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RECIRCULATION IN TRICKLING FILTERS

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اعادة المياه المعالجه فى المرشحات الزلطيه

تعتبر اعاده المياه المعالجه فى المرشحات الزلطيه من أقل العوامل المؤثره فى ميكانيكيه المرشحات لمعالجه مياه المجارى. واعاده مياه المجارى المعالجه فى المرشحات الزلطيه يعنى زياده الحمل الهيدروليكى مع ثبات الحمل العضوى على المرشحات ونقص فى التركيز العضوى.

وفى هذا البحث تم تقسيم التركيز العضوى المطبق على المرشحات الزلطيه الى قسمين:

- الأول عندما يكون التركيز منخفض وهنا تكون العلاقه الأسيه لازاله المواد العضويه من الدرجه الأولى.

- والثانى عندما يكون التركيز عالى وفيه تكون العلاقه الأسيه لازاله المواد العضويه من الدرجه صفر بالنسبه لتركيز المواد العضويه.

ولقد تم دراسه اعاده المياه المعالجه تحت هذين القسمين نظريا وعمليا باستخدام تحليل نتائج بعض الباحثين الآخرين وكما أنه تم بحث تأثير اعاده المياه المعالجه على كفاءة المرشحات الزلطيه باستخدام معادلة اكنفلدر وتبين من الدراسه الآتى:-

١- أن اعاده استخدام مياه المجارى المعالجه يؤثر سلبيا فى كلتا الحالتين المذكورتين بعاليه.

٢- أثبت استخدام معادله اكنفلدر أن تأثير اعاده مياه المجارى المعالجه على المرشحات الزلطيه يعتمد على خصائص الوسط الترشيحى المستخدم N وثابت المعادله V وبالتالى فان نوع الوسط يجب أن يؤخذ فى الاعتبار عند استخدام اعاده المياه المعالجه فى التصميم.

٣- بتطويع نتائج أبحاث بعض الباحثين لاستبيان تأثير اعاده المياه المعالجه على كفاءه المرشحات فى ازاله الملوثات العضويه عضدت ما ذكر فى ١ ، ٢.

ABSTRACT

Recirculation is the least understood of factors that affect on the mechauism and performance of the trickling filter. When recirculation is used, this works out in to applying almost the same organic mass to the trickling filter but with the increased hydraulic rate and a lower organic concentration than without recirculation.

In this analysis, the organic concentration was divided into low organic concentration where the first order kinetic prevails and high organic concentration where the zero order kinetic predominates. The effect of recirculation on trickling filter performance under the two kinetic conditions were studied theoretically and by manipulating other researchers data found in the literature. The effect of recirculation on the trickling filter performance using design models was also investigated.

The results of the study showed that:

1- Under both kinetic conditions, recirculation affects the removal efficiency of trickling filters negatively.
2- Eckenfelder design model (the most widely accepted model) showed that recirculation effect on trickling filters performance depend on the media characteristics and the tredtability constant.
3- Manipulated results from other researchers experimental works confirmed the above findings.

KEYWORDS
Wastewater, Trickling Filters, Recirculation, Organic Mass, Organic Concentration, Hydraulic Loads, Fixed Film.

INTRODUCTION

Trickling filters are one of the oldest methods of biological treatment of domestic and industrial wastewater. They have been in use since the late 1800 s when they were introduced in England. Trickling filters are used as a secondary treatment process for purifying wastewater. They are contact beds of a solid support medium on the surface of which mixed microbial populations in the form of a slime become attached. Organic removal is achieved by trickling the wastewater over the solid support medium arranged in the form of a packed bed.

Many models have been proposed to describe the efficiency of the removal of organic material in trickling filters by the fixed film. However it has not been possible with these models to explain accurately the true mechanisms of the trickling filter. The two main reasons for the problem in understanding of the trickling filter process and the difficulties in describing it mathematically are : the hydraulic flow pattern in the trickling filter is very complicated, and the substrate is very complex and variable in a domestic sewage.

Several factors affect the trickling filter performance e.g. : organic loading, hydraulic loading, recirculation, temperature, characteristics of applied wastewater, volume and geometric shape of the filter medium, void fraction, air recirculation, the composition of the microorganisms, and the specific surface area of the medium. These factors complicate the modeling of the trickling filter organic removal efficiency.

Recirculation is the least understood of all the factors that affect the mechanism and performance of tricking filters. Although, it was reported in the literature that recirculation improves the trickling filter performance, the minimal or even deleterious effects of increasing the recycle ratio have been identified in several references (Metcalf and Eddy Inc. 1979).

It is the purpose of this paper to study, theoretically and by manipulating other researchers experimental result, the merit of using recirculation in the trickling filter process.

TRICKLING FILTER REMOVAL MECHANISM

In recent years investigators have initiated studies aimed at elucidating the mechanism of purification in trickling filters.

They agree on the important parameters of trickling filter bed to consist of the following (figure 1):

1- The supporting surface;
2- The slime layer which is divided into aerobic and anaerobic layers;

3- The liquid film which is divided into stagnant layer and running layers, and;
4- Liquid-air interface.

Maier et al. (1967) stated that the removal of impurities in waste depends on the mass transfer of the organics from the liquid film to the slime layer. They assumed that the fixed film reactor system is mass transfer limited which may occur when the rate of use of the substrate at the slime liquid interface is faster than the rate of transfer of the substrate from the bulk of the liquid film to the liquid-biofilm interface.

Williamson and McCarty (1976) equated the difference between the mass transfer of the substrate into and out of the differential element in the biofilm with the amount of substrate utilized by the microorganisms which exist in the differential element. They obtained a second order nonlinear ordinary differential equation. In their model, they defined conditions under which either organics substrate (electron donor) or oxygen (electron acceptor) may be flux or substrate (metabolism) limiting within a microbial film.

Jennings et al., (1976) tried to modify williamson and McCarty's model (1) and combined that with a plug flow model through a biological filter using some dimensionless parameter and Monod nonlinear expression for the substrate utilization rate, they obtained an analytical solution representing a first and zero order behavior of the substrate utilization.

Harris and Hansford (1976) used a modified expression for Monod equation, which takes into consideration the effect of both oxygen and organics on the microorganisms growth rate. Their model was derived by equating the substrate transferred from the bulk of the liquid to the slime liquid interface with the substrate diffused into the biofilm. They obtained two secondary differential equations for both oxygen and organics utilization rates. They solved their equation numerically by trial and error.

Another model was proposed by Rittmann and McCarty (1980) for predicting a minimum substrate concentration below which a steady state biofilm cannot exist, i.e., the substrate flux and the biofilm thickness are zero. In this model, they considered both growth and decay rates of the bacteria composing the biofilm. They classified the biofilm according to its depth into a shallow and a deep biofilm. For the shallow biofilm, which exists at a very low organic concentration, the reaction order is higher than one. This is because increasing the organics concentration leads to a greater biofilm thickness as well as substrate removed.

From the above explanations for trickling filters substrate removal mechanism it can be concluded that the rate of substrate utilization can be classified into three kinetic behaviors according to the substrate concentration as follows:

a) At very low organic concentration:
There is a minimum concentration below which no significant biofilm activity occurs at a steady state condition (4). In this case, the thickness of the biofilm decreases as the concentration decreases and approaches zero as the substrate concentration approaches its minimum level.

b) At low organic concentration:
In this case, Oxygen is not flux and substrate limiting and organics

are flux and substrate limiting. The increase of organics concentration in the bulk liquid will lead to an increase of the substrate flux into the biofilm and more utilization could be achieved, meaning that the rate of substrate utilization is dependent on the substrate concentration. The reaction order, under this conditions, is considered a first order kinetic with respect to organics concentration.

c) At high organics concentration:
Here, oxygen start to be flux limited (due to oxygen concentration limitation, maximum about 5 to 7 mg/l in the bulk liquid) and the organic removal rate reaches its maximum level. This means that increasing the organics concentration will have no effect on its removal and accordingly the efficiency will decrease. The reaction order under this condition could be considered as zero order behavior with respect to the organics concentration.
Figure (2) represents the three kinetic behaviors for the substrate utilization versus concentration.

RECIRCULATION
In trickling filter process, there are several possible conditions of flow rates with respect to organics concentration such as :-

1- Constant flow rate while organic concentration increases.
2- Flow rate increases with constant organic concentration, and
3- Flow rate increases while the organic concentration decreases.

Both the first and the second conditions had been investigated experimentally and given close attention by different researchers (1, 2, 3, and 4). Their findings of the trickling filter performance under these two conditions can be summarized as follows:

When the flow rate is constant and the organics concentration increases the percent removal efficiency will be independent of the organics concentration up to the level where zero order behavior pertains. Above that level, the percent removal efficiency of the organics will be dependent on the organics concentration and an increase of the concentration leads to a decrease in the percent removal efficiency.

When the flow rate increases while the organics concentration is constant, two constraints could affect the performance of the trickling filter:

1- Organics are flux limited
This condition prevails at organic concentration below the level at which first order kinetics prevails. The increase of flow rate will reduce the stagnant layer depth. Decreasing the stagnant layer will lead to an increase of the flux of the organics and increase the substrate removal. On the other hand, the mass load applied increases with increase of the flow rate and the net result will be a decrease in the percent removal efficiency. As further increases are made in the flow rate additional increases of mass transfer become negligible so that no benefits occur to offset the negative effect of the decreased contact time.

2- Oxygen is flux limited
This condition exists when the zero order behavior prevails. Increasing the flow increases the oxygen flux through the stagnant layer. On the other hand, the thickness of the liquid film will increase and the transfer for oxygen from the air liquid interface to

the liquid stagnant layer interface will be less. This effect, besides reducing the liquid detention time in the filter, will lead to a decrease in the mass of the substrate removal.

The condition of increasing the flow rate and decreasing the organic concentration, the third condition, represents the recirculation process.

Based on the review conducted herein for the different mechanisms describing the removal of substrate by trickling filter, the functional effect of the recirculation process can be clarified. This can be achieved by looking at the trickling filter operation at different flow rates and organics concentrations under two conditions:

1- At low organics concentration

At low organics concentration, organics are flux limiting while there is no oxygen limitation in the biofilm. Increasing the flow rate by recirculation (the mass load is considered constant) will lead to two opposite trends : a) a decrease of the stagnant layer thickness and accordingly an increase in the organic flux, and b) a decrease in the organics concentration and accordingly reduction in the mass transfer into the biofilm. The net results for both effects, under the same condition of wet surface area may cause reduction of the organic removal this can be detected from manipulating the experimental data obtained from Maier et al., (1967) presented in Table 1.

Table (1) : Recirculation effect on trickling filter performance under low organic concentration.

Q/min	Concentration mg glucose/1	Applied mass load mg/10 min	Organics mass removed mg/10 min
445	90	40.05	6.8
1000	40	40	5.2

From the above table, the second flow is approximately two times the first flow, i.e. recirculation ratio 1:1, and the applied mass load is almost the same. The net removal with recirculation was less without recirculation.

2- At high organic concentration waste

At high organic concentration, zero order behavior prevails and oxygen is the flux limiting factor. Increasing the flow, in contrast, will reduce the contact time and oxygen concentration will not increase beyond 8 mg/1, and the performance of the trickling filter will deteriorate. Table 2 with data obtained from Harris and Hansford (1976) represents evidences for this condition.

Table (2) : Recirculation effect on trickling filter performance under high organic concentration.

Flow rate 1/hr	Recirculation Ratio	Substrate concentration mg/1	Mass load applied mg/hr	Substrate removed mg
6	0	4000	24	6.0
12	1	2000	24	5.6
18	2	1300	24	5.8
24	3	1000	24	5.2

From the above discussion, and based on the experimental data used, it is clear that recirculation deteriorate the removal efficiency of trickling filters. However, there are some advantages of adopting recirculation in trickling filter such as increasing the wet surface area at low flow rates, dilute toxic waste, and increase the dissolved oxygen concentration in the bulk liquid.

TRICKLING FILTERS DESIGN MODELS AND RECIRCULATION

Models developed earlier did not explain the process reactions occurring in tricking filters. They were purely empirical. However, later models did attempt to consider rate limiting factors effect on substrate removal in the biofilm reaction. But due to the complexity involved, most trickling filters are designed by rules of thumb.

Several models have been proposed to describe the degradation of organic matter in streams. Velz (1948) proposed the first formulation delineating fundomental law as contrasted to previous empirical attempts based on data analysis. The Valz formula related BOD remaining at depth D as following:-

$$S_e = S_o\, e^{-KD} \qquad (1)$$

where

S_e = BOD concentration at the effluent.
S_o = BOD concentration at the influent.
K = removal rate constant
D = filter depth.

Eckenfelder, (1963) proved that "K" (removal rate constant) is not constant but is proportional to $1/D^m$ where m is an exponent on filter depth indicative of biological slime distribution with filter depth.

Eckenfelder considened the time of liquid contact with the biological mass is directly proportional to the filter depth and inversily proportional to the hydraulic loading rate as will as the effect of changes in filter depth on BOD Removal per unit of depth. Eckenfelder proposed the following equation:

$$S_e / S_o = e^{(-KD^m/Q^n)} \qquad (2)$$

where: n = Exponent characteristic of filter media.

Eq. (2) is considered the most useful equation in designing trickling filters. In most of the text books, the effect of recirculation on designing trickling filters, using the above equation, is usually accomplished by either one of the following equations (3) {Clark et al., (1977)} or (4) {Steel and McGhee (1979), and Metcalf and Eddy (1979)}.

$$S_e/S_o = e^{(-KD^m/Q^n)} / (1+R) - R\, e^{-KD^m/Q^n} \qquad (3)$$

OR

$$S_e/S_o = [(1+(S_e/S_o)R)/1+R]\, e^{-KD^m/(Q+Qr)^n} \qquad (4)$$

Where : R= Recirculation ratio and Qr = recirculated flowrate

Using equation (3), when designing trickling filter does not represent the real condition of flow in the trickling filter bed. The flow rate is no longer Q but (Q + Qr). Therefore, the removal ratio will be changed. The effect of recirculation is represented correctly in equation (4).

Applying equation (3) for different R, m, n, and K will indicate that recirculation improves the performance of trickling filter. On the other hand, using equation (4) will indicate that the recirculation effect depends on the values of K, and n as given in figures (3 a, b, and c). The value of n and K for different types of media were obtained from Clark et al. (1977). The figures illustrated that recirculation reduces the effluent organics concentration using media used in figure a, while recirculation have no effect when using media used in figure b. On the other hand, the effluent characteristics deteriorate drastically when applying recirculation for media used in figure c.

The above findings were proved by manipulating the experimental data presented by Wu and Beckman (13). The effect of K, m and n on the trickling filter removal efficiency at different recirculation ratio for two types of plastic media were also conducted. Table (3), illustrates the experimental manipulation and the theoretical calculation of the effect of recirculation on the performance of trickling filters using Equations 3 and 4.

CONCLUSION

Because more than one factor can limit the reactions occurring in trickling filter, organics modeling is very complicated.

In the investigation conducted in this study for some of the models suggested by researchers it was concluded that the substrate removal mechanisms in trickling filter followed three kinetic behaviors:

1- Higher than first order at very low substrate concentration.
2- First order at low concentration.
3- Zero order at high substrate concentration.

Two conditions with regard to organics concentration were investigated. At low organics concentration, organics are the limiting factor and recirculation increases the organic flux by reducing the stagnant layer thickness. At the same time, decreasing the organics concentration by recirculation reduce the mass transfer into the biofilm. At high organics concentration, oxygen is the limiting factor and recirculation will not increase the oxygen concentration beyond its maximum concentration. In both cases recirculation does not improve the trickling filter performance.

When using Eckenfelder equation in predicting the effect of recirculation on the trickling filter performance, media characteristic, n, treatability constant, k, and the expondent for filter depth m are play important roles in predicting the performance of trickling filter.

Manipulating the experimental results in all cases investigated showed that little to no improvement in reducing effluent organics concentration was realyed when recirculation in trickling filter plants is employed.

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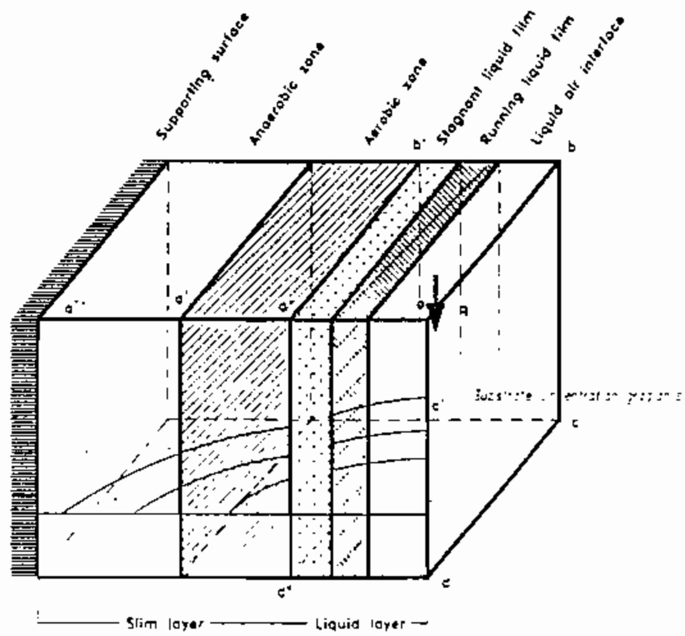
Table (3) : Experimental and modeling verification for the effect of recirculation for different media

Media type	Set of results	Q	Experimental Results						Model prediction (eq. 3)			Model prediction (eq. 4)		
		m^3/m^2-hr	Influent BOD_5 mg/l	Effluent BOD_5 mg/l	Recircu-lation ratio I:	Organic mass applied gm/m^3-hr	organic mass removed gm/m^3-hr	Removal eff. %	Effluent BOD_5 mg/l	Mass removed gm/m^3-hr	% Removal	Effluent BOD_5 mg/l	Mass removed gm/m^3-hr	% Removal
Vinyle core	1	0.76 1.24 1.63	97.5 78.6 64.2	45.9 42.4 40.2	0.00 0.63 1.14	74.10 97.46 104.65	39.20 44.88 39.12	53.0 46.0 37.0	42.3 27.9 24.8	38.15 62.90 64.20	51.5 74.5 61.4	47.3 45.1 44.4	38.15 48.50 32.30	51.5 42.6 30.5
media m = 0.2782	2	0.76 2.29 2.58	101.2 64.7 59.1	47.1 46.7 43.6	0.00 2.01 2.40	76.90 148.00 152.50	41.12 41.22 39.99	53.0 28.0 26.0	47.8 21.7 21.1	40.96 95.47 98.04	53.3 66.5 64.3	47.3 42.8 42.2	48.96 50.19 43.62	53.3 33.9 28.6
k = 3.516 n = 0.682	3	0.69 1.82	77.6 49.1	39.6 31.8	0.00 1.64	53.50 87.50	26.20 29.60	49.0 34.0	34.9 18.35	29.50 54.10	55.0 62.0	34.9 33.1	29.50 27.30	55.0 31.2
Biodek 27060	1	0.98 2.29 2.58	111.3 64.7 59.1	42.8 32.2 30.6	0.00 1.34 1.63	109.10 148.10 152.50	67.13 73.28 73.52	61.5 49.5 48.0	44.8 24.9 22.7	6.17 91.10 94.00	59.8 61.5 61.6	44.8 34.5 33.2	65.17 69.15 66.88	59.8 46.7 44.0
media m = 0.042	2	1.00 1.24 1.78	90.8 78.6 65.7	38.4 33.9 29.6	0.00 0.24 0.78	90.80 97.50 117.01	52.40 55.80 64.30	57.8 56.8 54.5	36.8 32.2 25.2	5.00 57.50 72.10	59.5 59.0 61.6	36.8 34.7 34.2	54.00 54.40 56.20	59.5 55.8 48.0
k = 1.608 n = 0.367	3	0.76 1.61 1.63	101.2 59.2 64.2	36.1 24.5 28.7	0.00 1.12 1.14	76.9 95.3 104.6	49.50 55.20 57.80	64.0 58.0 55.0	32.3 21.9 21.7	63.80 60.10 69.20	63.0 63.1 66.0	37.3 29.7 29.2	63.80 47.50 57.00	63.0 50.0 51.0



Fig(1)- ELEMENTAL VOLUME OF SLIME AND LIQUID

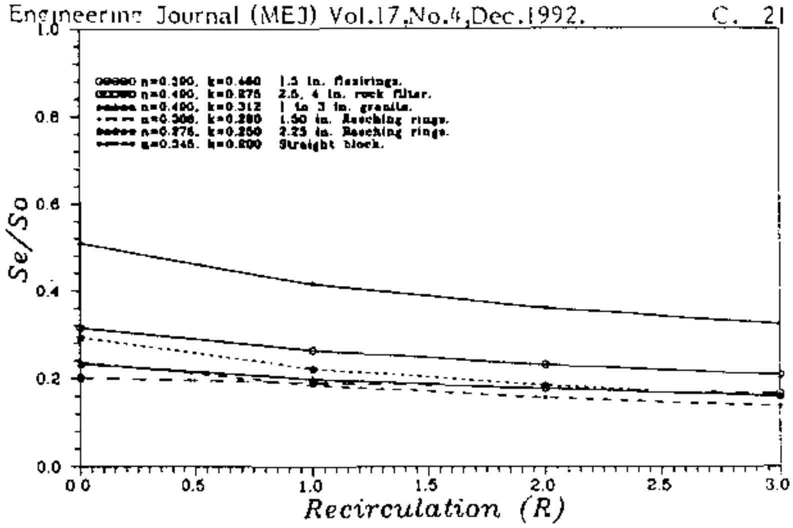


Fig. (3-a)

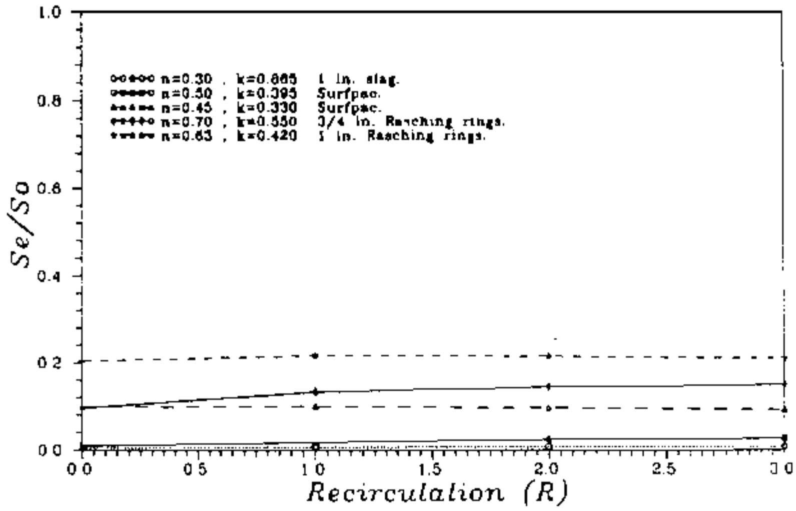


Fig. (3-b)

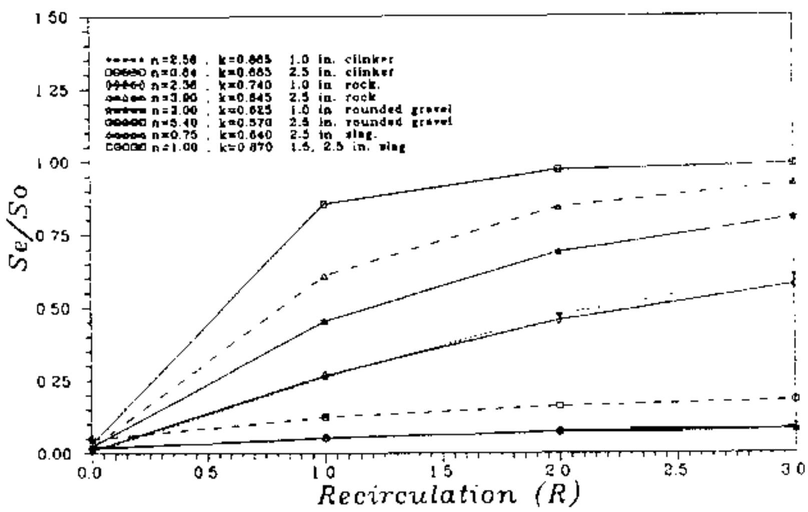


Fig. (3-c)