6 Dimensioning of the Secondary Settling Tank

6.1 Range of Application

The dimensioning is based on the maximum inflow during wet weather (Q_M), see 4.1, the sludge volume index (*SVI*) and the suspended solids concentration of the sludge in the influent to the secondary settling tank (SS_{EAT}). Except in the case of step-feed denitrification, $SS_{EAT} = SS_{AT}$.

The following parameters are to be determined or calculated for the dimensioning of the secondary settling tank:

- Shape and dimensions of the secondary settling tanks,
- Thickening time,
- Return sludge flow and its control,
- Type and mode of operation of the sludge removal systems,
- Arrangement and form of the influent and effluent.

The following dimensioning rules apply to:

- Secondary settling tanks with lengths or diameters up to approx. 60 m,
- Sludge volume index 50 l/kg < *SVI* < 200 l/kg,
- Diluted sludge volume *DSV* < 600 l/m^3,
- Return sludge flow rate:
  $Q_{RS} \leq 0{,}75 \cdot Q_M$ (horizontal flow tanks) or $Q_{RS} \leq 1{,}0 \cdot Q_M$ (vertical flow tanks),
- Suspended solids concentration in the inflow to the secondary settling tank SS_{AT} or
  $SS_{EAT} > 1{,}0$ kg/m^3.

These dimensioning rules do not apply to inflow situations in which the density of the inflow to the secondary settling tank rises considerably in a short time, as in the case of rapid snow melting and a corresponding rapid drop in the inflow temperature. Such unusual operating conditions are beyond the dimensioning limits of this Standard.

If a further treatment stage is located downstream, a higher concentration of settlable and / or filterable solids can be permitted in the effluent of the secondary settling tank. In this case, a higher sludge volume surface loading rate and a higher surface overflow rate are permitted. This is conditional on the downstream stage being able to accommodate and restrain the suspended solids occurring there.

The principles of dimensioning and design can be found in the ATV Manual (ATV 1997b) and in IAWQ Report No. 6 (Ekama et al. 1997).

6.2 Sludge Volume Index and Thickening Time

The sludge volume index is established in relation to the wastewater composition and the mixing properties of the aeration tank. High proportions of readily biodegradable organic substances, such as are contained in some commercial and industrial wastewater, can lead to higher sludge volume index.

The correct assumption of the sludge volume index is of particular importance for the design of the secondary settling tank. If the design problem is limited to an extension of the secondary settling stage without any modifications to the process in the aeration tank, the sludge volume index for dimensioning can be taken from the operating records for the critical season, or, alternatively, based on a 85th percentile value. Even if process modifications in the aeration tank are planned, the operating records in conjunction with the values in Table 4 are helpful in the estimation of the sludge volume index. If sludge volume indices of $SVI > 180$ l/kg occurred in the 85th percentile in the past, measures should be taken to reduce the sludge volume index.

If no usable data are available, the values presented in Table 4 are recommended for use as the sludge volume index for dimensioning.

The lower values for the sludge volume index (*SVI*) can be applied in each case when

- a primary settling tank is dispensed with, or
- a selector or an anaerobic tank is installed upstream, or
- the aeration tank is designed as a cascade (plug flow).

Table 4: Standard values for the sludge volume index *SVI*

Treatment objective	*SVI* (l/kg),influenced by industry	
	Favourable	Unfavourable
Without nitrification	100 – 150	120 – 180
Nitrification (and denitrification)	100 – 150	120 – 180
Sludge stabilization	75 – 120	100 – 150

With regard to sludge thickening, the sludge volume index in conjunction with the thickening time (t_{Th}) determines suspended solids concentration in the bottom sludge (SS_{BS}). In order to avoid redissolution and the formation of floating sludge as a consequence of undesirable denitrification in the secondary settling tank, the retention time of the settled sludge in the thickening and sludge removal zone must not be extended arbitrarily. It is therefore recommended to set the thickening time in the context of dimensioning to $t_{Th} = 2{,}0$ h.

Assuming a sludge volume index of significantly less than 100 l/kg, it is to be demonstrated on selection of the thickening time that the bottom sludge concentration (SS_{BS}) indicated by equation (40) is actually achieved in operation. In plants without dedicated denitrification, a thickening time shorter than 2 h should be selected.

6.3 Suspended Solids Content of the Return Sludge

The flow of return sludge Q_{RS} is diluted by a short circuit sludge flow Q_{short}, which is taken in the case of suction scrapers from the zone above the thickening layer, and in the case of sludge scrapers from the area of the sludge hopper.

The achievable suspended solids concentration in the bottom sludge SS_{BS} (average suspended solids concentration in the sludge removal flow) can be empirically estimated as follows on the basis of the sludge volume index *SVI* and the thickening time t_{Th} (see also Figure 6):

$$SS_{BS} = \frac{1.000}{SVI} \cdot \sqrt[3]{t_{Th}} \quad \text{(kg/m}^3\text{)} \qquad (40)$$

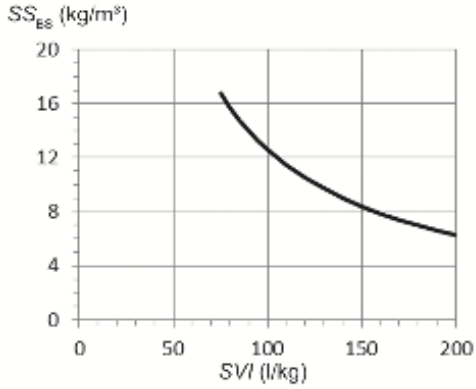

Figure 6: Suspended solids concentration in the bottom sludge with a thickening time of 2 h in relation to the sludge volume index

A calculation of SS_{BS} using the settling velocity of the activated sludge (RESCH 1981, DWA 2013) or from experimental results is also possible.

The suspended solids content of the return sludge (SS_{RS}) can, as a consequence of the dilution with the short circuit sludge flow Q_{short}, be assumed in a simplified form to be:

- With spiral scrapers $SS_{RS} \approx 0{,}7$ to $0{,}8 \cdot SS_{BS}$

Higher values than 0,7 only apply to circular tanks with optimized inlet design as presented in 6.8, so that it is ensured that the return sludge flow is not notably diluted by a short circuit flow from the inlet structure.

- With suction scrapers $SS_{RS} \approx 0{,}5$ to $0{,}7 \cdot SS_{BS}$

Higher values than 0,5 only apply to suction scrapers in which adjustments to the quantity removed are possible in several sections, so as to minimize the withdrawal of clear water.

In the case of vertical flow secondary settling tanks without sludge removal facilities, $SS_{RS} \approx SS_{BS}$ can be assumed.

6.4 Return Sludge Ratio and Suspended Solids Content in the Sludge at the Influent to the Secondary Settling Tank

The operating conditions in the aeration tank and in the secondary settling tank are mutually influenced by the dependence between the mixed liquor suspended solids concentration in the inflow to the secondary settling tank SS_{AT}, between the mixed liquor suspended solids concentration of the return sludge SS_{RS} and the return sludge ratio $RS = Q_{RS}/Q$. For the equilibrium state the following results from the suspended solids mass balance, neglecting $X_{SS,IAT}$, are:

$$SS_{AT} = \frac{RS \cdot SS_{BS}}{1 + RS} \quad (\text{kg/m}^3) \qquad [41]$$

The dimensioning of the secondary settling tank and the aeration tank is to be based on a return sludge flow of max. $0{,}75 \cdot Q_M$. It should be possible to set different return sludge ratios, also allowing for dry weather, either by using a frequency converter and / or by staging the pump output. Continuous adjustment of the return sludge flow to match the inflow has frequently proved to be expedient.

In case of vertical flowed secondary settling tanks, the dimensioning can be performed for max. $Q_{RS} = 1{,}0 \cdot Q_M$; the dimensioning of the return sludge pumps (including back-up) should make an operational adjustment of Q_{RS} up to $1{,}5 \cdot Q_M$ possible (see 8.4).

Return sludge ratios *RS* for the transitional area between predominantly horizontal flow and predominantly vertical flow tanks can be taken from Table 5 (see 6.5).

Higher return sludge ratios and erratic increases of the return sludge flow impair the settling process by increasing flow rates. Return sludge ratios of $RS < 0{,}5$ should be avoided as they demand high suspended solids concentrations in the return sludge, which are only achievable with a low sludge volume index and a long thickening time.

6.5 Surface Overflow Rate and Sludge Volume Surface Loading Rate

The surface overflow rate q_A for the dimensioning case results from the permissible sludge volume surface loading rate q_{SV} and the selected diluted sludge volume *DSV* as follows:

$$q_A = \frac{q_{SV}}{DSV} = \frac{q_{SV}}{SS_{EAT} \cdot SVI} \text{ (m/h)} \tag{42}$$

In order to prevent an excessive rise in the sludge level up to the clear water outlet, with the associated massive sludge drifting, the following sludge volume surface loading rate q_{SV} is not to be exceeded:

$$q_{SV} \leq 500 \text{ l/(m}^2\cdot\text{h)}$$

For predominantly vertical flow secondary settling tanks, the following applies when a complete sludge blanket is formed, or with easily flocculating activated sludge:

$$q_{SV} \leq 650 \text{ l/(m}^2\cdot\text{h)}$$

Inlet structures should in principle meet the requirements set out in 6.8. In such cases, significantly lower outflow values than $X_{SS,EST} < 20$ mg/l can be achieved.

It is recommended to optimise relation between the sludge volume loading rate and the depth of the tank, taking account of the applicable background conditions (subsoil, groundwater level and space available).

Predominantly horizontal flow tanks are those where the ratio of the distance from the inlet aperture to the water surface (vertical component, h_{in}) to the horizontal distance from inlet to outlet at the height of the water level (horizontal component) is smaller than 1 : 3. Predominantly vertical flow tanks are those where the ratio is greater than 1 : 2. For ratios between the two, the permitted sludge volume loading rate can be interpolated in a linear fashion. It is recommended that the values in Table 5 are used for dimensioning.

The surface overflow rate q_A is not to exceed 1,6 m/h with predominantly horizontal flow secondary settling tanks, and with predominantly vertical flow secondary settling tanks it is not to exceed 2,0 m/h. For the transition area, values can be taken from Table 5.

Table 5: Permissible values for the transition area between predominantly horizontal and predominantly vertical flow secondary settling tanks (complete sludge blanket)

Parameter	Permissible values						
Ratio*)	≥ 0,33	≥ 0,36	≥ 0,39	≥ 0,42	≥ 0,44	≥ 0,47	≥ 0,5
q_{SV} [l/(m^2 · h]	≤ 500	≤ 525	≤ 550	≤ 575	≤ 600	≤ 625	≤ 650
q_A (m/h)	≤ 1,60	≤ 1,65	≤ 1,75	≤ 1,80	≤ 1,85	≤ 1,90	≤ 2,00
RS (–)	≤ 0,75	≤ 0,80	≤ 0,85	≤ 0,90	≤ 0,90	≤ 0,95	≤ 1,00
NOTE *) Vertical component to horizontal component, e.g. 1 : 2,5 = 0,4							

For existing tanks in the transition area, higher sludge volume surface loading rates can also be permitted on the basis of operating records.

For newly designed circular tanks with horizontal or slightly inclined bases, the sludge volume surface loading rate in relation to the area of the water surface should not exceed a value of 500 l/(m^2·h).

6.6 Settling Tank Surface Area

The required surface area of the secondary settling tank is calculated as follows:

$$A_{SST} = \frac{Q_M}{q_A} \quad (m^2) \tag{43}$$

The above equation does not include the surface area of the inlet structure. Practical implementation of an inlet structure with an F_D of approx. 1 is more difficult in rectangular tanks, owing to the more uneven inflow distribution, than in circular tanks. It is therefore not necessary to take account of a disturbance zone in circular tanks only. With rectangular tanks, a lump-sum addition of 2 m is sufficient.

For vertical flow secondary settling tanks, the relevant surface area A_{SST} is to be taken as the effective area at the mid-point between the inlet aperture and the water level; see 6.7, Figure 10. The geometry of standard tank shapes is also taken into account in this way.

6.7 Settling Tank Depth

The various processes in secondary settling tanks are explained with the aid of functionally determined zones, which are shown schematically in figures 7 and 8

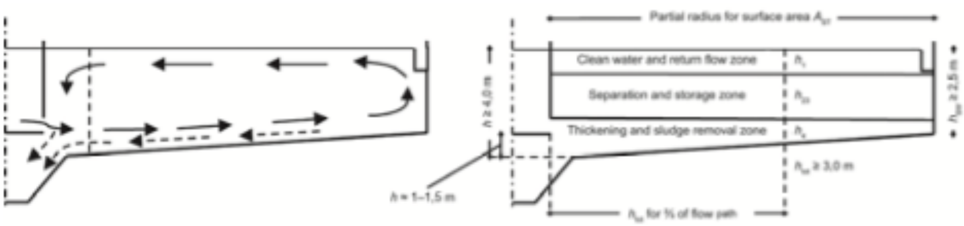

Figure 7: Main flow directions and functional zones of horizontal flow circular secondary settling tanks

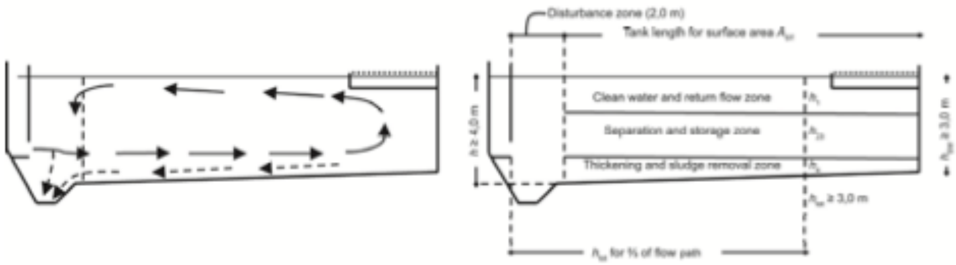

Figure 8: Main flow directions and functional zones of horizontal flow rectangular secondary settling tanks

The required depth of the secondary settling tank is, in this theoretical model, made up of effective volumes or zones for the following essential functions:

- h_1 Clean water zone
- h_{23} Separation and storage zone
- h_4 Thickening and sludge removal zone

The division into functional zones shows the areas in which the processes take place in the theoretical model. In reality, the processes do not take place in horizontally layered zones, but rather permeate each other. In the inlet and outlet areas of the tank there are additional hydraulically caused disturbance zones, which are to be kept as small as possible by means of suitable inlet and outlet design.

Figure 9 shows the arrangement of the clean water zone for various outlet designs. The clean water zone fundamentally starts at the height of the water level and extends downwards for 50 cm (cases a), b) and d)). With clipped sluices (with inflow from both sides or externally from one side), the clean water zone extends from the water level to 20 cm below the bottom of the channel (Figure 9c). Clipped sluices with inflow from one side only should be avoided in new designs.

In order to prevent the ingress of floating sludge into the outlet pipes, the water level must be at least 20 cm above the inlet openings in the submerged pipes.

With tangentially arranged submerged pipes, drifting of sludge may occur at high sludge levels or during disturbances to operation. An added margin to the clean water zone is therefore to be considered in individual cases.

Below the clean water zone, there is the separation and storage zone. In the inlet area, the clean water and return flow zone, the separation and storage zone and in some cases the thickening and sludge removal zone form a single unit. The sludge-water mixture is fed into the lower part of the inlet area and evenly distributed in the tank. Flocculation processes occur, creating favourable conditions for settling of the sludge.

Outside the inlet area, return flow processes take place, returning wastewater with a low suspended solids content to the inlet area.

The height of the separation and storage zone h_{23} is calculated on the basis of empirical approaches which have proven successful in practice. The calculation has two parts. Firstly, the separation effect is calculated with a theoretical retention time of 0,5 hours in relation to the maximum inflow including the return sludge flow. The second part deals with the storage of activated sludge. This is dimensioned in such a way that the additional volume of sludge with a concentration level of 500 l/m^3 flowing out of the aeration tank in a period of 1,5 hours ($0{,}3 \cdot SS_{AT} \cdot SVI$) can be accommodated. In that time, the activated sludge settles into the thickening and sludge removal zone, and is assumed to be evenly distributed across the secondary settling tank surface area A_{SST}. The individual proportions of the separation and storage zone are explained in greater detail in Annex C.

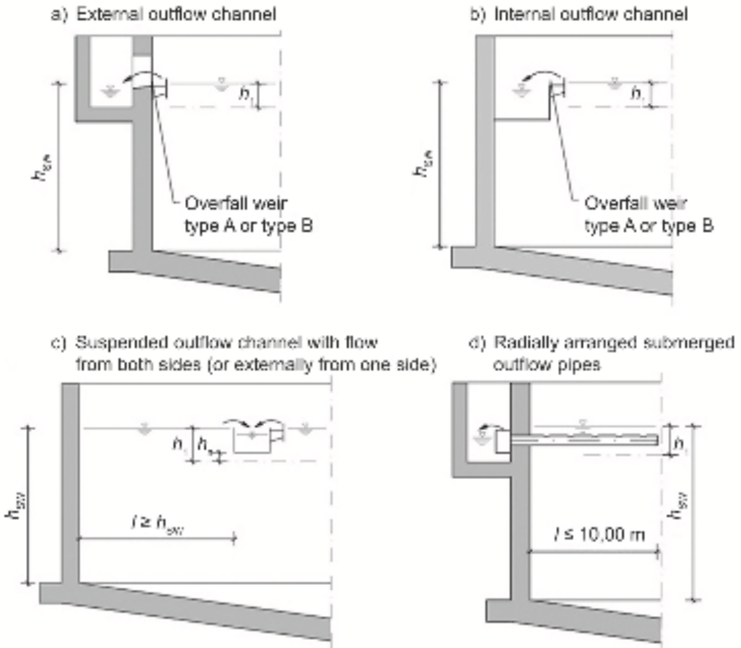

Figure 9: Clean water zones with various outlet designs c: clipped sluices

The height h_{23} is calculated as follows:

$$h_{23} = q_A \cdot (1+RS) \cdot \left[\frac{500}{1.000 - DSV} + \frac{DSV}{1.100} \right] \quad \text{(m)} \tag{44}$$

At the bottom of the tank, in the thickening and sludge removal zone, the settled activated sludge is concentrated. There is a layer of sludge in which low flow velocities in the direction of the sludge outlet prevail.

The thickening and sludge removal zone must be large enough for the sludge load which has flowed into the secondary settling tank with a suspended solids content of SS_{EAT} can be thickened within the thickening time t_{Th} to the bottom sludge concentration SS_{BS}. Assuming an even distribution of the sludge mass which has flowed into the secondary settling tank across its surface area, the height of the thickening and sludge removal zone is calculated as follows:

$$h_4 = \frac{SS_{EAT} \cdot q_A \cdot (1+RV) \cdot t_{Th}}{SS_{BS}} \quad \text{(m)} \tag{45}$$

The wastewater-sludge mixture which enters the inlet area in the thickening and sludge removal zone is distributed in layers in the tank according to its density, and flows towards the outer edge of the tank.

Under dry weather inflow conditions, the sludge layer is not very high. When stormwater flow sets in, the sludge layer expands into the separation and storage zone. The sludge displaced from the aeration tank, even when a high return ratio is selected, is temporarily stored there.

The calculated total tank depth h_{tot}, as the sum of the partial depths h_1, h_{23} and h_4, is to be maintained at two thirds of the flow path for horizontal flow secondary settling tanks with inclined tank bottoms. There, it must be at least 3 m. In circular secondary settling tanks, the side water depth may not fall below 2,5 m.

With inverse cone or hopper tanks, the partial volumes V_{23} for the separation and storage zone and V_4 for the thickening zone are obtained by multiplying the surface area A_{SST} (see 6.6) with the corresponding zone depths h_{23} and h_4. For calculation of the total depth, these partial volumes are interpolated into the selected geometry of the tank (see Figure 10).

In principle, the volume resulting from the geometric boundary conditions must be at least equal to the sum of the required partial volumes. If this is not the case, for instance with small tanks < 8 m diameter, the tank dimensions have to be increased accordingly. In addition, for tanks with D < 8 m, an examination of the geometry in accordance with Standard DWA-A 222 or Standard DWA-A 226 has to take place. The larger resulting diameter is to be selected.

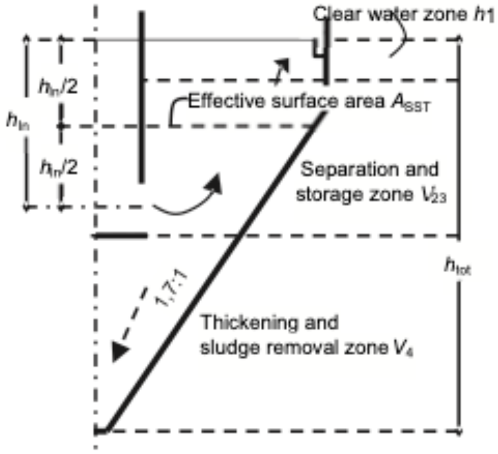

Figure 10: Functional zones and depths in vertical flow inverse cone tanks

6.8 Design of Inlet Structure

The design of the inlet structure has a fundamental influence on the flow through and efficiency of secondary settling tanks. In the case of rectangular tanks, it is recommended that inlet slots be provided across the width of the inlet, and with circular tanks around the circumference of the central structure. The inlet design is considered optimum when the sum of kinetic and potential energy applied at the entry to the inlet structure of the secondary settling tank reaches a minimum. This state is achieved, when the densimetric Froude number gives the value of F_D=1.

$$F_D = \frac{u}{\sqrt{\frac{\rho_0 - \rho}{\rho} \cdot g \cdot h}} \quad [-] \qquad (46)$$

In the equation, u is the horizontal flow velocity in the inlet cross-section at maximum inflow including return activated sludge, and h is the height of the opening of the inlet cross-section (slot height). ρ_0 is the density of the activated sludge (e.g. 1.001 kg/m^3), resulting from the densities of the fluid and the dry solids (e.g. 1.450 kg/m^3), and ρ is the density of the ambient fluid (e.g. 1.000 kg/m^3). For dimensioning, it is recommended to apply a densimetric Froude number which tends to be slightly smaller than 1. In practice, inlet designs with slot heights of 30 cm to 60 cm and inlet velocities of < 7 cm/s have proven successful. Alternatively, inlet structures with adjustable height can be used.

In order to minimize the potential energy applied with the activated sludge and to use the blanket effect of the sludge bed as well as possible, the top of the inlet to the secondary settling tank should ideally be at the same height as the sludge level. If the inlet is positioned too low, however, there is the risk of a rapid rise of the sludge level on inflow of mixed water. The resulting recommendation in practice, therefore, is to stipulate the inlet height for circular tanks at 1,0 m to 1,5 m above top of the hopper, and for rectangular tanks in accordance with the height of the thickening zone h_4.

Furthermore, for good flocculation, the value of G (a parameter for turbulent shear stress) in the inlet chamber at maximum influent during rainfall

$$G = \sqrt{\frac{P_{IN}}{\mu \cdot V_{IS}}} \text{ (1/s)} \quad [47]$$

should be between 40 s^{-1} and 80 s^{-1}. V_{IS} is the volume of the inlet structure, and μ is the dynamic viscosity of the activated sludge (approx. 0,0013 Ns/m^2 at 10 °C).

Central structures in circular tanks and antechambers of rectangular tanks should be dimensioned for a retention time of at least 1 minute at $(1 + RS) \cdot Q_M$.

The power input into the inlet structure P_{IN} is then calculated as

$$P_{IN} = 0{,}5 \cdot \rho_0 \cdot v_{IN}^2 \cdot Q_M \cdot (1+RS) \text{ (Nm/s)} \quad [48]$$

where the intake velocity v_{IN} at the inlet structure (in the cross-section of the intake culvert) is as folllows

$$v_{IN} = \frac{Q_M \cdot (1+RS)}{A_{IC}} \text{ (m/s)} \quad [49]$$

where A_{IC} is the cross-sectional area of the intake culvert leading to the inlet structure. Detailed notes on inlet design can be found in DWA (2013).

6.9 Examination and Recalculation of Existing Secondary Settling Tanks

When recalculating existing secondary settling tanks, q_{SV} has to be adjusted iteratively until the calculated depth agrees with the actual depth.

If the existing tank depth falls below the required minimum value, a reduction in the maximum acceptable inflow rate is advisable in order to prevent hydraulic disturbances as a result of a tank depth which is too small. A further use of existing secondary settling tanks with a total water depth of less than 2,0 m is in general not advisable.

In special conditions, e.g. strongly fluctuating inflows, special inlet structures or unusual sludge properties, the use of numerical flow simulation may be expedient. This allows the efficiency of the secondary settling tank or any optimization measures to be estimated on the basis of velocity and solid material profiles.

As a result, an optimization of the inlet structure can, for example, increase the efficiency of the secondary settling tank without any modifications to the tank itself.

6.10 Dimensioning of the Sludge Removal System

The sludge scraping and the return sludge flow rate essentially determine the retention time of the activated sludge in the secondary settling tank.

There are various sludge scrapers and sludge return conveyance devices available for the different types of secondary settling tanks. In horizontal flow circular tanks, blade scrapers and suction scrapers are employed. In horizontal flow rectangular tanks, in addition to spiral scrapers, blade scrapers are used.

If sludge removal is required in predominantly vertical flow tanks or in transverse flow secondary settling tanks, the above-named systems can also be deployed.

Sludge removal systems in new secondary settling tanks can be dimensioned as shown in Table 6. The dimensions are to be selected especially in relation to the tank diameter or length, and the tank design.

The effects and mutual dependencies of the scraper blade height, number of scraper arms and sludge scraping velocity can be checked by means of a solids balance as set out in Annex B.

The variables h_{SR}, v_{SR} and l or a, which are decisive for the sludge removal performance and mutually dependent, can be calculated using the solids balance presented in Annex B.

On the dimensioning of the sludge removal system, attention is drawn to the report (ATV 1988a) and corrigendum (ATV 1988b) and the notes in the ATV Manual (ATV 1997b, see 3.5.4).

Table 6: Standard values for the dimensioning of sludge scrapers

Parameter	Unit	Circular tank	Rectangular tank	
		sludge scraper	sludge scraper	belt scraper
Scraper blade height	m	0,3 – 0,6	0,3 – 0,8	0,15 – 0,3
Scraper speed	m/h	72 – 144	max. 108	36 – 108