Design measures to increase the efficiency of secondary sedimentation tanks

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Abstract Due to the fact that there is very little difference between the density of water and activated sludge, turbulences and energy inputs in secondary sedimentation tanks impair the sedimentation behaviour of the sludge particles. Consequently, all measures that reduce turbulence can be said to be positive and, thus, desirable. Bearing this in mind, a new type of secondary sedimentation tank has been developed. As hydraulic energy is predominantly introduced via the inflow, it is recommendable to feed the sludge/water mixture directly into the sludge layer on the bottom of the tank. In addition, sludge and water should, if possible, flow in the same direction. If these principles, which can be applied to both rectangular and circular secondary sedimentation tanks, are taken into account, the tanks can be designed more cost-effectively and efficiently.

Keywords Biological wastewater treatment; final sedimentation tank; new design; higher efficiency; operational experiences

Introduction
The discussion surrounding the correct design and dimensioning of secondary sedimentation tanks is almost as old as biological wastewater treatment itself. The main reasons for this are the complicated, and very difficult to model, processes that take place in such tanks. Not least for this reason, numerous studies have been carried out on the design of these tanks. A more in-depth analysis of the processes that take place shows, as will be discussed in the following, that there is an optimization potential which can be used as the basis to design new tanks, or to modify existing tanks, in a more cost-effective way in order to increase efficiency.

Dimensioning of secondary sedimentation tanks
Applying ATV-A 131 (1991), secondary sedimentation tanks are dimensioned based on:
• a permissible sludge volume surface loading in order to determine the size of the tank surface;
• a layer model, in order to determine the tank depth.

These dimensioning rules are based on the results of comprehensive empirical studies and analyses, which, however, do not contain a precise description of the actual processes taking place. Therefore, in order to be able to further increase the efficiency of these tanks, a more in-depth analysis of the process sequence is required.

At first, the dimensioning of a secondary sedimentation tank on the basis of the sludge volume surface loading, according to the equation:

\[ q_{sv} = q_A \cdot MLSS \cdot SVI \text{ in } l/(m^2 \cdot h) \] (1)

where:

\[ q_A = \frac{Q}{A} \text{ = surface flow rate in m/h} \]
\[ Q = \text{ flow rate in } m^3/h \]
\[ A = \text{ secondary sedimentation tank surface in } m^2 \]
would seem to be correct and plausible. When dimensioning, it is assumed that vertical-flow tanks can be subject to a higher load than horizontal-flow tanks. However, in reality, due to the spatial flow conditions, there are both horizontal and vertical flows in both types of tank (Deininger, 1997), so that no clear delineation is possible.

The sludge volume surface loading \( q_{sv} \) and the tank depth \( h \) are directly linked with each other, the tank depth necessary increasing with increasing \( q_{sv} \). As a result, with given tank dimensions, the permissible sludge volume surface loading is essentially a function of the existing tank depth. Therefore, the tank depth is calculated according to the following equation:

\[
h_{total} = C_f \cdot t_{th} \cdot q_{SV} \cdot \frac{(1+RASR)}{1000}
\]

where:

- \( h_{total} \) = sludge level in m
- \( C_f \) = construction factor
- \( RASR \) = return activated sludge ratio
- \( t_{th} \) = thickening time in h.

In the past, too little attention has been given to the influence of the turbulence caused by the scraper installation and the position of the inlets and outlets. An increase in the efficiency of secondary sedimentation tanks can, in particular, be achieved if these factors have as little as possible influence on each other and are limited to a small area.

In this context, the arrangement of the inlet must be regarded as the most important factor. If the incoming wastewater flows into a zone in the area of the inlet with a higher sludge density (as in the case of Dortmund tanks), a floc filter can develop, as a result of which turbulence will decrease and the separation efficiency increase. As opposed to this, in tanks where the inlet is arranged at a higher level, the risk that suspended solids will be carried off increases, because, in this case, the turbulence caused by the inflow of the wastewater/sludge mixture can spread more easily.

**Increased efficiency through arrangement of the inlet at a low level**

**Tank design and effects**

In ATV-A 131, it is, in general, assumed that, with the exception of the vertical-flow Dortmund tanks, the inlet should be above the thickening zone in order to avoid turbulence in the settled sludge and, thus, prevent higher contents of suspended solids in the effluent. However, when the inlet is arranged at a low level, as has, in the meantime, been done at several plants belonging to the Emscher and Lippe Associations, the height, and thus the volume, of this zone can be considerably reduced.

This is based on the knowledge that the kinetic (hydraulic) energy introduced into the tank via the inflow, and the resultant turbulence in the inlet area caused by the resistance of a more dense thickened sludge, decrease very much quicker than when inflow is largely unchecked in the clear water zone. Depending on the volume of water flowing in and the width over which it is distributed, this “inlet disturbance” continues up to a maximum length of 3 metres in the tank. Subsequently, due to its lower density, this sludge deposits itself on the already existing sludge layer. This process is schematically illustrated in Figure 1. The sludge already deposited in the tank is not swirled around as a result. The
prerequisite is, however, that an adequately thick sludge layer is maintained, which should not be less than about 50 cm thick and must be higher than the inlet.

Due to the immediate formation of macro flocs as a result of this, water and sludge are separated more rapidly, even the finest flocs being incorporated in the sludge layer, so that hardly any sludge particles are found above this layer. Nor is the macro flow (accompanied by a marked return flow at the surface of the tank) as described, inter alia by Deininger (1997), to be found here. The reason for this is that there is no longer any densimetric flow above the level of the sludge, since water and sludge are separated, for the most part, immediately after flowing into the tank. Consequently, the water above the sludge layer can flow unhindered to the outlet troughs.

When storm water flow begins, the sludge level slowly rises, but, for the most part, remains horizontal, the point at which the outlet is arranged being more or less irrelevant. The sill load also has little influence. Only when the sludge level rises to 30–50 cm from the edge of the outlet does sludge drift off to a higher degree as a result of the suction effect. For this reason, however, an outlet as wide as possible is of advantage.

When the inflow volume decreases, the sludge level rapidly drops. Theoretically, this could be used to advantage, if this type of tank were to be loaded differently in terms of time, or operated at intervals. In case of an overload, the tank could be taken out of operation for a short time (approximately 30 minutes) until the sludge level has dropped. This alternative mode of operation would only be possible at large plants with an adequate number of tanks and, in addition, would require a considerable amount of control equipment.

In order to achieve a high degree of efficiency, scraping has to be carried out in such a way that the sludge layer forming in the area of the inlet is not disturbed and, thus, not removed. If, in addition, sludge is removed in the case of rectangular tanks in the same direction as the incoming flow of sludge and water, using, e.g., a belt scraper, the sludge can continue to thicken while being transported towards the other end of the tank. Due to the fact that the direction and speed of the scraper and that of the water above the sludge layer differ only negligibly, turbulence and, thus, a swirling around of the sludge, is avoided. Consequently, even with long thickening periods, any redissolution of phosphorus is harmless since, due to the absence of turbulence in the thickening zone, practically no water with a high phosphorus content flows into the clear water zone.

The arrangement of an inlet close to the bottom of the tank is recommendable not only with deep, but also, and in particular, with shallow tanks, because then, the otherwise usual turbulence over a wide area does not occur. However, the arrangement of the inlets and outlets, as well as sludge removal, must be carefully harmonized. A remarkable increase in efficiency can be achieved by means of this technique, in particular in the case of already existing tanks which are actually too shallow.
Measuring results

*Bottrop Wastewater Treatment Plant.* Experience in the operation of the Emscher Association’s Bottrop Wastewater Treatment Plant (1.34 million p.e.) has shown that a distinct increase in efficiency can be achieved with a low-level inlet (Schlegel, 1997; Teichgräber, 1996). The tanks, optimized in the course of studies, were constructed as transverse-flow, rectangular tanks (Figure 2). The inlets, arranged at the bottom of the secondary sedimentation tank, stretch over the entire length of the tank. The inlets are completed by an angular plate installed behind them, which leaves a space of only 6 cm between its lower edge and the bottom of the tank. The sludge is removed from these tanks by means of suction scrapers with vacuum-cleaner-type nozzles. The outlet troughs are arranged along both longitudinal walls of the tank.

As can be seen from the measuring results, the design chosen for the secondary sedimentation tank promotes the sedimentation process. With operational values of

- SVI = 77 ml/g
- MLSS = 3.9 g/l
- $q_A = 1.38 \text{ m/h}$
- $q_{SV} = 414 \text{ l/(m^2.h)}$
- RASR = 0.53

a sludge level of only 1.5 m was determined in the 5.7 m deep secondary sedimentation tanks. Calculation according to A 131 would have produced a value of 2.6 m in this respect. Consequently, the tank depth could be theoretically reduced accordingly. In this case, however, the greater depth helps to prevent flotation of the activated sludge which, due to the very deep aeration tanks (10 m) existing there, cannot be excluded.

*Waltrop Wastewater Treatment Plant.* The two horizontal-flow secondary sedimentation tanks at the Lippe Association’s Waltrop Wastewater Treatment Plant have the following design characteristics:

- Max. surface flow rate: 1.4 m/h
- Tank depth: 3.0 m
- Scraper system: suction scrapers
- Clear-water outlet troughs: on the longitudinal sides of the tank

In order to prevent sludge drift-off, with an SVI of 70 ml/g in the aeration tank, a maximum solids content MLSS of 3.5 g/l could be maintained.

![Figure 2 Sectional view of a secondary sedimentation tank at the Bottrop Wastewater Treatment Plant](image-url)
The efficiency of the plant could be increased by means of the restructuring measures described above. Since arrangement of the inlet at a low level and retrofitting of a belt scraper operating in flow direction (Figure 3) it is now possible to operate the tanks with a sludge volume surface loading of up to 500 l/(m² h), in spite of the fact that the existing tanks are relatively shallow. Moreover, the sludge clouds which were previously clearly visible in the area of the inlet even with dry-weather flow, are no longer to be seen. Nor did the taking out of operation of a tank during the retrofitting phase, which led to the hydraulic load of the remaining tanks being doubled, have a negative influence on the operating results.

The following mean operating data of the Waltrop Wastewater Treatment Plant (35,000 p.e.) have been observed (Table 1).

Finally, the increase in the activated sludge content, possible as a result of restructuring the tanks, has led to a stabilization of the nitrification process. As a result, the minimum requirements with respect to the parameter nitrogen can now be adhered to (Figure 4) without having to structurally expand the wastewater treatment plant. The lower ammonia concentrations are a result of the higher MLSS concentrations which could be increased from an average 3.6 up to 4.8 g/l. According to this the sludge age went up from 9 to 12 d.

Conclusions
Based on this knowledge, a new type of secondary sedimentation tank has been developed by the Emscher and Lippe Associations. This is characterized by the following main features which, in some cases, differ greatly from conventional designs:

• a low-level inlet;
• no sludge scraping in the area of the inlet;
• a uniform flow direction of water and sludge.

With the low-level inlet, two objectives are being pursued. On the one hand, this should minimize the kinetic energy introduced into the tank and, on the other, the influent will flow directly into the sludge layer. This mode of procedure is completely contrary to conventional

Table 1  Mean operating data of the Waltrop WWTP

<table>
<thead>
<tr>
<th>Prior to restructuring</th>
<th>After restructuring</th>
</tr>
</thead>
<tbody>
<tr>
<td>SVI</td>
<td>70 ml/g</td>
</tr>
<tr>
<td>Attainable MLSS</td>
<td>3.5 kg/m³</td>
</tr>
<tr>
<td>Sludge level with QDW</td>
<td>0.6 m</td>
</tr>
<tr>
<td>Max. sludge level observed</td>
<td>2.8 m</td>
</tr>
<tr>
<td>Surface flow rate qa</td>
<td>1.4 m/h</td>
</tr>
<tr>
<td>Sludge volume surface loading qSV</td>
<td>340 l/(m²h)</td>
</tr>
<tr>
<td>Depth of secondary sedimentation tanks</td>
<td>3.0 m</td>
</tr>
<tr>
<td>Calculated depth according to ATV-A 131</td>
<td>3.05 m</td>
</tr>
</tbody>
</table>
approaches but, based on relevant studies and experience, has proven to be optimal. The reasons which could support this theory are as follows.

- The higher the level at which the wastewater/sludge mixture is introduced into the tank, the stronger the turbulence immediately after the inlet of the secondary sedimentation tank due to sedimentation processes caused by differences in density.
- The volume of the sedimentation zone can be greatly reduced by feeding the influent into the sludge layer, because the influent comes in contact with a compact sludge layer which, due to its higher mass, reduces the energy introduced as a result of the inflow rate far more rapidly than when the inlet is arranged above the sludge layer. Moreover, there is a spontaneous formation of macro flocs that settle far more rapidly than would otherwise be the case.
- Due to the fact that the sludge, and the water separated from the sludge, flow in the same direction, far less turbulence is produced than in the case of a counter-directional mode of operation.

Additional design features in respect of rectangular tanks (see Figure 3):

- The inlets and sludge outlets are arranged on opposite sides of the tank.
- Belt scrapers should be given priority over other types of scraper equipment.
- Due to the slow operating speed of the belt scraper, the turbulence which impairs thickening is avoided and, because of the gentle and slow forward movement of the sludge, water discharge is accelerated. As a result, the solids content of the sludge gradually increases from front to rear and, thus, the sludge volume decreases.
- Ideally, sludge should be removed by means of suction nozzles stretching across the entire width of the tank, which cost considerably less than the conventional sludge hopper. Moreover, the use of suction equipment prevents new turbulence from developing as a result of the sludge sliding into the sludge hopper.
- Due to the fact that the clear water is discharged along the entire flow path, the entire secondary sedimentation tank can be used hydraulically to a maximum. In this way, the flow rate of the water from which solids have been removed gradually decreases, which further contributes towards decreasing turbulence.
- The returning span of the belt scraper can be effectively used to transport floating sludge from the tank surface.
Additional design features in respect of circular tanks (see Figure 5):

- Either suction nozzles, or several short blade rakes equipped with suction pipes, are used to remove the sedimented sludge.
- To remove the clear water, priority should be given to the use of submerged, perforated pipes, arranged over as wide an area as possible.

The plants installed to date have proven their efficiency. In particular, this design allows the tanks to be shallower than in the case of a conventional design, it being of secondary importance whether or not so-called vertical or horizontal-flow tanks within the meaning of ATV-A 131 are concerned. As the present results show, an improvement of at least 20% in the efficiency can be expected. Where wastewater treatment plants with shallow secondary sedimentation tanks are overloaded, this technology can preclude the necessity to construct additional secondary sedimentation tanks. In the case of new plants, lower investment costs can be estimated.

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