6.3.1 Optimised design procedure

Equation (6.15) is the basis of secondary settler design. It expresses that the solids loading rate must never exceed the largest flux that can be transported through the settler. This equation is valid for both clarification and thickening. Using Eq. (6.15) as a starting point, expressions will be derived for the superficial loading rate. This is the most important parameter for settler design, because it reflects the ratio between the influent flow rate and the cross-sectional area.

(a) Clarification

In the case of clarification, Eq. (6.15) can be described as:

$$F = (F_v + F_u)_{X=Xt} = F_{sol} \quad (6.26)$$

or using Eq. (6.13)

$$X_t \cdot (v_0 \cdot Exp(-k \cdot X_t) + s \cdot Q_i / A_{min}) = X_t \cdot (s + 1) \cdot Q_i / A_{min}$$

Now, by applying the definition of superficial loading rate in Eq. (6.11) and rearranging:

$\ln(T_{sm}/v_0) = - k \cdot X_t$ or

$$T_{sm} = Q_i / A_{min} = v_0 \cdot \exp(-k \cdot X_t) \quad (6.27)$$

Where:

T_{sm} = maximum superficial loading rate
A_{min} = minimum cross sectional settler area

Equation (6.27) shows that the maximum superficial loading rate is proportional to the constant v_0 and has an inverse exponential relationship with the constant k and the suspended solids concentration X_t. It can also be noted that T_{sm} is independent of the recirculation factor "s" and the return sludge concentration X_r.

(b) Thickening

Applying Eq. (6.15) for thickening one has:

$$F_l = X_r \cdot v_0 \cdot (k \cdot X_l - 1) \cdot \exp(-k \cdot X_l) = F_{sol} = X_t \cdot (s + 1) \cdot Q_i / A_{min} \quad (6.28)$$

The corresponding maximum superficial loading rate is given by:

$\ln(T_{sm}/v_0) = \ln((k \cdot X_l - 1)/s) - k \cdot X_l$ or

$$T_{sm} = [v_0 \cdot (k \cdot X_l - 1)/s] \cdot \exp(-k \cdot X_l) \quad (6.29)$$

Equation (6.29) shows that the maximum superficial loading rate in the case of thickening is proportional to the constant v_0 and a complex function of the constant k, the recirculation factor "s" and the return sludge concentration X_r.

In this case the T_{sm} value does not depend on the inlet concentration X_t. With the aid of Eqs. (6.27 and 6.29) and Fig. 6.7 it becomes a simple matter to calculate the superficial loading rate of an activated sludge settler for any pair of inlet and outlet concentrations, X_t and X_r, provided the values of the constants k and v_0 are known. The following procedure may be used:

(1) For the chosen values $k \cdot X_t$ and $k \cdot X_r$, determine in Fig. 6.7 if the criterion for design is clarification or thickening;
(2) Use Eq. (6.27) for clarification or Eq. (6.29) for thickening to determine the maximum superficial loading rate.

Fig. 6.8 shows the T_{sm}/v_0 values as a function of the inlet suspended solids concentration for several values of the recirculation factor. The curves were calculated with the aid of Eqs. (6.27 and 6.29) for clarification and thickening respectively. For convenience an adimensional presentation was used with $k \cdot X_t$ on the horizontal axis and the natural logarithm of the v_0/T_{sm} ratio on the vertical axis. If the constants k and v_0 are known, Fig. 6.8 allows an immediate determination of T_{sm} for any value of the mixed liquor suspended solids concentration and for different values or the return sludge factor "s".

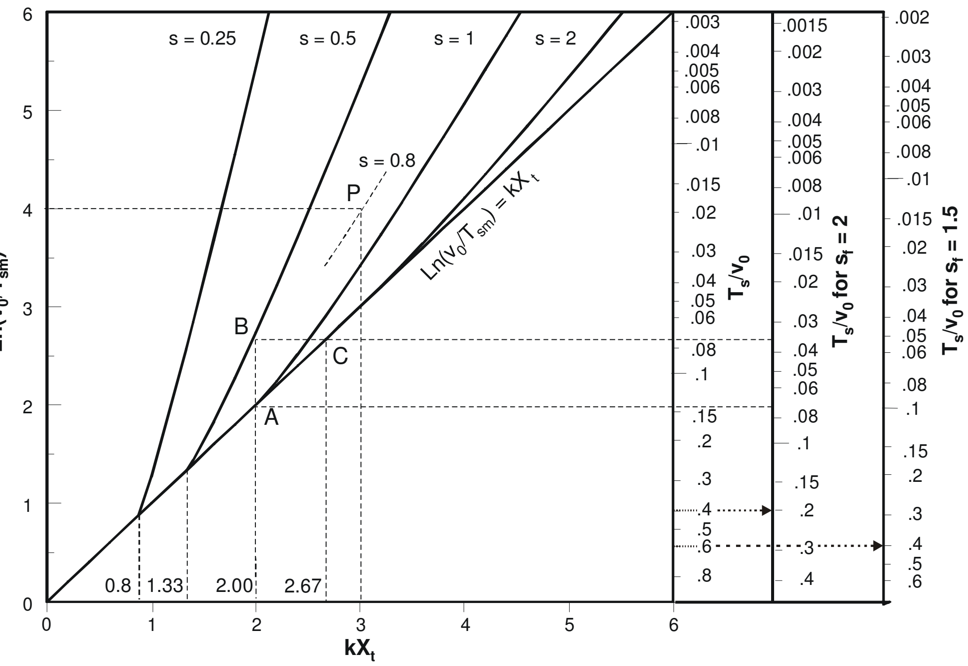

Figure 6.8 Ln(T_{sm}/v_0) ratio as a function of the adimensional product $k \cdot X_t$ for different values of the recirculation factor s

The diagram may be interpreted in the following way: the straight line corresponding to clarification (Eq. 6.27) divides Fig. 6.8 in two parts:

- One part (the lower triangle) is characterised by the condition that $\ln(v_0/T_s) < k \cdot X_t$. The operational conditions are inadequate and the settler cannot function due to an excessive solids load and/or hydraulic load;
- In the other part of the diagram (the upper triangle), where $\ln(v_0/T_s) > k \cdot X_t$, the settler will function if the values of the operational variables are adequate.

Fig. 6.8 also shows that there are three variables that influence settler performance: the sludge concentration X_t, the superficial loading rate T_s and the sludge recycle factor s. In most existing plants the values of the operational variables X_t and T_s are not determined by considerations regarding optimisation of the settler: the sludge mass (and hence its concentration X_t) is determined by the sludge age, whereas the superficial loading rate T_s is given by the ratio of the influent flow and the settler area. Hence in many cases only one variable can be chosen freely: the sludge recycle factor s. The appropriate value of this factor can easily be identified: for any given combination of values of the variables X_t and T_s calculate the corresponding values $k \cdot X_t$ and $\ln(v_0/T_s)$. These two values are the coordinates of a point in Fig. 6.8. The necessary recycle factor can now be determined graphically by interpolation of the thickening curves for different s-values, such that the curve passes through the intersection point P.

It is important to realise that the value of the superficial loading rate determined by Eq. (6.27 or 6.29) is a theoretical value based on a mathematical deduction, which makes a number of assumptions (refer to Section 6.3) that, in practice, may not always be realistic. In reality, the maximum applied superficial loading rate is always less then the value calculated for T_{sm}. In practice, a correction must be made for the fact that not the entire settler volume is effectively utilised for liquid-solid separation: part of it is a stagnant zone, so that in fact the superficial loading rate is higher than the ratio Q_i/A_{min}. Therefore this ratio must be multiplied by a safety factor to represent the superficial loading rate under actual operational conditions.

The value of the safety factor depends on the size of the stagnant volume fraction (dead volume) in the settler, resulting from the non-ideality of the settler. In practice the dead volume is often in the range of 30 to 40 percent. Taking into consideration that there are other adverse conditions as well (winds, density differences due to temperature gradients), it is concluded that a value between 1.5 to 2.5 would appear to be suitable for the safety factor. For this reason, in Fig. 6.8 the values of T_s/v_0 are also indicated with a safety factor of $s_f = 2$ (right hand scale). The scale for $s_f = 2$ is produced by displacing the ordinate numeric values by a factor 2: if the scale value is 0.8 for $s_f = 1$ (first value of the ordinate scale for $s_f = 1$) at this same level there will be the value of 0.8/2 = 0.4 for s_f =2. Similarly the scale can be produced for any desired s_f value, by sliding the ordinate scale downwards by a factor such that the numeric value N on the $s_f = 1$ scale becomes N/s_f on the scale with a safety factor s_f . Fig. 6.8 shows that the superficial loading rate that can be applied on a settler depends of the following factors:

- Values of the settleability constants k and v_0;
- Sludge concentration of the mixed liquor in the inlet to the settler;
- Value of the sludge recycle factor s (if thickening is the limiting function);
- Value of the safety factor.

The determination of the maximum superficial loading rate of a settler is the most important part of settler design. Once the value of T_{sm} is established, the settler design is completed as follows:

(1) Establish a suitable safety factor to guarantee proper operation of the settler under adverse conditions. If it is not possible to determine the value of s_f experimentally (as was done in Example 6.4), then a default figure should be adapted, possibly $s_f = 2$;

(2) For the applied safety factor the cross-sectional settler area is calculated;

$$A = s_f \cdot Q_i/T_{sm} \tag{6.31}$$

(3) An adequate depth (in practice generally around 4m) is chosen and the settler volume is calculated:

$$V_d = A \cdot H = s_f \cdot H \cdot Q_i / T_{sm} \quad (6.32)$$

Equation (6.32) can be used to determine the volume of the settler per unit influent flow:

$$v_d = V_d/Q_i = s_f \cdot H/T_{sm} = s_f \cdot (H/v_0)/(T_{sm}/v_0) \quad (6.33)$$

Equation (6.33) shows that it is possible to calculate the required volume per unit influent flow (v_d) if the values of s_f, H, v_0 and T_{sm} are known. Equation (6.33) can be rearranged as:

$$\ln(v_d) = \ln(s_f \cdot H/v_0) - \ln(T_{sm}/v_0) = \ln(s_f \cdot H/v_0) + k \cdot X_t \quad \text{(clarification) or} \quad (6.34a)$$

$$\ln(v_d) = \ln(s_f \cdot H/v_o) + k \cdot X_l - \ln((k \cdot X_l - 1)/s) \quad \text{(thickening)} \quad (6.34b)$$

Numerically, the v_d value is equal to the average hydraulic retention time of the liquid in the settler. In practice, this retention time is subjected to an upper and a lower limit. The lower limit is imposed by the hydraulics of the settler: if the actual retention time is shorter than about l hour, the efficiency of solid-liquid separation tends to be poor due to excessive turbulence. On the other hand, a very long retention time in the settler may lead to denitrification in the settler with the consequential formation of a floating sludge layer. This may also cause the formation of filamentous organisms, which are responsible for poor settling characteristics of the sludge. Thus the actual liquid retention time in a settler is usually not longer than about 3 hours. Taking these limits into consideration one has:

$$1\ h < V_d/((s + 1) \cdot Qi) < 3\ h \text{ or } (s + 1)/24 < v_d < 3 \cdot (s + 1)/24 \quad (6.35)$$

If the v_d value found by Eqs. (6.33 or 6.34) is not within the range set by Eq. (6.35), other values must be defined for X_t and/or X_r.