing flow rates. Where other values (i.e., lower values of recycle ratio) the course was inverted upside down since the BOD_5 values were increased in the effluent with increasing values of flow rates. At the highest values of the recycle ratio (i.e., 1.732) the increasing in performance with flow rates was contributed to higher values of mass transfer coefficients that was endued as the aerobic layer becomes thinner with higher velocities. Also higher values of recycle ratio with higher values of flow rates would increase the growth rate of the organisms inside the aerobic film since the filter medium was aerated vigorously. Whereas, the lower values of the recycle ratios (i.e. 0, -1 and –1.732), shows decreasing in trickling filter performance with increasing the flow rates as they attributed to the scouring of the organisms. Furthermore, increasing the velocities will match lesser residence times inside the biological reactor. Eventually, the worst operating condition was found equal to 1.732 recycle ratio and –1.732 flow rate.

Examining Fig (6), it was found once more that there was a significant interaction between flow rate and media thickness. Herein, the two extreme limits of the flow rates (i.e. −1.732 and 1.732) that conjugated with opposite extreme limits of the media thickness (i.e. 1.732 and −1.732 respectively) shows higher performance as in the two operating conditions with the same environments would occur inside the reactor (two closely matched optimum points were found, i.e. two valleys). The first optimum operating condition that was occurred at flow rate equal to -1.732 and media thickness equal to 1.732, was attributed to long residence time whereas the second operating condition was found at flow rate equal to 1.732 and media thickness equal to -1.732, was attributed to the fact that 90 % reduction of the biodegradable 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 flow rate with lower media thickness), and by the usual processes of synthesis and respiration from the part of the flow with long residence time (low flow rate with higher media thickness).

In Fig (7) the curves are intersected sharply at about −0.5 media thickness. Low value of performance was found at 1.732 recycle ratio and 1.732 media thickness which correspond to the lowest performance of the trickling filter as was previously found in Fig (6) (i.e., 1.732 recycle ratio and −1.732 flow rate).

CONCLUSIONS

It has 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 biochemical oxygen demand was achieved.

Typical data are presented and interpreted in terms of various conditions. The process was operated under various conditions of feed rate, recycle ratio and bed height, which have shown significant interaction between these three variables in terms of the objective variable (i.e. % biochemical oxygen demand). Besides a significant nonlinearity dependence was found relative to the flow rate and media thickness whereas linear dependence was found in account to recycle ratio

NOMENCLATURE

BOD	Biochemical Oxygen Demand
B_{ii}	Coefficient of the estimated model
e_i	Residual of the ith experiment: $e_i = y_i - \acute{y}_i$
H	Media thickness in eq (4)
L	Flow rate in eq. (2)
R	Recycle Ratio in eq (3)
X_k	Coded variable X for element k
y_i	Response for the ith experiment
$\acute{y}_i$	Estimated response for the ith experiment
ε	Random Error Component

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