MATERIAL BALANCE IN SEWAGE TREATMENT

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Abstract

The most important characteristics of sewage purification is: cell retention time (CRT), sludge loading, ratio of recirculation or rather excess sludge removal. Of course, these parameters are in close connection with each other. To examine these connections, material balance seems to be the most suitable for either the aeration tank or for the aeration tank and sedimentation basin together. These equations are suitable to examine the method of sludge load, the most basic possibility of regulation, the ratio of recirculation and also the excess sludge can be determined.

Introduction

Our institute received an assignment to optimalize the solution of sewage treatment and disposal of a smaller region in Western-Hungary. As a part of this work we studied the operation of the largest sewage purification plant in the region ($Q \approx 35\ 10^3 m^3/d$) and the efficiency of the purification. Considering that in this plant such outlets can occur which exceed some limits (the maximum permitted COD is 75 mg/l here), we concentrated our efforts on the better reveal of the connection between the parameters describing sewage purification with activated sludge, for the sake of making a proposal for setting some operation parameters so that

- the prescribed outlet limits are kept,
- the balanced transport of material is guaranteed
- sludge bulking is prevented.

Examinations

Our examinations during operation were based on studying the special literature and on laboratory experiments. We studied:

- the effect of changing the method of activated sludge loading (the inlet of recirculated sludge or sewage),
- the effect of changing the size of sludge load (L_s) and in accordance with this;
- the effect of changing the concentration of activated sludge (C_s);
- the change of the concentration (C_R) and the discharge (Q_R) of recirculated sludge;

- the connection between cell retention time (Θ) and sludge wastage (Q_{sw}) in case of several circulation ratio;
- the load capacity of the (secondary) sedimentation basin and thickener in case of several values of sludge concentration, recirculation (R) and wastage (W) ratio.

In our examinations, of course, we regarded the aeration tank(s) and the secondary sedimentation basins as a unified system, considering that unless the load of suspended material coming from the preliminary sedimentation basin is too small ($L < 30$ mg/l), then the efficiency of the plant should be influenced by the concentration of suspended material too, and not only by the load of organic material dissolved [5]. The duty of the secondary sedimentation basin is double: from the point of view of outlet water the settling, and from the point of view of recirculation or excess sludge the thickening or preliminary thickening. In a technology with activated sludge it is significant from the point of view of load, how the activated sludge can be thickened [12]. (It can be proved by examining the material flux; the material rejection flux of suspensions decreases with the increasing concentration (Fig. 7)).

Sludge bulking has several reasons.

It can be caused by

- too little or too big sludge load;
- not proper aeration;
- the unbalance of feed (the ratio C:N:P),
- considerable deviation from the equilibrium pH value
- the change in temperature,
- too long time in preliminary sedimentation basin ($t > 2h$), which causes the deterioration of sewage,
- the raw and excess of sludge, staying in the preliminary sedimentation basin for a long time,
- if the raw sewage gets into the plant in decomposed condition (sewer storage), but that is the case if there is no possibility for the regulation inside the plant, that is why the method of regulation ensures a constant hydraulic load (Q = const) [4].
- the disadvantageous type of aeration tank as a biochemical reactor from the point of view of material flux;
- or any combination of the above conditions.

Sludge load

Sludge load, beside cell retention time, is one of the most important parameters of sewage purification on which, after all, the operation of purification, total or partial purification, nitrification depends. One can reckon with the most advantageous purification efficiency $-\eta = 90\%$ — if the sludge load is relatively high, $0.7 > L_s > 0.3$ (5, 10) so that this load serves the prevention of sludge bulking, too. In case of lower load the purification efficiency can be — theoretically — higher, but the long-yarn Filomentous organisms having the advantage of growing well even under feed-poor conditions (with relatively large surface comparing to volume) will cause sludge bulking.

From the respect of settling the lower (activated) sludge concentration, i.e. the higher sludge load is also advantageous.

Aeration

The extent of aeration is determined by the oxygen concentration demand. So it is not a constant value, but practically 10—12% of the saturation value of a given temperature [12].

It also means the input air (immersion of rotors, number of revolutions) must continuously be controlled, or at least periodically, to which the continuous determination of oxygen distribution profile is necessary.

Rate of feed

The ratio of the required feed balance C:N:P = 100:5:1 [12] is usually not realized. It is advantageous if the ratio P:N is growing — caused by the biological hydrolysis of phosphorus — which means the dominance of Acetinohakter organism in a certain period (at the beginning of the system) accompanied by some denitrification process. (The ammonium has inhibitor effect upon the biological hydrolysis of phosphorus). This requirement can technically be fulfilled if before aeration there is anoxic volume having a size one third of aeartion tank or one fifth of the secondary sedimentation basin [13].

Methods of loading

Rensink based on his wide-scale studies, considers the method of loading (i.e. the applied method of inlet of sewage and recirculated sludge into the basin) more important than the sludge load [11]. This statement is supported by the fact that the method of loading determines how the aeration basin as a biochemical reactor is operating between the states of completely mixed or plug flow reactor, and consequently what conversion capacity it has. Actually, the longitudinal dispersion, remixing must be described for which purpose as tracer exactly the pollutants are the most suitable to use.

If longitudinal dispersion is low, the sludge sedimentation is better. But the more-pass step-feed aeration basins correspond to a system with high longitudinal dispersion (Figs 1, 2, 3).

With the help of balance equations describing mass flow balance the methods of loading, occurring in sewage purification, the changes of the developing concentration of activated sludge (C_s), the distribution of average hydraulic retention time (t_i), the formation of sludge labour (S_L) and sludge loading (L_S) in the case of different loading methods (inlet methods) have been examined.

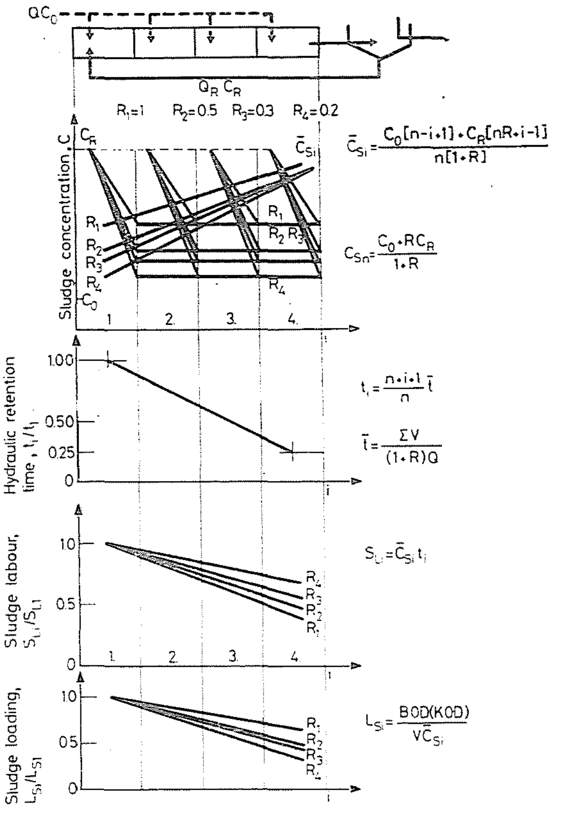

Fig. 1

Similarly to other authors [8, 9] after Monod we applied balance equations for the aeration tank. The variation of the suspended substances is:

$$\frac{dC_s}{dt} V = QC_0 + Q_RC_R + \mu C_sV - K_eC_sV - Q\,(1 + R)C_s \tag{1}$$

The variation of the quantity of the dissolved feed, i.e. infiltration into the cell-body is:

$$\frac{dS}{dt}V = QS_0 - Q(1+R)S_e - \frac{1}{Y}\mu C_s V \tag{2}$$

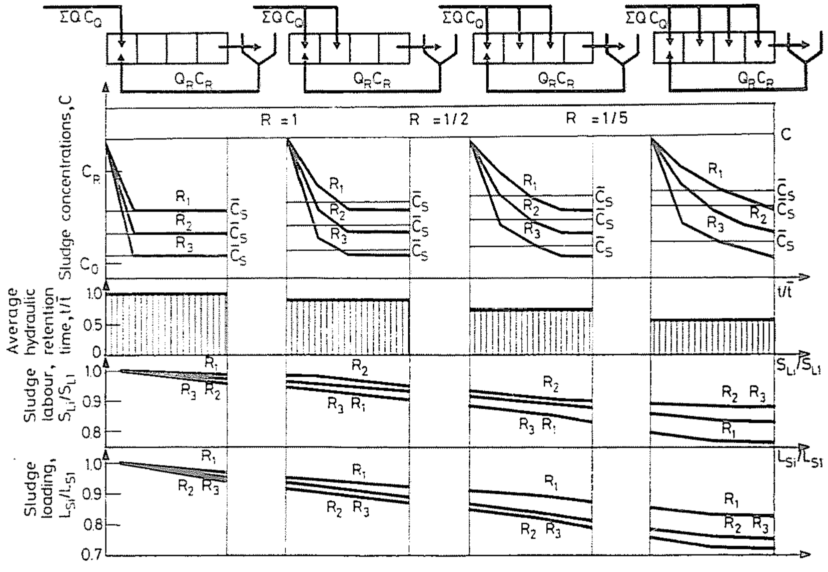

Fig. 2

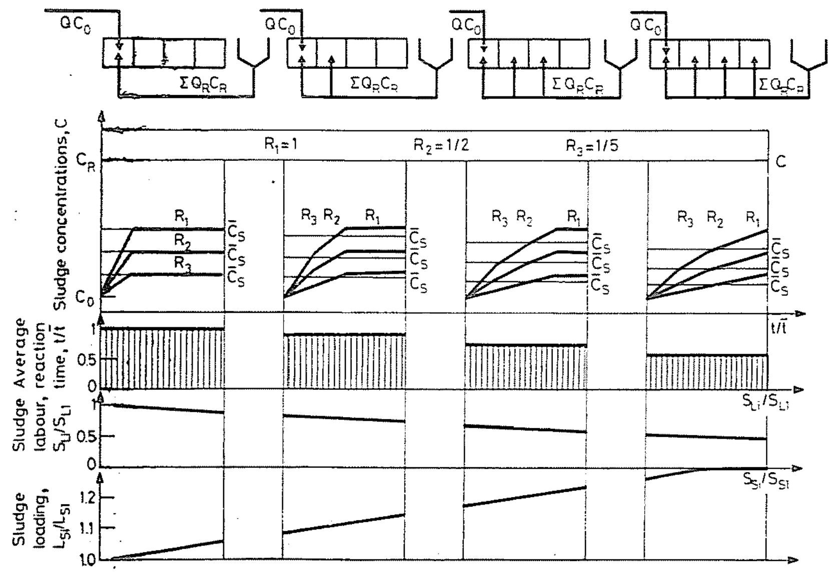

Fig. 3

where: C_s = concentration of activated sludge [kg/m³]
C_0 = concentration of suspended substance of the sewage getting into the tank [kg/m³]
C_R = concentration of recirculated sludge [kg/m³]
R = recirculation ratio [Q_R/Q]
μ = growth rate [$1/T$]
K_e = dissolvation (endogenic aearation) factor [$1/T$]
S_0 = initial dissolved feed concentration [kg/m³]
S_e = concentration of dissolved feed of outlet sewage [kg/m³]
Y = yield of cell material.

As in sewage purification with activated sludge the aim of excess sludge removal is just to ensure the balance, that is why:

$$S_w = \mu C_s V \left(1 + \frac{1}{Y}\right) = \mu' C_s V \tag{3}$$

or more accurately, removing the organic material becoming inert as excess sludge:

$$S_w = \mu' C_s V + K_e C_s V \tag{3a}$$

In this equation the smaller the second part at the right hand side (due to the decrease of K_e), the higher is the sludge load.

The balance of materials not remaining in solution, for the whole system of aeration tank and secondary sedimentation basin is as follows:

$$\frac{dC}{dt} V = QC_0 + Q_R C_R + (Q + Q_R)\, C_s = 0 \tag{4}$$

Getting the sewage inlet to the direction of the sedimentation basin (Fig. 1), the average concentration of the system considerably increases which is suitable to decrease the high sludge load and to prevent the sludge bulking. But this method is just a desultory solution, because the shorter retention time, i.e. the less sludge labour decreases the efficiency of purification. In the respect of sewage purification the best solution is to let both the sewage and the sludge into the tank No. 1.

Figure 2 shows a step feed method (dilution of sludge) which is in all respects unfavourable. Figure 3 demonstrates the gradual concentration of sewage during which the average sludge concentration of the whole system gradually decreases, the sludge loading increases.

On Figure 4 the results of the examinations on loading methods are summarized. From this it can clearly be seen that in the most advantageous case, the plug flow reactor is best approximated if both sewage and sludge are let into the first aeration casket. If this cannot be solved, let the sludge inlet be divided, but in the least possible measure.

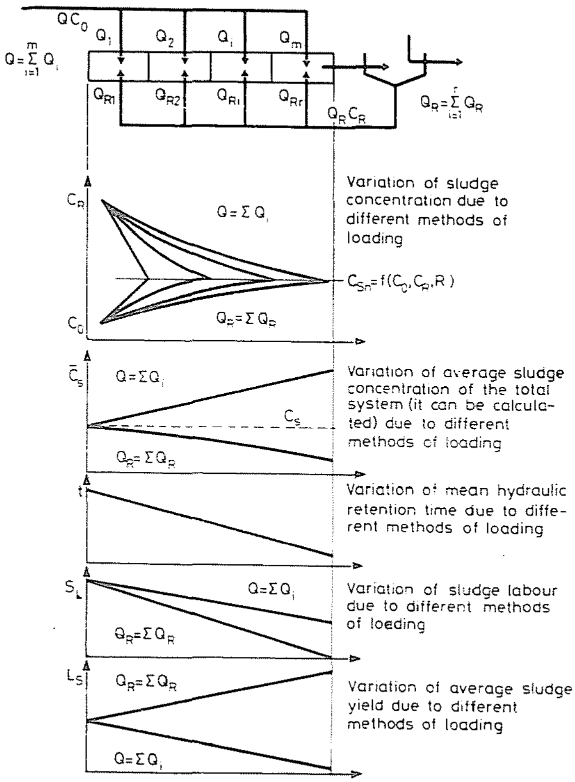

Fig. 4

Aeration tanks of operating plants which were formerly designed to be totally mixed, can be modified so that all the inlet would be at the first part of the tanks or a mixer tank should also be built where the recirculated sludge and sewage are mixed and afterwards flow like a plug. (According to Rensink this contact tank should be square-shaped.)

Efforts for the plug flow has other advantages, too. The not aerated just mixed contact tank is useful to remove biological N and P, and to adjust feed ratio [7]. It integrates more duties in one structure so that the processes are separated from each other not in space but in time.

Cell retention time (CRT)

The cell retention time, the ratio of the removed excess sludge and of all the suspended matter in the system can generally be described by the following balance equation:

$$\Theta[d] = \frac{V_L C_s + V_u C_u}{(Q - Q_{sw}) C_E + Q_{sw} C_{sw}} \qquad (5)$$

where V_L = volume of aeration tank [m^3]
V_u = volume of sedimentation basin [m^3]
C_s = activated sludge concentration [kg/m^3]
C_u = average concentration in sedimentation basin [kg/m^3]
Q = discharge [m^3/d]
Q_{sw} = discharge of excess sludge [m^3/d]
C_E = suspended matter concentration of water leaving the secondary sedimentation basin [kg/m^3]
C_{sw} = concentration of sludge taken from the thickener sump of secondary sedimentation basin [kg/m^3]

Further on, considering

$$C_R = C_{sw}$$

$$C_u \simeq C_S$$

and from Eq. (4)

$$C_s = \frac{R\,C_R}{1+R} \tag{6}$$

and $C_E \ll C_R$,

and $W = \dfrac{Q_{sw}}{Q}$

$$R = \frac{Q_R}{Q}$$

$$T = \frac{Q}{V}$$

suitably arranging Eq. (5) we get

$$\frac{R}{(1+R)W} \tag{7}$$

or

$$\frac{C}{WC_R} \tag{8}$$

High cell retention time is needed in total biological purification. If there is no nitrification, CRT can be lower. One can expect sludges which can be well sedimented if CRT is high, $\Theta > 8$ days, or if CRT is low $\Theta < 2$ days. So in the case of high load, sludge bulking can be prevented by short CRT. It also means a low recirculation ratio, and at least 2% excess sludge removal (Fig. 5).

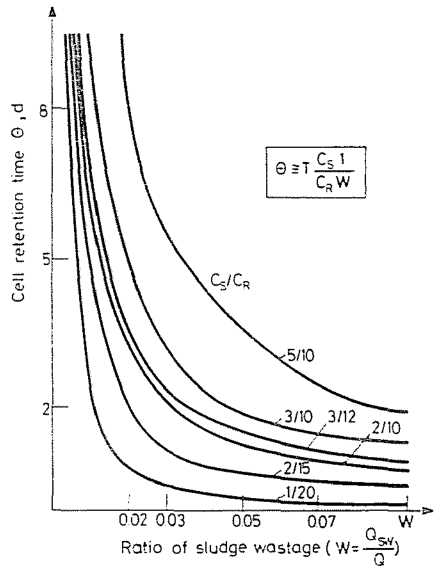

Fig. 5

Sludge recirculation

According to the equation of balance (4) applied for the activated sludge tank:

$$Q \cdot C_0 + Q_R \cdot C_R = (Q + Q_R)\, C_s$$

Let us take into consideration that generally

$$C_0 \ll C_s < C_R.$$

So, the needed sludge recirculation which is necessary to ensure the required continuous sludge concentration, is by the rearrangement of Eq. (6) as follows:

$$C_R = C_s \frac{Q + Q_R}{Q_R} \tag{9}$$

which shows that at a fixed ratio R the process operates itself. If Q increases, C_R increases too, until the load of the sedimentation basin as a thickener, is able to take it [10].

So, the mass flow RC_R must be ensured and it does not necessarily mean a high recirculation rate, quite to the contrary, a high recirculation rate supposes a thin sludge, otherwise (according to the equation of balance) the activated sludge concentration increases and sludge load decreases. And instantly the danger of sludge bulking may occur.

Thus, the recirculation rate should be as low as possible, so low that the mass balance both in the activated sludge tank and in the secondary sedimentation basin can be kept ($R = 0.2-0.4$).

The surplus sludge

The amount of sludge wastage necessary to keep the retention time is automatically given by the determination of CRT (Fig. 5), but it can also be expressed by the biochemical production Equs. (1) and (2):

$$S_w[\mathrm{kg/m^3}, d] = (bv_s - K_e)C_s \cdot s + (C_s \cdot s' - C_E)\frac{Q}{V} \tag{10}$$

where the terms not yet discussed are as follows:

b = biological yield constant (~ 0.6)

s = the organic part of the activated sludge

s' = the inert organic part of activated sludge.

The relationship between specific excess sludge discharge and the parameters of Eq. (10) can be seen on Fig. 6. The volume of excess sludge expressed by dry substance depends on the operation of secondary sedimentation basin:

$$Q_{sw} = \frac{S_w}{C_{sw}} \tag{11}$$

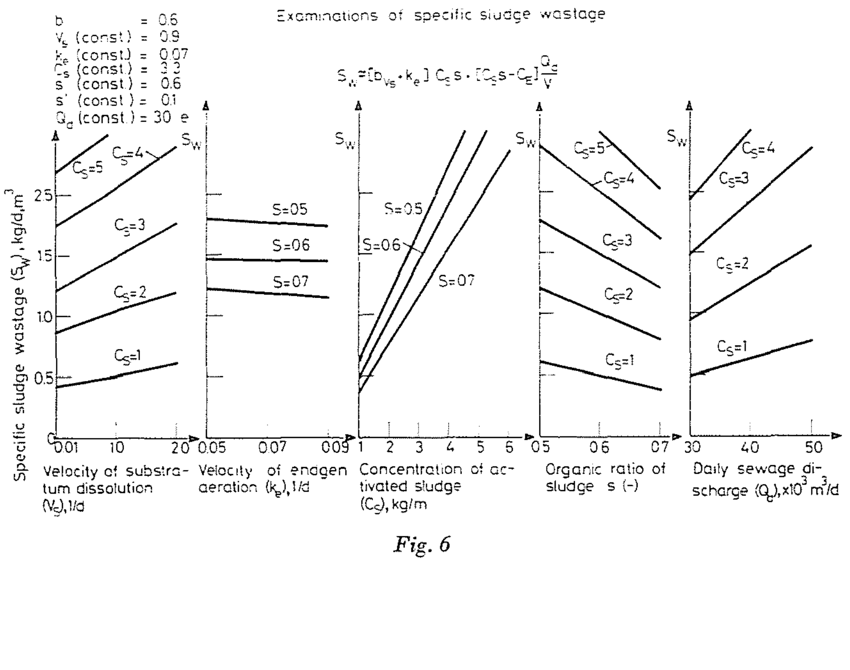

Fig. 6

Secondary sedimentation basin

The operation of the secondary sedimentation basin is a definitive factor of sewage purification with activated sludge and primarily from the point of view how the excess or the recirculated sludge can be concentrated. Namely, the dry substance loss of the thickening over unit area (flux) determines the maximum surface load of the sedimentation basin. This flux depends on the settling velocity of the suspension, this being the function of the concentration [10]. So during the progress of thickening the settling velocity continuously decreases (Fig. 7) that is why the substance loss over unit area is decreasing, too.

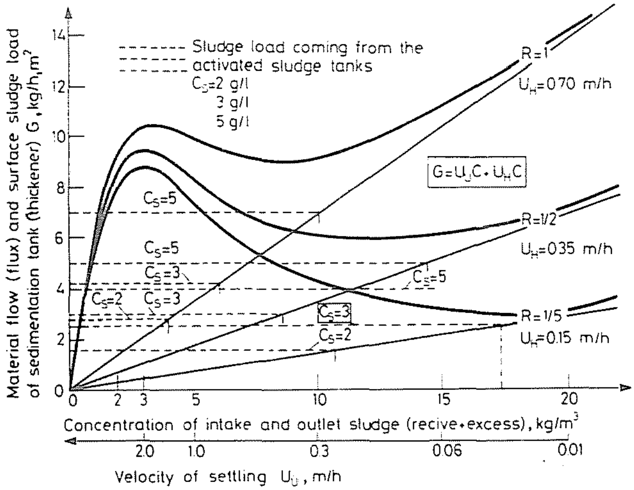

Fig. 7

Beside the sedimentation, the total flux is determined by the material flow taken from the sedimentation basin or thickener, i.e. by the discharge of the recirculated sludge.

To each recirculation ratio different material loss flow, or surface sludge load of sedimentation basin is belonging.

If the sedimentation basin is intended to be completely utilized, but not overloaded (because it causes sludge bulking) then the surface load must be equal to the total flux of sedimentation basin/thickener.

In a particular case this condition can be best approximated by the values $C_s = 3$ g/l, $R \simeq 0.3$. In this case the concentration of recirculated sludge is expected to be $C_R \approx 15$ g/l (Fig. 8).

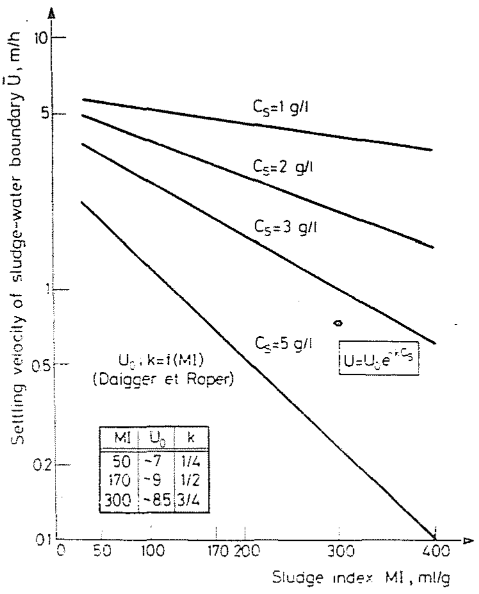

Fig. 8

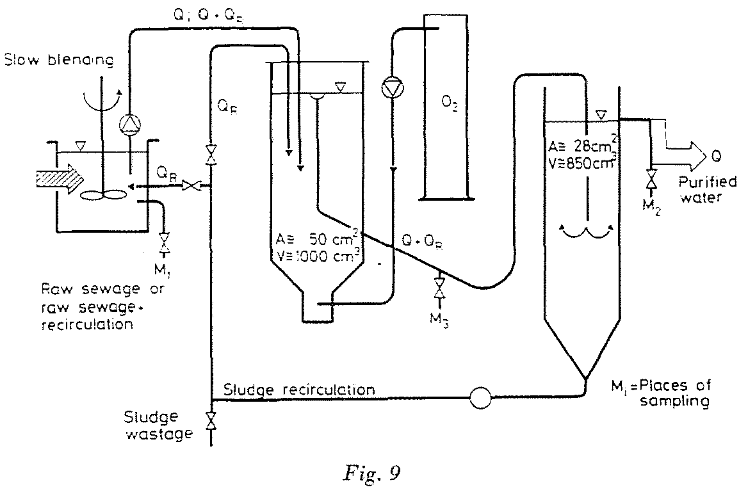

Fig. 9

Laboratory model experiments

Laboratory experiments were also completed on the field of sewage purification with activated sludge to control the above theoretical studies. The equipment applied can be seen on Fig. 9.

During the experiments, the equipment was filled with preliminary settled sewage taken by two hours corresponding to the hydraulic retention time of the model and different values of activated sludge concentration and recirculation ratio were adjusted.

Plug flow operation was modelled so that the recirculated sludge was not let directly back to the aeration reactor, but into a preliminary mixer (contact) tank. In this tank the mixture of sewage and recirculated activated sludge was blended by a slow mixing and was let into the aeration tank.

Conclusions

Summarizing the theoretical and laboratory investigations, a proposal was made for the most suitable operation parameters of a sewage purification plant:

- sewage inlet (Q) 1500 m^3/h
- sludge concentration (C_s) ~ 3 kg/m^3
- recirculation (Q_R) 4—500 m^3/h
- excess sludge (Q_w) 7—800 $m^3/d = 8 \cdot 9 \cdot 10^3$ kg/d
- concentration of recirculated sludge (C_R) 12—15 kg/m^3
- sludge load (L_S) ~ 0.5 kg/m^3 BOD/d · kg
- efficiency of expected purification (η) 93% [3]
- the inlet of sewage and recirculated sludge should not be divided but in the first casket of a row of tanks,
- in these caskets of tank there should not be aeration, just mixing.

The testing of these parameters under real operation conditions is under way.

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