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IMPACT OF INDUSTRIAL DISCHARGE ON THE PERFORMANCE OF A BIOLOGICAL POTW – MODEL DEVELOPMENT

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ABSTRACT

This paper describes the development of a mathematical model and its application for predicting the dimensions of an industrial wastewater pretreatment system, and its comparison with alternative solutions. The model is based on pseudo first order kinetics for both the municipal and the industrial wastewater, and also on the Monod kinetics for the industrial wastewater. In the combined treatment process the biomass is taken as a mixture of specialist microorganisms capable of degrading target compounds. The kinetic rate of the combined stream is taken as the weighted average of the reciprocal K values. The model was used to compare the alternative treatment schemes and the main conclusions were: (1) pretreatment of industrial wastewater is always the most efficient alternative, and (2) an optimal VSS concentration exists in the pretreated effluent, leading to the most efficient treatment system. Experimental studies aimed at validation of this model are strongly recommended. © 1997 IAWQ. Published by Elsevier Science Ltd

KEYWORDS

Industrial wastewater; biological treatment; pretreatment; combined treatment; mathematical model.

INTRODUCTION

Wastewaters from many industries contain organic pollutants of various biodegradability characteristics. Direct discharge versus municipal sewer discharge depends, among other things, on its effect on the POTW performance. This, in turn, determines the pretreatment needs or the expansion of the POTW. This paper describes the development of a mathematical model and its application for predicting the pretreatment facility's dimensions, and its comparison with alternative solutions. The alternatives include expansion of the POTW or direct discharge of the industrial wastewater after separate treatment.

The principal objective of the model is to predict the performance of an activated sludge treatment plant fed by a mixture of waste streams, if the biodegradability characteristics of both waste streams are known. The major assumptions used for this model are:

- municipal wastewater biodegradation rate follows the pseudo first order kinetics, due to its multi-substrate composition of zero order degradation components;

- industrial wastewater biodegradation rate can be similar in nature to that of the municipal's, but it can also follow the Monod kinetics, if it is composed of one predominant component;

- biomass in an activated sludge system is comprised of "specialist" microorganisms capable of degrading target compounds only (Chudoba *et al.*, 1989; Ellis *et al.*, 1995). Hence, in a POTW treating municipal and industrial wastewater two separate biomass populations will exist;

- cometabolism does not occur i.e. both wastewaters are considered as growth limiting substrates, and no inhibition or any other interaction between the two biomasses is taking place.

It is well known that not all these assumptions are valid for all municipal/industrial wastewater combinations. In many cases the latter two assumptions are far from reality, and its solution must be based on treatability studies or other sources of data for the specific situation. However, it is believed that there are cases for which these assumptions are reasonable and the model is justified. In any case experimental studies aimed at validation of this model are strongly recommended.

MODEL EQUATIONS

Basic biodegradation kinetics

The key model equation related to the activated sludge process treating a multicomponent wastewater is the pseudo first order kinetics based on the assumed multi zero-order substrate (Tichler and Eckenfelder, 1969; Grau *et al.*, 1975; Adams *et al.*, 1975). Under a non-segregated flow regime the conversion of a zero order reaction in a CSTR is the same as in a PFR (Argaman, 1991; van Niekerk *et al.*, 1987). Thus, assuming that the curve fitted equation of a batch test BOD removal data is a second order equation, the CSTR performance is expressed as

$$S_e = \frac{S_o^2}{S_o + K\,X_v t} \tag{1}$$

where

S_0 = influent concentration of degradable organics, mg/l
S_e = effluent concentration of degradable organics, mg/l
X_v = concentration of active biomass in the reactor, mg/l
K = biodegradation rate coefficient, day^{-1}
t = hydraulic residence time, day

In the present model equation 1 is used for all the municipal and some of the industrial wastewaters. For industrial wastes consisting of one major component the Monod kinetics is used, and the effluent concentration is given by the solution of a quadratic equation:

$$S_e = \frac{S_o - K_s - q_{max} X_v t + \sqrt{(q_{max} X_v t + K_s - S_o)^2 + 4 K_s S_o}}{2} \tag{2}$$

where

q_{max} = maximum specific removal rate, day^{-1}
K_s = half saturation constant, mg/l

When equation 1 is used for pretreated industrial waste, the K coefficient in the second treatment stage is related to its original value by

$$K_{pi} = K_i \frac{S_{pi}}{S_{oi}} \tag{3}$$

where

K_{pi} = rate coefficient for pretreated industrial wastewater, day^{-1}
K_i = rate coefficient for raw industrial wastewater, day^{-1}
S_{pi} = substrate concentration of pretreated industrial wastewater, mg/l
S_{oi} = substrate concentration of raw industrial wastewater, mg/l

Equation 3 is appropriate for a second stage treatment where an intermediate secondary clarifier exists between the two stages , leading to the development of a biomass specifically acclimated to the substrates remaining in the first stage effluent. Without an intermediate clarifier the second stage's kinetic coefficient is proportional to the squared ratio of the pretreated to raw substrate concentrations.

Combined wastewaters treatment kinetics

In an activated sludge system treating combined industrial and municipal waste streams a mixed acclimated culture will develop, consisting of an industrial wastewater biomass, and a municipal wastewater biomass. Assuming that the observed yield coefficient of the two wastewaters are nearly equal, and since the two microbial cultures have the same SRT, the biomass composition may be expressed by

$$\frac{X_{vi}}{X_{vm}} = \frac{S'_{oi} - S_{ei}}{S'_{om} - S_{em}} \tag{4}$$

where

X_{vm}= municipal waste's "specialist" biomass, mg/l
X_{vi} = industrial waste's "specialist" biomass, mg/l
S'_{oi} = industrial substrate concentration in the combined influent, mg/l
S'_{om}= municipal substrate concentration in the combined influent, mg/l
S_{ei} = industrial substrate concentration in the combined effluent, mg/l
S_{em} = municipal substrate concentration in the combined effluent, mg/l

and the combined biomass concentration is expressed as

$$X_v = X_{vi} + X_{vm} \tag{5}$$

The effluent concentration in a combined wastewater system is calculated as the sum of the two effluent substrates:

$$S_{ec} = S_{ei} + S_{em} \tag{6}$$

where S_{ec} = substrate concentration in the combined effluent, mg/l

The effluent concentration of the municipal substrate is calculated by equation 1 for municipal influent:

$$S_{em} = \frac{S'^2_{om}}{S'_{om} + K_m X_{vm} t} \tag{7}$$

where K_m = municipal wastewater degradation rate constant, day^{-1}

The effluent concentration of the industrial substrate, in a non-pretreated system is calculated as:

$$S_{ei} = \frac{S'^2_{oi}}{S'_{oi} + K_i X_{vi} t} \tag{8}$$

and in a system with pretreated industrial waste stream:

$$S_{ei} = \frac{S'^2_{pi}}{S'_{pi} + K_{pi} X_{vi} t} \tag{9}$$

where S'_{pi} = concentration of pretreated industrial substrate in the combined influent, mg/l.

Using an average K term, the combined effluent concentration can be expressed by

$$S_{ec} = \frac{S'^2_{oc}}{S'_{oc} + K_c X_v t} \tag{10}$$

where

S'_{oc} = substrate concentration in the combined influent, mg/l
K_c = average rate coefficient of the combined influent, day^{-1}

Based on equations 7, 8, and 10, and using the biomass and substrate correlations as expressed in equations 4, 5, and 6, the following equation is obtained:

$$\frac{S'_{om}}{K_m t} + \frac{S'_{oi}}{K_i t} = \frac{S'_{oc}}{K_c t} \tag{11}$$

Since the substrate concentration in the combined stream is proportional to the original concentration multiplied by the dilution factor, equation 11 can be rearranged to:

$$\frac{1}{K_c} = \frac{\frac{1}{K_m} Q_m S_{om} + \frac{1}{K_i} Q_i S_{oi}}{Q_m S_{om} + Q_i S_{oi}} \tag{12}$$

where

Q_i = industrial wastewater flowrate, m^3/day
Q_m = municipal wastewater flowrate, m^3/day

Equation 12 shows that the combined K is a weighted average of the reciprocal K values of the two components, with the weight being equal to the flowrate times concentration product.

Effect of pretreatment effluent VSS on combined treatment

In general, the pretreated industrial waste stream contains some VSS which is composed mainly of a biomass from the biological pretreatment of the industrial wastes. This VSS will affect the composition of the biomass in the combined treatment system following the pretreatment. Under these conditions the industrial biomass concentration will be expressed by the following equation, rather than equation 4:

$$X_{vi} = X_{vm} \frac{(S'_{pi} + \frac{X'_{vep}}{a} - S_{ei})}{(S'_{om} - S_{em})} \qquad (13)$$

where

X'_{vep} = pretreatment effluent VSS concentration in the combined stream, mg/l
a = yield coefficient

MODEL APPLICATIONS

The model was applied to a variety of alternatives in which both municipal and industrial wastewaters are to be treated. In each case three alternative treatment schemes, as shown in Figure 1, were compared quantitatively. In all cases the municipal wastewater characteristics were the same, while the industrial's kinetic coefficients were varied over a wide range. The BOD was selected as the substrate characterization parameter. The wastewaters quantity and quality characteristics selected for the present analysis are given in Table 1. Model application was based on a simultaneous solution of the process equations relevant to the specific alternative.

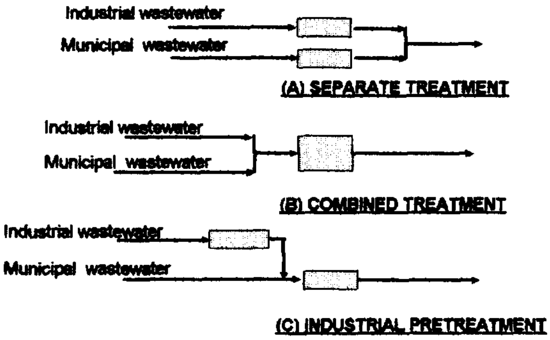

Figure 1. Alternative treatment schemes.

Table 1. Wastewater characteristics used in model application

Parameter	Municipal Wastewater	Industrial Wastewater	General
Flowrate, m3/day	20,000	3,000	23,000
Raw WW BOD, mg/l	150	1000	
K rate, day^{-1}	10	2.0 - 20.0	
q_{max}, day^{-1}	N/A	0.2 - 2.0	
K_s, mg/l	N/A	10	
MLVSS, mg/l			3,500
Effluent SBOD, mg/l			20

Case I - New industrial and municipal plants

A comparison of the three treatment alternatives when the municipal and industrial wastewater treatment plants do not exist, is shown in Figure 2. In the separate treatment alternative the required effluent SBOD from each of the two plants was set at 20 mg/l. In the pretreatment alternative, the BOD removal at the pretreatment plant was set at 75 percent. As seen in Figure 2 the most effective alternative, in terms of total reactors volume, is the industrial pretreatment system, and the least effective is the separate treatment system. The effect of pretreatment level on total reactors volume is shown in Figure 3. It shows that in this system the optimal pretreatment removal level is around 70 percent. The optimal removal level seems to increase as the industrial removal rate coefficient is increasing.

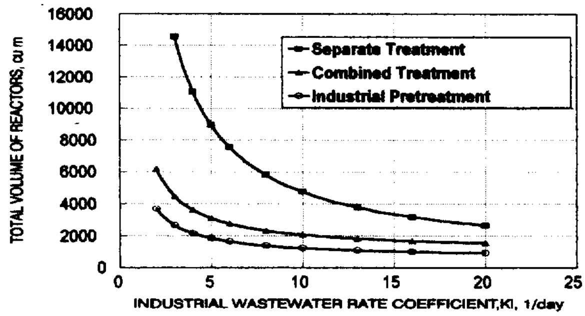

Figure 2. Volume requirements in alternative treatment schemes - Case I conditions.

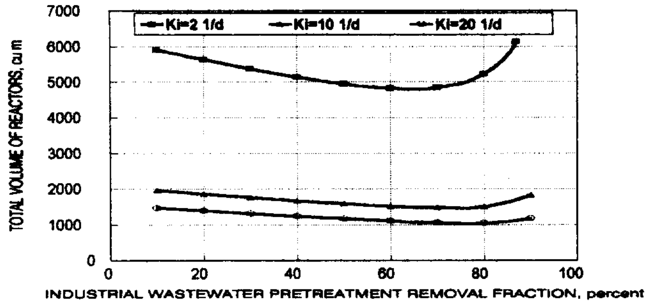

Figure 3. Effect of pretreatment removal fraction on total reactors volume - Case I conditions.

The effect of pretreatment effluent VSS on total reactors volume is shown in Figure 4. When the industrial's rate is higher than the municipal's, the optimal level is zero. For industrial wastewater with lower rates the optimal value increases with decreasing rate coefficient. In Figure 4 the optimal value for Ki = 10 day^{-1} is around 100 mg/l, while for $K_i = 2.0$ day^{-1} the optimal value is higher than 500 mg/l.

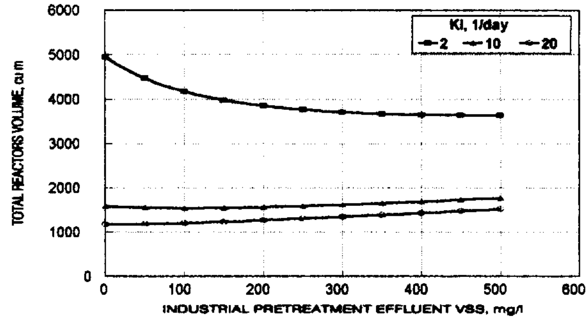

Figure 4. Effect of pretreatment effluent VSS on total reactors volume - Case I conditions.

A comparison of the three treatment alternatives was made for the more common case in which the municipal wastewater treatment plant already exists, and the industrial wastewater treatment problem has to be solved. In this case the two wastewaters quantities and qualities were also taken as shown in Table 1, with an existing municipal treatment plant of 1200 m^3. The municipal plant could achieve an effluent SBOD of 10 mg/l when treating the municipal wastewater only.

In this case the performance requirement in the separate treatment alternative was an average effluent SBOD of 20 mg/l in the combined effluent stream, rather than in each one of the separate effluents. In the pretreatment alternative the BOD removal in the pretreatment unit was not a fixed value as in Case I, but was determined as needed for achieving the effluent quality.

Case II - Existing municipal wastewater treatment plant

Results of these calculations are shown in Figure 5. As can be seen in this figure, the most effective alternative is the pretreatment system with biomass released from the pretreatment unit into the combined treatment unit (typically $X'_{vep} \geq 50$ mg/l). The required volume addition in the plain pretreatment alternative, without industrial biomass contribution, is exactly equal to that of the separate treatment alternative when the industrial rate coefficient is 6.0 day^{-1} or less. In this range of K_i the required BOD removal in the pretreatment system is such that the biomass in the following combined system is 100 percent municipal. When the industrial rate coefficient is equal or higher than the municipal one, the pretreatment alternatives with or without industrial biomass release are the same. The combined treatment has nearly equal volume requirements as the separate one, although it is somewhat less effective at the low K_i range, and somewhat more effective at the high K_i range. For a given industrial wastewater, and an existing municipal system, the pretreatment volume requirement varies with varying pretreated effluent VSS. A minimum volume and a maximum industrial pretreated effluent BOD exist, as shown in Figure 6.

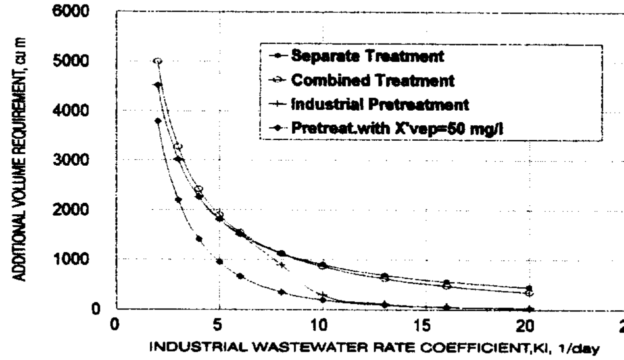

Figure 5. Additional volume required with existing municipal plant of 1,200 m^3 - Case II conditions.

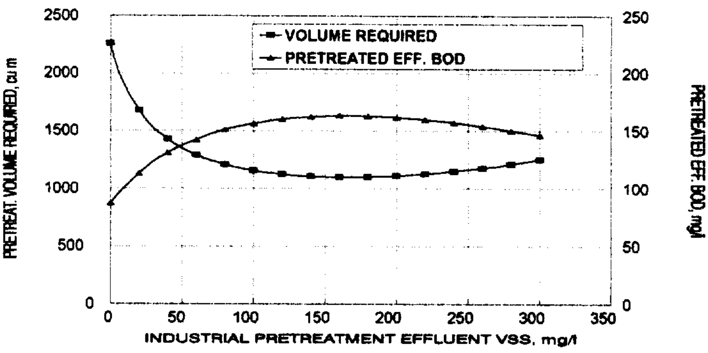

Figure 6. Effect of pretreatment effluent VSS on additional volume requirement - Case II conditions Ki=4 d^{-1}.

For industrial wastewater composed of one major substrate component the Monod kinetics were used, and the volume requirements at the treatment alternatives are shown in Figure 7. In this case the combined treatment was considerably less effective than all other alternatives which were nearly equal. This is because in the combined treatment the industrial effluent BOD must be much lower than in the other alternatives, and in the Monod kinetics the required SRT is related to the effluent concentration's absolute value.

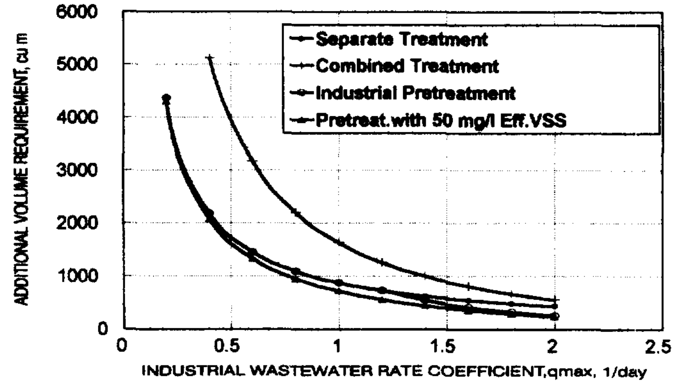

Figure 7. Volume requirements in alternative treatment schemes with Monod kinetics for industrial wastewater.

SUMMARY AND CONCLUSIONS

A mathematical model was used to examine the alternative treatment schemes of municipal and industrial wastewaters. In Case I, when both plants are under design and each stream has to meet the effluent quality limit, pretreatment of the industrial wastewater prior to combined treatment is the most efficient scheme. Separate treatment is the least efficient, and the combined treatment is of intermediate efficiency. In Case II, when a municipal treatment plant already exists, industrial pretreatment is also the most efficient solution, particularly for the more readily degradable industrial wastewater. For a lesser degradable industrial wastewater, the pretreatment efficiency is affected by the discharge of VSS from the pretreatment system, and there is an optimal concentration of that VSS. Separate and non-pretreated combined treatment alternatives are of nearly equal efficiency under the Case II conditions. For industrial wastewater following the Monod kinetics combined treatment is the least efficient alternative while all others are nearly equal. The main conclusions from these model applications are: (1) pretreatment of industrial wastewater is always the most effective scheme in terms of total reactors volume, and (2) pretreatment effluent VSS is desirable at an optimal concentration, depending on wastewater characteristics and operational conditions. These conclusions are based on a theoretical model, and experimental studies aimed at validation of this model are strongly recommended.

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