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PREDICTION OF EFFLUENT POLLUTION LEVEL IN ACTIVATED SLUDGE SYSTEMS

II. THE EFFECT OF RECIRCULATION AND RECIRCULATION RATIO

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The paper describes substrate removal and biomass production in activated sludge wastewater treatment systems with special attention to the effect of recirculation. Applicability of the models presented is verified experimentally.

In our previous paper (Holló and Donáth-Jobbágy, 1980) we described a model suitable for the prediction of the concentration of a poorly biodegradable substrate in purified water, at a given influent concentration and dilution rate, based on batch laboratory experiments.

For a gradual approach to real circumstances, non-recycled systems were modelled first. Our current topic of investigation concerns the theoretical basis and description of the effect of recirculation and ratio of recirculation.

Modelling of Substrate Removal

An activated sludge wastewater treatment system working with sludge recirculation is schematized in Figure 1; V is the volume of culture in the reactor vessel, w stands for flow rate, S is the concentration of the given substrate and x the concentration of live cells.

For the symbolized ideal, continuous, perfectly mixed reactor the following material balance equation is valid in steady state:

$$V.\frac{dS}{dt} = w_1.S_o + w_2.S_i - (w_1 + w_2)S_{er} + r_S.V = 0 \qquad (1)$$

In case feeding, recirculation and effluent removal are interrupted, the reactor is batch operated; thus the consumption rate of the given substrate $r_s = \left(\frac{dS}{dT}\right)_{batch}$.

In our assumption, this equation is also valid (except for some special cases) for the continuous run, within a wide range irrespective of the value of dilution rate. Therefore, in steady state:

$$-r_s = -\left(\frac{dS}{dt}\right)_{batch} = \frac{w_1 S_o}{V} + \frac{w_2 S_i}{V} - \frac{w_1 + w_2}{V} S_{er} \qquad (2)$$

If substrate consumption in the settling tank is negligible and there is no substantial decrease in the water content of the settled sludge related to that measured in the reactor,

$$S_i \simeq S_{er} \simeq S_{es}, \qquad (3)$$

and thus,

$$-\left(\frac{dS}{dt}\right)_{batch} = \frac{w_1}{V} . S_o - \frac{w_1}{V} . S_{er} \qquad (4)$$

Considering equation (4), the absence of the recirculation flow-rate w_2 is remarkable. It seems as though the recirculation ratio w_2/w_1 would not affect the effluent pollution level (the value of S_{er}). This conclusion is, naturally, not acceptable as it is in contradiction with practical experience.

In order to elucidate the effect of recirculation, let us consider the following.

The reactor represented in Figure 1 is actually fed with a sewage substrate concentration $S_{o(real)}$ and $(w_1 + w_2)$ flow rate. Thus e.q. (4) may also be written as

$$-\left(\frac{dS}{dt}\right)_{batch} = \frac{w_1 + w_2}{V} . \underbrace{\frac{w_1 S_o + w_2 S_{er}}{w_1 + w_2}}_{S_{o(real)}} - \frac{w_1 + w_2}{V} S_{er} \qquad (5)$$

The straight lines defined by eqs. (4) and (5) intersect in the point $\left\{ -\left(\frac{dS}{dt}\right)_{batch,\ S_{er}} ;\ S_{er} \right\}$ (see Figure 2 and Holló and Donáth-Jobbágy, 1980).

Since these equations concern the same system, they must give the same solution. Therefore, the curve of $\left(\frac{dS}{dt}\right)_{batch}$ versus S will necessarily cross the intersection of the lines, yielding thus two identical S_{er} effluent substrate concentrations. Our previous experience in the removal of poorly biodegradable substances clearly indicated that the curves of $\left(\frac{dS}{dt}\right)_{batch}$ versus S belonging to different S_o starting substrate concentrations have different shapes. Therefore, the curve that crosses the intersection of the straight lines defined can belong to only one given S_o value. In our assumption this is $S_{o(real)}$. Thus, in eq. (4) the effect of the recirculation ratio is represented by $-\left(\frac{dS}{dt}\right)_{batch}$.

On the basis of the above, planning of the continuous experiments and evaluation of the results were made as follows:

With the use of $S_{o(real)}$ starting substrate concentration - to be applied as the $S_{o(real)}$ influent concentration in the continuous run - a batch experiment was carried out. Prediction of the effluent concentration was made from the substrate consumption curve obtained (see Figure 2 and Hollo and Donath-Kobbagy, 1980).

Modelling of Biomass Production

Concerning live cells, the steady state material balance equation for the ideal, continuous, perfectly mixed reactor is:

$$V.\frac{dx}{dt} = w_1.x_o + w_2.x_i - (w_1 + w_2)x_{er} + r_x.V = 0 \qquad (6)$$

Provided that the equation of multiplication rate $r_x = \left(\frac{dx}{dt}\right)_{batch}$ is also valid for the continuous run, for $x_o = 0$, eq. (6) can be written as

$$\left(\frac{dx}{dt}\right)_{batch} = \frac{w_1 + w_2}{V}.x_{er} - \frac{w_2}{V}.x_i \qquad (7)$$

Thus, prediction of the cell concentration x_{er} at a given $S_{o(real)}$ influent substrate concentration and a given dilution rate $D = (w_1 + w_2)/V$ was made as shown in Figure 3.

The multiplication curve of x against t was taken in a batch system with $S_{o(real)}$ (!) starting substrate concentration.

Applicability of the Models

In the experiments linear dodecyl benzene sulfonic acid (DBS) served as the sole carbon source and $NH_4H_2PO_4$ as the nitrogen source. The experiments were carried out in a laboratory-scale equipment, using activated sludge provided by a waste-water treatment plant. Values of all parameters given in Figure 1 were determined at each

Applicability of the models

The substrate S was n-dodecylbenzene sulphonic acid

S_o [mg/l]	$\frac{w_2}{w_1}$	S_{er} [mg/l] calculated	measured	$x_{er} \cdot 10^{-7}$ [No./l] calculated*	measured	$D = \frac{w_1 + w_2}{V}$ [h^{-1}]	$S_{o\,real}$ [mg/l]
30.6	0.43	2.50	2.34	359	305	0.013	22.0
30.8	0.44	2.60	2.51	360	300	0.018	22.0
30.6	0.41	3.00	2.95	360	360	0.029	22.0
35.4	0.71	2.50	2.31	356	340	0.014	22.0
35.5	0.69	2.60	2.51	357	360	0.018	22.0
35.3	0.68	3.00	3.06	360	350	0.029	22.0
35.6	0.76	4.90	4.84	348	350	0.065	22.0
40.5	0.92	2.50	2.34	362	365	0.013	22.0
40.5	1.00	2.70	2.51	359	335	0.019	22.0
40.4	0.96	2.95	2.87	360	345	0.028	22.0
40.8	0.95	4.15	3.89	355	325	0.056	22.0
40.4	1.10	4.90	4.84	353	335	0.065	22.0
44.5	1.12	3.00	2.72	355	300	0.029	22.0
22.0	1.01	2.50	2.45	294	300	0.063	12.2
22.2	1.01	2.70	2.65	289	285	0.093	12.2
22.2	1.06	2.72	2.62	290	275	0.097	12.2

*values calculated by using the measured values of x_i as input parameters

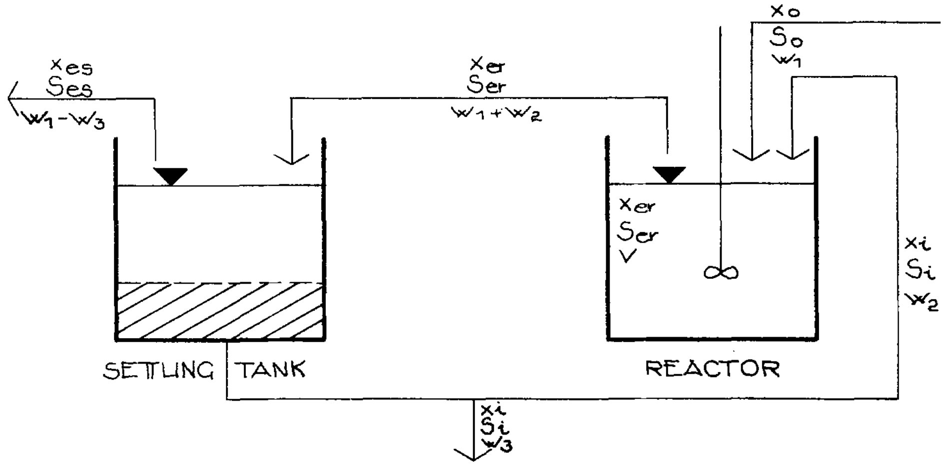

Fig. 1. Schematical representation of an activated sludge treatment system

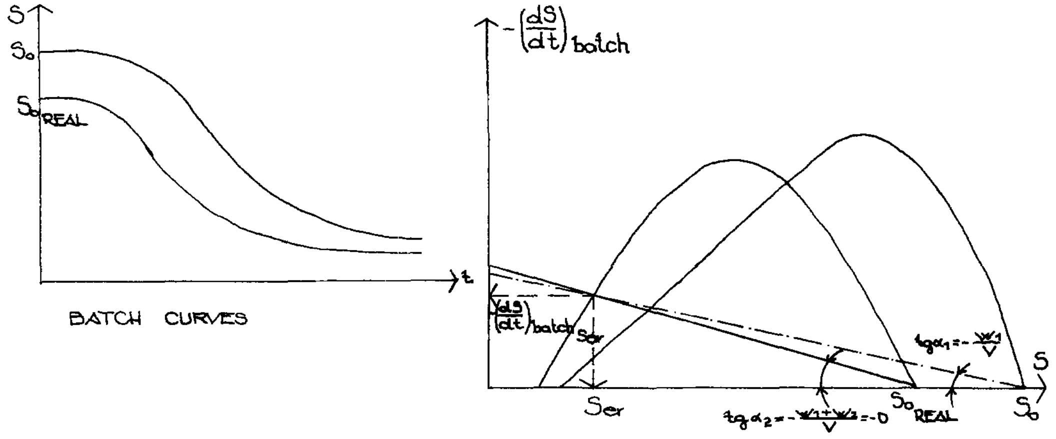

Fig. 2. Prediction of the effluent pollution level on the basis of batch experiments

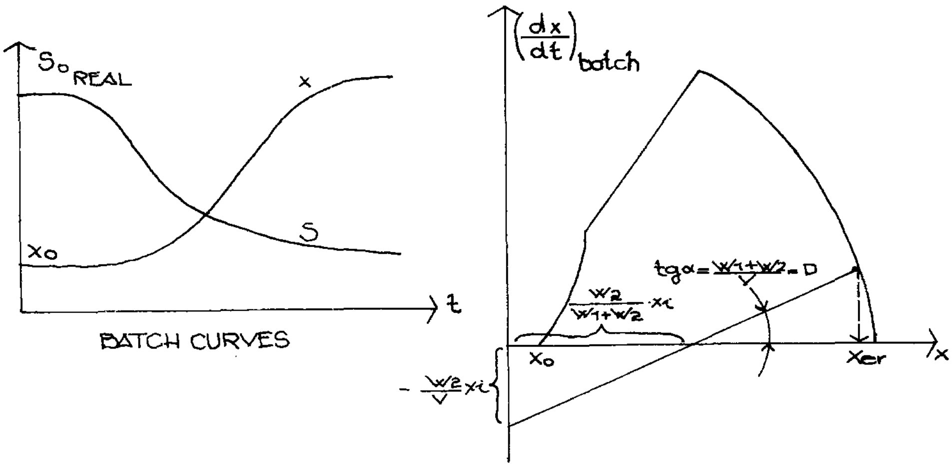

Fig. 3. Prediction of biomass production on the basis of batch experiments

s_o, w_1, w_2 datacombination applied. The assumption expressed by eq. (3) was verified by the results obtained.

Planning of the continuous experiments was as follows: first an influent concentration of DBS, S_o, and the corresponding value for effluent concentration S_{er} to be attained, were chosen. The value of $-\left(\frac{ds}{dt}\right)_{batch,\ S_{er}}$ was determined on the basis of the curve of $\frac{dS}{dt}$ versus S relating to the $S_{o(real)}$ concentration to be applied. The values of w_1 and w_2 were calculated by the definition of $S_{o(real)}$ and from equation (5).

The data presented in the table support the applicability of the models. In particular, it has been stated that S_{er}, the effluent concentration of a given substrate, is dependent only on the values of $S_{o(real)}$ and D. The recirculation ratio w_2/w_1 is included in $S_{o(real)}$, determining its value. Reduction of $S_{o(real)}$ at a given D leads to the decrease of S_{er}.

Our experience indicates that the models presented are adequate for planning treatment systems even if $r_i \neq \frac{dc_i}{dt}_{batch}$; this occurs, for example, if the poorly biodegradable substrate, non-existent in the perfectly mixed continuous reactor, is detrimental to the cells. In this case the necessary sections of the corresponding curves must be taken in a continuous run.

Reference

Holló, J., and Donáth-Jobbágy, A. (1980). Biotechnol. Letters, 2,55-60.