6.2 SETTLING IN A CONTINUOUS SETTLER

The term "clarifier" or "secondary clarifier" only covers one of the main processes taking place in the settler. Thickening is the second important process. Therefore throughout this text the term "settler" has been used instead. Final settlers in activated sludge processes operate under continuous flow and load conditions. Mixed liquor flows from the aeration tank to the settler and return sludge, containing the concentrated sludge, is pumped back to the aeration tank, while a clarified effluent flow (equal to the waste water influent flow) is discharged from the system.

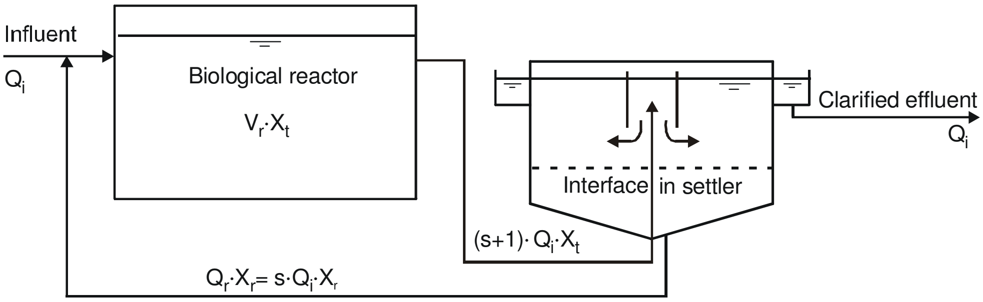

Figure 6.4 Schematic representation of an activated sludge process with a final settler

Fig. 6.4 shows a schematic representation of a final settler and the incoming and outgoing flows. In order to describe settling in a continuous settler the following assumptions and approximations are made:

(1) The flow entering the settler is the sum of the waste water flow and the return sludge flow. The incoming flux of solids can be expressed as $(Q_i+Q_r) \cdot X_t$, while the outgoing flux is equal to $Q_r \cdot X_r$. Assuming that no sludge accumulation takes place in the settler, the incoming and outgoing solids flows are equal, so that:

$(Q_i + Q_r) \cdot X_t = Q_r \cdot X_r$ or

$$X_r = X_t \cdot (s+1)/s \qquad (6.10)$$

Where:

X_r = return sludge concentration
r = recirculation factor = Q_r/Q_i

(2) The incoming flow $(Q_i + Q_r)$ is distributed uniformly over the cross sectional area at a certain level. The flow direction in the settler is vertical. In the supernatant region above the level of incoming solids, the liquid is free of solids and rises to the effluent discharge level at the top of the settler. The upward velocity is called the superficial loading rate and can be expressed as:

$$T_s = Q_i/A \qquad (6.11)$$

Where:

T_s = superficial loading rate (upward velocity of the supernatant)
A = cross sectional area of the settler

Below the level of the incoming sludge a suspension is formed that flows in a downward direction to the return sludge discharge at the bottom of the settler. The downward velocity of the liquid phase is given by:

$$u = Q_r/A = s \cdot Q_i/A \tag{6.12}$$

Where u = downward velocity of the liquid phase due to the return sludge flow

(3) In addition to the downward velocity of the liquid phase, in the lower part of the settler the solids have a settling velocity, which means that they move downwards in the liquid phase. The settling velocity is given by Vesilind's equation (Eq. 6.1).

(4) The displacement velocity of the solids is given by the sum of the liquid velocity "u" and the settling velocity "v". Hence the solids flux, defined as the solids mass passing per unit area and per time unit at a certain level in the settler can be expressed as:

$$\begin{aligned} F &= X \cdot (v + u) \qquad (6.13) \\ &= F_v + F_u \\ &= X \cdot (v_0 \cdot \exp(-k \cdot X) + s \cdot Q_i/A) \end{aligned}$$

Where:

F = solids flux passing at a particular level in the settler
X = suspended solids concentration at a certain level in the settler
F_v = solids flux due to settling
F_u = solids flux due to return sludge abstraction

(5) The solids loading rate is defined as the mass of suspended sludge solids entering the settler per unit settler area and per time unit:

$$F_{sol} = X_t \cdot (s + 1) \cdot Qi/A \tag{6.14}$$

Where:

F_{sol} = sludge loading rate

(6) An essential condition for the settler to perform properly is that the sludge loading rate does not exceed the solids flux at any level in the settler. If this condition is obeyed, all solids are transported from the feeding point to the abstraction point and no accumulation of solids will occur in the settler. However if at some level between the inlet and the abstraction point the solids loading rate exceeds the solids flux, then at that level solids will accumulate at a rate equal to the difference between the solids loading rate and the solids flux. Eventually the settler will be completely filled with solids resulting in the discharge of sludge together with the effluent. The basic condition for a settler to perform properly can therefore be expressed as:

$$F = F_v + F_u > F_{sol} \text{ for } X_t < X < X_r \tag{6.15}$$

Equation (6.15) forms the basis for final settler design. To evaluate the solids flux F, the components F_v and F_u are calculated. In Fig. 6.5a the solids flux due to settling F_v is shown plotted as a function of the solids concentration X. It is assumed that Vesilind's equation applies. Figure 6.5b shows the solids flux due to return sludge abstraction F_u, also as a function of the sludge concentration. In Fig. 6.5c the resulting total flux F is plotted. For the chosen values of the sludge concentrations at the inlet point of the settler and of the return sludge at the outlet (X_t and X_r respectively, Fig. 6.5c), the curve F has a relative minimum F_l, for a sludge concentration X_l at some intermediate value between X_t and X_r. The flux F_l limits the maximum solids transport to the abstraction point in the settler and for that reason is called the limiting flux. The corresponding sludge concentration X_l is called the limiting concentration.

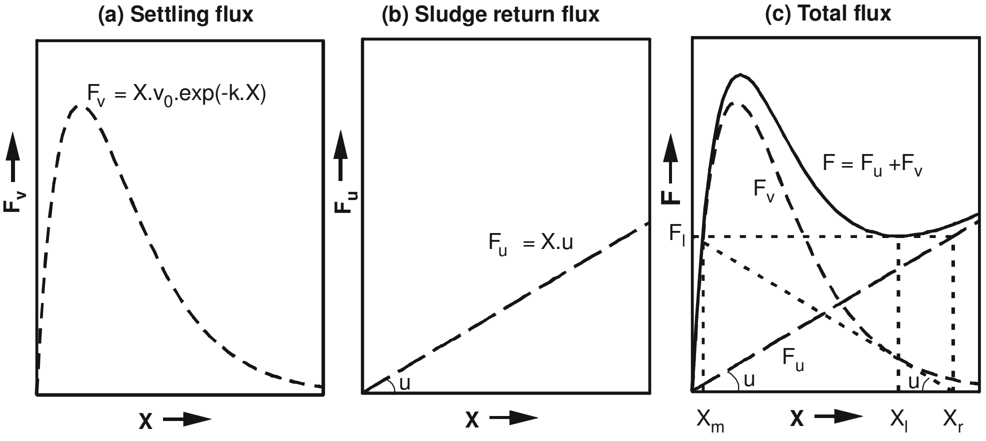

Figure 6.5 The solids flux due to settling (a), the solids flux due to return sludge flow (b) and the resulting total flux (c) in a continuous settler as a function of the sludge concentration

Figure 6.5c also shows how the limiting sludge concentration can be determined on the basis of geometry when the return sludge concentration X_r and the batch settling curve F_v (Fig.6.5a) are known. In Fig.6.5c the method developed by Yoshioka et al (1957) is presented:

(1) Draw a straight line tangential to the batch settling curve F_v, passing through the point X_r at the horizontal axis
(2) The limiting flux corresponding to the chosen X_r value is found as the intersection of the straight line and the vertical axis.

From Fig. 6.5c it is quite clear that the limiting flux depends directly on the return sludge concentration. Therefore the limiting flux, i.e. the maximum flux that can be transported in the settler, is determined by the thickening function of the settler through which the return sludge concentration is produced. Furthermore, Fig. 6.5c shows that in the case of an inlet sludge concentration X_t greater than the limiting concentration X_l, the resulting flux curve F is a function that increases monotonously with increasing sludge concentration in the range from X_t to X_r. Hence in this case, the largest flux that can be transported through the settler is equal to the inlet flux with concentration X_t and is independent on the outlet concentration X_r.

When the inlet concentration is smaller than a particular concentration X_m, the flux related to the inlet concentration will be smaller than the limiting flux and hence limits the solids transport in the settler. It is concluded that when the inlet concentration X_t is greater than the limiting concentration X_l or smaller than the minimum concentration X_m, the flux related to the inlet sludge concentration is the maximum flux that can be transported through the settler. This maximum flux is determined by the clarification function of the settler.

It can be observed in Fig. 6.5c that Yoshioka's method to determine the limiting flux is only applicable if it is possible to draw a tangent line to the concave part of the batch settling curve F_v. There is a critical concentration X_c such that, for any return sludge concentration $X_r < X_c$, it is not possible to draw this tangent line and consequently the limiting flux and the limiting concentration do not exist. The tangential line passing through the critical concentration point at the horizontal axis intersects the curve F_v at the point where its gradient is maximum.

This occurs at the inflection point of this curve (F_i, X_i), a situation that is shown in Fig. 6.6. It can be noted that the limiting flux has its maximum value when the return sludge concentration is equal to the critical concentration $X_r = X_c$. In this situation, the downward liquid velocity is also maximum. The observations above about the solids flux curve F and its components F_v and F_u can be summarised as follows:

- The maximum flux that can be transported in a settler depends either on the inlet concentration (equal to the mixed liquor concentration) or on the outlet (return sludge) concentration;
- In the first case, clarification is the limiting function of the settler and consequently will determine settler design;
- In the second case, sludge thickening is the limiting function and the criteria for thickening will determine settler design;
- Thickening is limiting when the inlet concentration has a value between the minimum concentration X_m and the limiting concentration X_l and when the outlet concentration is greater than the critical concentration X_c. In all other cases the limiting function of the settler will be clarification.

In order to establish if sludge settling in a settler will be determined by clarification or by thickening, it is necessary to derive expressions for the concentrations X_l, X_m and X_c. In the following sections these expressions will be derived with the aid of Vesilinds equation.