6.3.3 Optimisation of the reactor - settler system

The optimisation of the reactor-settler system has two aspects:

(1) When the activated sludge plant is designed, certain values are assumed for the settling constants k and v_0 and the design optimisation is carried out for these values. The problem is that the values of the constants tend to fluctuate considerably in time. Therefore, for conservative design, the chosen values must be such that liquid-solid separation will be efficient, even under adverse conditions (Section 6.6). This design approach will be discussed here

(2) Once the plant has been constructed (on the basis of the optimised design) and been put into operation, the actual settling constants at any time may be different from the values adopted for design. Hence a different problem is posed, namely to carry out the operational optimisation of the plant, which means to choose the optimal operational conditions for the actual values of k and v_0 (Section 6.4).

In the previous sections it was shown that it is possible to rationally design an activated sludge settler for specified values of the inlet and return sludge concentration if the settling constants k and v_0 are known. The objective of settler design optimisation is to determine values for X_r and X_t, such that the activated sludge process has a good operational stability, the efficiency of liquid-solid separation in the final settler is high, while total costs are minimum. These costs consist of construction- and operational costs.

The former is defined mainly by the volumes of the aeration tank and the settler. The aeration tank volume is inversely proportional to the sludge concentration and the settler volume increases exponentially with this concentration if the critical recirculation factor is applied. The important factor that determines the operational costs is the value of the recirculation factor: at larger return sludge flow rates, the pumping costs will increase. The optimisation procedure for settler design involves the optimisation of two operational variables: X_t and s. These two then define a third variable X_r by Eq. (6.10). In principle, the chosen recirculation factor will be equal to s_c, unless there is a reason why this value cannot be applied. Thus the following optimisation procedure is suggested:

(1) With the aid of Fig. 6.9 determine the value of the critical recirculation factor s_c as a function of the sludge concentration X_t;

(2) Initially it is assumed that the critical recirculation factor may be used for design optimisation. This allows the clarification expressions to be used for calculation of the volume of the settler i.e. Eq. (6.33) can be used:

$$v_d = S_f \cdot (H/v_0) \cdot \exp(k \cdot X_t)$$

Note that the same settler volume is obtained when the thickening expression Eq. (6.34) is used, which is to be expected for the critical recirculation factor where both thickening and clarification are limiting processes;

(3) Use Eq. (3.51) to calculate the aeration tank volume per unit of influent flow:

$$v_r = mX_t \cdot S_{ti}/X_t$$

(4) The v_r and v_d values as well as their sum $v_t = v_r + v_d$ are plotted as a function of X_t, the sludge concentration in the aeration tank, and the minimum value of v_t is determined. The corresponding sludge concentration is in principle the optimal value, assuming construction costs per m^3 of settler volume are equal to those of the biological reactor. If not, it is easy to multiply v_d and v_r with their respective cost indices (refer to Chapter 10);

(5) For the optimal sludge concentration determine the critical recirculation factor s_c and verify if the actual retention time in the settler is within the desired range between approximately one and three hours (Eq. 6.35);

(6) If the retention time in the settler is too long there are two options: (l) increase the recirculation factor s to a value larger than the critical value and/or decrease the sludge concentration X_t below the optimal value, thus accepting less than optimal operation and/or construction costs, but designing a system with an adequate retention time in the settler. In practice the operational value of s will be larger than the value of s_c, in order to prevent accidental overloading of the settler should the influent flow rate increase or the sludge concentration be somewhat higher than anticipated. The additional pumping costs will be small and the penalty associated with exceeding the effluent limits or overloading the settler will be much larger.

As an example, in Fig. 6.10 the values of v_r, v_d and v_t are shown plotted as functions of the sludge concentration in the aeration tank X_t for the following conditions: $s_f = 2$; H = 4m; $S_{ti} = 0.5 g.l^{-1}$ and $mX_t = 2$ mg TSS.mg^{-1} COD.d^{-1}. This mX_t value corresponds to a sludge age of about 8 days in the case of raw sewage (Eq. 3.51). In Fig. 6.10, three characteristic pairs of Vesilind constants were considered:

(a) Poor settleability: k = 0.46 l.g^{-1} and $v_0 = 6$ m.h^{-1} (Fig. 6.10a);
(b) Medium settleability k = 0.36 l.g^{-1} and $v_0 = 9$ m.h^{-1} (Fig. 6.10b);
(c) Good settleability: k = 0.31 l.g^{-1} and $v_0 = 12$ m.h^{-1} (Fig. 6.10c).

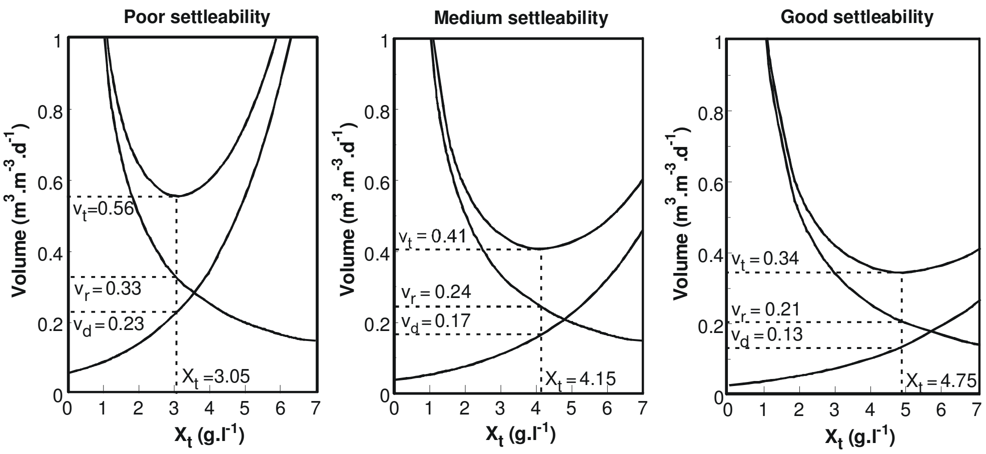

Figure 6.10 v_r, v_d and v_t values as a function of the sludge concentration and assuming the critical recirculation factor is applied ($mX_t = 2$; $S_f = 2$; $S_{ti} = 0.5$ and H = 4 m)

For the specified conditions and in the case of average settleability, it can be observed that the minimum volume v_t for the aeration tank-settler system is obtained for a sludge concentration $X_t = 4.15$ g.l^{-1}, with $v_d = 0.17$ and $v_r = 0.24$ m^3.m^{-3}.d^{-1} so that $v_t = 0.41$ m^3.m^{-3}.d^{-1}. Using Figs. 6.9 and 6.10 it is possible to construct Fig. 6.11, where the critical recirculation factor s_c and the actual settler retention time $v_d/(s_c+1)$ are plotted as functions of the sludge concentration X_t.

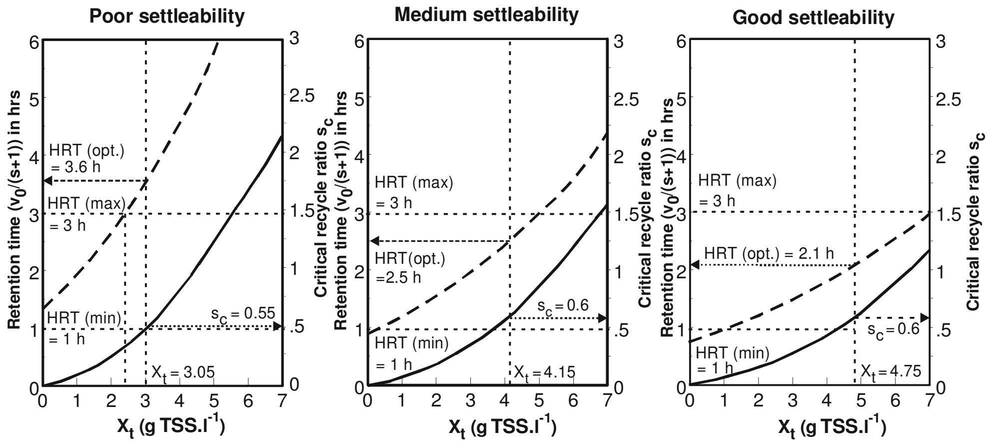

Figure 6.11 Critical recirculation factor and retention time in the settler as function of the sludge concentration (for the conditions specified in Fig. 6.10)

Considering again medium settleability (Fig. 6.11b), it can be observed that the retention time in the settler is 2.5 hour for the optimum concentration of 4.15 g·l^{-1}, which is within the required range of l to 3 hours. Hence, for the optimal sludge concentration and the critical recirculation factor, the retention time in the settler is adequate and for this reason these values can be accepted as the optimal values for design. Thus the optimal design for the aeration tank - settler system of Fig. 6.11b can be summarised as:

- Sludge concentration in the aeration tank X_t = 4.15 g.l^{-1};
- Recirculation factors s_c = 0.56 (critical, determined with Fig. 6.9);
- Return sludge concentration $X_r = X_t \cdot (s_c+1)/s_c = 4.15 \cdot 1.56/0.56 = 11.5$ g.l^{-1}.

In the case of poor settleability (k = 0.46 1.g^{-1}; v_0 = 6 m.h^{-1}), the design optimisation leads to a retention time that may be considered as excessively long. For the sludge concentration resulting in the minimum total volume (X_t = 3.05 g.l^{-1}) and the critical recirculation factor s_c = 0.55 the actual retention time is 3.6 hours. If this is considered too long, one possibility is to increase the recirculation factor, thereby reducing the retention time from 3.6 to 3 hours. The required recirculation factor can be calculated as $(l+s)/(l+s_c)$ = 3.6/3 = 1.2. Hence s = 1.2·1.55 - 1 = 0.86.

The second possibility is to apply a lower sludge concentration by increasing the reactor volume. In Fig. 6.11a it can be noted that the maximum retention time of 3 hours is obtained for the critical recirculation factor when the sludge concentration is 2.4 g.l^{-1}. When this concentration is adopted, the total volume v_t is equal to 0.60 m^3.m^{-3}.d^{-1}, which is bigger than the calculated minimum (v_t = 0.56 m^3.m^{-3}.d^{-1}). Which of the options would be preferable in the final design will depend on the value of the increase of the operational costs (sludge recirculation factor from 0.55 to 0.86 or 61 percent) and on the value of the increase of the construction costs (v_t from 0.54 to 0.60 or 8 percent).