Chapter 6

Settling-Thickening Tanks

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Learning Objectives

- Understand in what contexts settling-thickening tanks are an appropriate treatment technology.
- Understand the fundamental mechanisms of how settling-thickening tanks function.
- Have an overiew of potential advantages and disadvantages of operating a settling-thickening tank.
- Know the appropriate level of operations, maintenance and monitoring necessary to achieve solids-liquid separation in settling-thickening tanks.
- Be able to design a settling-thickening tank to achieve the desired treatment goal.

6.1 INTRODUCTION

Settling-thickening tanks are used to achieve separation of the liquid and solid fractions of faecal sludge (FS). They were first developed for primary wastewater treatment, and for clarification following secondary wastewater treatment, and it is the same mechanism for solids-liquid separation as that employed in septic tanks. Settling-thickening tanks for FS treatment are rectangular tanks, where FS is discharged into an inlet at the top of one side and the supernatant exits through an outlet situated at the opposite side, while settled solids are retained at the bottom of the tank, and scum floats on the surface (Figure 6.1). During the retention time, the heavier particles settle out and thicken at the bottom of the tank as a result of gravitational forces. Lighter particles, such as fats, oils and grease, float to the top of the tank. As solids are collected at the bottom of the tank, the liquid supernatant is discharged through the outlet. Quiescent hydraulic flows are required, as the designed rates of settling, thickening and flotation will not occur with turbulent flows. Baffles can be used to help avoid turbulence at the inflow, and to separate the scum and thickened sludge layers from the supernatant.

Following settling-thickening, the liquid and solid fractions of FS require further treatment depending on their final fate, as the liquid and solids streams are still high in pathogens, and the sludge has not yet been stabilised or fully dewatered (for combinations of technologies reader is referred to Chapter 5 and 17). Settling-thickening tanks can be used in any climate, but are especially beneficial when treating FS with a relatively low solids concentration, and/or in temperate or rainy climates. This is an important

consideration in urban locations where space is limited, as it can reduce the required area of subsequent treatment steps. For example, achieving solids-liquid separation in settling-thickening tanks prior to dewatering with drying beds reduces the required treatment area (footprint) for drying beds.

When using settling-thickening tanks there should be at least two parallel streams to allow for an entire operational cycle of loading, maintenance and sludge removal. For increased sludge compaction and ease of operations and maintenance, tanks should not be loaded during compaction, if the sludge is left to thicken at the bottom of the tank, or during the desludging period, when the supernatant is drained and the scum and thickened sludge are removed. Tanks are usually operated with loading periods ranging from one week to one month, depending on the tank volume. When operated in parallel, each tank is only loaded 50% of the time.

In most existing implementations in low-income countries, the sludge removal is done with backhoes, pumps if the sludge is not too thick to pump, or strong vacuum trucks. On the other hand, in wastewater treatment plants clarifiers typically include mechanical devices to remove the settled sludge from the tank.

This chapter presents an overview of the fundamental mechanisms, design recommendations, operational conditions and performances of settling-thickening tanks for FS treatment. It is also possible to have larger scale settling ponds, which are similar to anaerobic ponds in wastewater treatment. The main differences between ponds and tanks are that more sludge can accumulate, the sludge is more difficult to remove, and longer retention times result in anaerobic digestion. Due to a lack of actual operational settling-thickening tanks for FS, the information in this chapter is based on theoretical knowledge, and on operating experiences in West Africa. In Kumasi, Ghana, there are 100 m^3 settling-thickening tanks that are employed prior to drying beds at a FS treatment plant (FSTP), as shown in Figure 6.2. The design guidelines presented in this chapter are readily adaptable to other contexts.

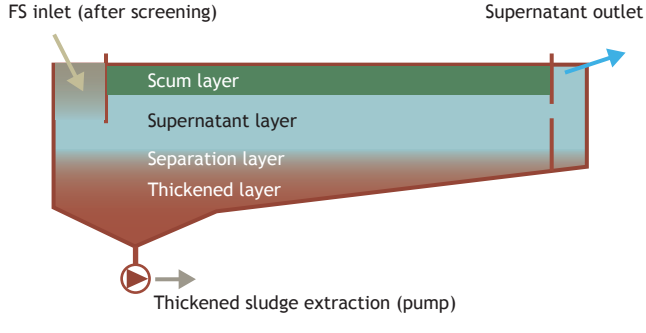

Figure 6.1 Schematic of the zones in a settling-thickening tank.

Figure 6.2 Left: the twin settling-thickening tanks of Rufisque faecal sludge management plant, in Dakar, Senegal. The operating cycle lasts two weeks (one week loading, one week desludging), and sludge is transferred to drying beds with a pump. Right: the settling-thickening pond in Achimota, Accra, Ghana, has an operational cycle of 8 weeks (4 weeks loading, 4 weeks desludging). As the sludge is thickened for four times as long, it is not possible to remove it with a pump, and manual extraction is carried out (photo: SANDEC).

6.2 FUNDAMENTAL MECHANISMS

Settling-thickening tanks rely on three main fundamental mechanisms: settling, thickening, and flotation, which are also described in more detail in Chapter 3. Anaerobic digestion also occurs in the tanks, although this is not a treatment goal of settling-thickening tanks, as anaerobic digestion results in gas production, and the resulting bubbles can hinder the solids-liquid separation through mixing and flotation of particles. A brief overview of these mechanisms is given in the following section.

6.2.1 Settling

In settling-thickening tanks the suspended solid (SS) particles that are heavier than water settle out in the bottom of the tank through gravitational sedimentation. The types of settling that occur are:

- discrete, where particles settle independently of each other;
- flocculant, where accelerated settling due to aggregation occurs; and
- hindered, where settling is reduced due to the high concentration of particles (Ramalho, 1977).

Discrete and flocculant settling happen rapidly in the tank. Hindered settling occurs above the layer of sludge that accumulates at the bottom of the tank, where the suspended solids concentration is higher. These combined processes result in a reduction of the solids concentration in the supernatant, and an accumulation of solids at the bottom of the tank.

Particles with a greater density settle faster than particles with lower densities. Based on the fundamentals of settling the distribution of types and shapes of particles in FS (and their respective settling velocities) could theoretically be used to design settling-thickening tanks. Although this theory is important in understanding the design of settling-thickening tanks, the reality is that when designing a settling tank, empirical values are determined and used for the design based on the characteristics of the FS in specific conditions.

The theoretical settling velocity of a particle is given by Equation 6.1. It is defined by the velocity attained by a particle settling in the tank as the gravitational strength overcomes the buoyancy and drag force that retain the particle in the top layer of the tank.

Equation 6.1: $$V_c = \left[\frac{4}{3} \cdot \frac{g \cdot (\rho_s - \rho) \cdot d}{C_d \cdot \rho} \right]^{1/2}$$

Where:

V_c = final settling velocity of the particle (m/h)
g = gravitational acceleration (m/s^2)
ρ_s = particle density (g/L)
ρ = fluid density (g/L)
d = particle diameter (m)
C_d = drag coefficient

The critical settling velocity, V_c, is selected based on the amount of solids that are to be removed. Theoretically, if the flow is laminar (i.e. not turbulent) and there is no shortcutting of the hydraulic flow in the tank, all the particles with a velocity greater than V_c will be removed. This allows the tank to be designed based on the percentage of desired particle removal in the settled sludge. As the flow in the tank is lengthwise, the length has to be designed to be long enough to ensure that particles with V_c have adequate time to settle out below the level of the outlet. Particles with $V_c < V_{co}$ will not have time to settle out, and will remain suspended in the effluent (as shown in Figure 6.3). How V_c is selected for actual design purposes is discussed in Section 6.3.2.

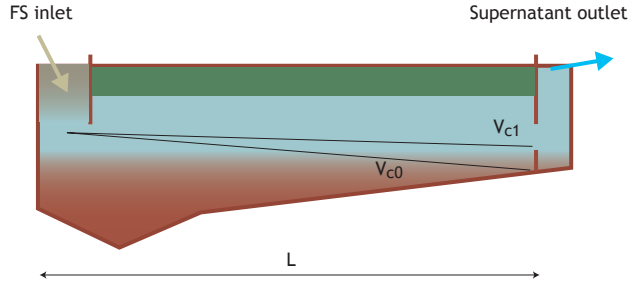

Figure 6.3 Schematic of the final settling velocity (V_c) needed for a particle to settle in a tank of length L.

6.2.2 Thickening

Particles that accumulate at the bottom of the tank are further compressed through the process of thickening. The settled particles are compressed due to the weight of other particles pressing down on them, and water is squeezed out, effectively increasing the concentration of the total solids. This happens as a result of gravity, when the concentration of SS is high and inter-particle strengths hinder the individual movement of particles. Allowing room in the tank for sludge storage as it settles and accumulates is an important consideration in the design of tanks, because as sludge accumulates, it effectively reduces the depth of the tank available for settling. This is also important in designing the ongoing operations and maintenance, and schedule for sludge removal.

6.2.3 Flotation

Similarly to the settling and thickening mechanisms, the influence of gravitational strength due to density differences explains flotation. Buoyancy is the upward force from the density of the fluid. For particles that float, the buoyancy is greater than the gravitational force on the particle. Hydrophobic particles such as fats, oils and greases, and particles with a lower density than water are raised to the top surface of the tank by flotation. Some particles are also raised to the surface by gas bubbles resulting from anaerobic digestion. This layer that accumulates at the top of the tank is referred to as the scum layer.

The scum layer is important to consider in the design process as it also effectively reduces the volume of the tank. The scum layer associated with FS settling can be significant, and cannot be overlooked. Significant scum layers can be seen on the surface of the settling-thickening tanks and ponds in Figure 6.2.

6.2.4 Anaerobic digestion

Anaerobic digestion also occurs in settling-thickening tanks, mainly in the thickened layer. The level of digestion depends on the degree of the initial stabilisation of FS, the temperature, and on the retention time inside the tank. This process degrades a part of the organic matter and generates gasses. Operational experience has shown that fresh FS that is not stabilised (e.g. from public toilets that are emptied frequently) does not settle well. This is because anaerobic digestion of fresh FS contributes to an increased upflow from gas bubbles, and FS that is not stabilised also contains more bound water. Thus, stabilised FS (e.g. from septic tanks) and/or FS that is a mixture of stabilised and fresh sludge are more appropriate for treatment in settling-thickening tanks (Heinss *et al.,* 1998; Vonwiller, 2007).

6.2.5 Solids-liquid zones

The interactions of these fundamental mechanisms result in the separation of the FS into four layers, as illustrated in Figure 6.1 (Heinss *et al.*, 1998; Metcalf and Eddy, 2003):

- A layer of thickened sludge at the bottom. The solid concentration is higher at the bottom than at the top of this layer.
- A separation layer between the thickened layer and the supernatant, as the transition between these is not immediate. Hindered settling occurs mainly in the separation layer, where the settled sludge is not completely thickened. Particles in the separation layer can be more easily washed out with the supernatant than particles in the thickened layer.
- A supernatant layer between the separation layer and the scum layer. This consists of the liquid fraction and the particles that do not settle out or float to the surface.
- A layer of scum at the top of the tank. This consists of the floating organic and non-organic matter, the fats, oils, and greases contained in FS, as well as particles that have been raised up by gas up-flow.

6.3 DESIGN OF SETTLING-THICKENING TANKS

This section provides recommendations for the design of settling-thickening tanks for the treatment of FS based on the current available knowledge. The tank design is based on the estimated volume of FS, and the resulting supernatant flow, and production of scum and thickened sludge layers. An adequate design needs to include regular and efficient removal of the scum and thickened sludge, which needs to be considered to optimise the solids-liquid separation. These design aspects are discussed below, and examples are provided in the case studies and the design example.

6.3.1 Laboratory tests and faecal sludge characteristics influencing the design

A good understanding of site specific FS characteristics is required in order to determine the tank surface and the volume of the scum, supernatant, separation, and thickened sludge layers. As discussed in Chapter 2, determining an accurate value for influent loading of FS can be challenging depending on the local infrastructure and existing management system. The design loading needs to take into account that FS quantities and characteristics can also vary seasonally. An empirical estimation of settling ability for the specific FS that the tank is being designed for needs to be determined for adequate design of the tank. Preliminary laboratory analyses should be conducted on the FS that is to be treated, especially in terms of settling ability, thickening ability, potential for scum accumulation and SS concentration (Strauss *et al.*, 2000). It is important to ensure that the FS used for these tests is that which will actually be treated. For example, if there is an existing network of collection and transport companies with vacuum trucks, sludge should be sampled from the trucks as this is what will be discharged at the treatment plant.

Figure 6.4 Imhoff cones being used in analyses of sludge volume index (photo: SANDEC).

The sludge volume index (SVI) is a laboratory method to empirically determine the settling ability of sludge based on the amount of suspended solids that settle out during a specified amount of time. To determine the SVI, first the suspended solids content of FS is determined, and then a graduated Imhoff cone is filled with the FS sample that is left to settle (see Figure 6.4). After 30-60 minutes, the volume occupied by the settled FS is recorded in mL/L. The SVI is then calculated by dividing the volume of settled FS by the SS concentration (in g/L), which gives the volume of settled sludge per gram of solids (see the example problem on the calcualtion of SVI below). The Imhoff tests do not provide exact estimates of the depth of the thickened layer, as they are batch tests and not continuous loading as in a settling-thickening tank. Imhoff cones with volumes greater than one litre provide a more representative result as the wall effect is reduced (Heinss *et al.*, 1999).

Based on experiences in the design of settling-thickening tanks for wastewater treatment plants, wastewater sludge with a SVI of less than 100 (mL/g SS) achieves good solids-liquid separation in settling-thickening tanks. Measurements with FS in Accra, Ghana and Dakar, Senegal showed that FS had a good settling ability and thickening ability with SVI of 30-80 mL/g (Heinss *et al.*,1998), and the personal experience of Dodane). SVI tests conducted in Dakar, Senegal showed that FS settled rapidly during the first 20 minutes, after which more thickening occurred and continued for 100 minutes (Badji *et al.*, 2011).

Example Problem: Calculation of sludge volume index (SVI)

A sample of FS from a septic tank in Burkina Faso has a SS concentration of 6.6 g/L.
The volume of the settled FS after 60 minutes is 198 mL/L.
The SVI = Volume of settled FS/SS concentration = 198/6.6 = 30 mL/g

This FS would be considered to be appropriate for treatment in a settling-thickening tank. With activated sludge, it is considered that ideal settling conditions are reached with SVI less than 100 mL/g SS (Pujol *et al.*,1990). For FS, the stability and origin also needs to be taken into account, but more studies are needed to assess the adequate limits.

6.3.2 Tank surface and length

The length of the tank needs to be sufficient and have adequate hydraulic distribution, to ensure that the entire tank surface area is used, and that particles have enough time to settle. The surface area of the settling-thickening tank can be calculated as shown in Equation 2, based on the upflow velocity (V_u) and the influent flow (Q_p) (Metcalf and Eddy, 2003).

Equation 6.2: $$S = \frac{Q_p}{V_u}$$

Where:
S = surface of the tank (m^2)
Q_p = influent peak flow (m^3/h)
V_u = upflow velocity (m/h)
$Q_p = Q \cdot C_p/h$,

Where:
Q = mean daily influent flow
C_p = peak coefficient
h = number of operating hours of the treatment plant (influent is only received during operating hours)

The upflow velocity (V_u) is defined as "the settling velocity of a particle that settles through a distance exactly equal to the effective depth of the tank during the theoretical detention period" (Ramalho, 1977). It is used to calculate the acceptable inflow that will allow for particles with the defined settling velocity to settle out. Particles with a settling velocity slower than V_u will be washed out with the supernatant. A value is selected for the desired percentage of suspended solids removal, and then the upflow velocity is selected to be equal to the final settling velocity of the lightest particles that will settle in the tank. For example, as shown in Figure 6.3, $V_u = V_{c0} > V_{c1}$. Thus, for a given FS influent, the upflow velocity in a tank surface corresponds to the removal of a given percentage of suspended solids. The peak coefficient is calculated by observation of when the greatest volumes of trucks are discharging at the FSTP. For example, in Dakar the peak period was observed to be 11:00 because trucks have their busiest emptying periods during the morning, and was calculated to be 1.6 times higher than the average.

V_u can be estimated based on SVI values. Despite the limits of the theoretical calculation for design purposes, methods and calculations to link SVI and V_u have been developed based on long-term experiences in activated sludge treatment (Pujol *et al.*, 1990). However, this type of empirical knowledge does not yet exist for FS. V_u = 0.5 m/h could be used for rectangular settling tanks treating FS that have a SVI less than 100 (personal experience, Pierre-Henri Dodane). Once the surface area has been calculated, the length: width ratio needs to be selected. For example (Heinss *et al.*, 1998) recommend a width to length ratio between 1:10 to 1:5. The lower the selected final settling velocity, the longer the tank needs to be, and the more particles that will settle out.

6.3.3 Tank volume

Once the surface area of the tank has been determined, the volume can be calculated, considering the depth of the four layers described in Figure 6.1. It is necessary to plan for the reduction in depth that will occur due to the accumulation of scum and thickened sludge, which will result in solids washed out with the supernatant if underestimated.

Based on field observations of settling-thickening tanks in Accra and Dakar (Heinss *et al.*, 1998), the following values are recommended for designing tanks for FS with similar characteristics:

- scum zone: 0.4 m (with 1 week loading, 1 week compaction and cleaning) to 0.8 m (with 4 weeks loading and 4 weeks compaction and cleaning);
- supernatant zone: 0.5 m; and
- separation zone: 0.5 m.

The depth of the thickened sludge zone needs to be calculated given the expected load inflow and the concentration of the thickened sludge (C_t). The design of a sufficient storage volume for the thickened sludge is crucial to avoid outflow of settled sludge during one operating cycle. Therefore, the expected operating cycle duration (i.e. loading, compaction and sludge removal) and methods for scum and thickened sludge removal need to be defined in the first place. The volume of the thickened sludge storage zone (V_t) can be calculated as shown in Equation 6.3 (Metcalf and Eddy, 2003).

Equation 6.3: $$V_t = \frac{Q \cdot C_i \cdot e \cdot N}{C_t}$$

Where:
V_t = volume of thickened sludge storage zone (m^3)
Q = mean FS daily inlet flow (m^3/day).
C_i = suspended solids mean concentration of FS load (g/L)
e = expected settling efficiency (= proportion of suspended solids separated, as %)
N = duration of the FS load for one cycle in days
C_t = suspended solids mean concentration of thickened sludge after the loading period (g/L)

The mean daily flow is used for the sludge accumulation estimate, but the peak flow is used for the tank surface and length design to ensure settling is achieved under all the expected operating conditions. The volume of the thickening zone is based on the expected settling of FS. It is not considered in the design, but longer storage times when the tanks are not loaded prior to sludge removal, result in increased thickening and compaction. In the field, average FS settling efficiencies of only about 60% have been observed, due to poor operation and maintenance and gas upflow (Heinss *et al.,* 1998). However, it is recommended to use 80% to estimate the maximum efficiency.

Care must be taken to ensure a relatively accurate estimate of C_t. An overestimation will lead to an insufficient storage volume and to a reduced settling efficiency, as solids may be washed out without being able to settle. An underestimation will lead to the design of an unnecessarily large storage volume and increase in construction costs. Table 6.1 presents examples of SS concentrations given the initial FS load and thickening duration.

Table 6.1 Concentration of sludge in the thickening zone of settling tanks in Accra and Dakar (Heinss *et al.*, 1998; Badji *et al.*, 2011)

Place of measurement	Concentration at inlet (g SS/L)	Thickening duration (day)	Concentration in thickened zone (g SS/L)
Dakar, FSTP	5	10	60-70
Accra , FSTP	15-20	9	60-85
Accra , FSTP	15-20	30	>100
Accra , FSTP	15-20	50	140
Accra , laboratory	40	7	100

The FS loading period needs to be defined given the FS characteristics, the expected total solid concentration of the thickened sludge, and the seasonal variations. The advantages of short loading and compaction periods are that the scum layer is maintained at a minimum depth, and the thickened sludge is easily removed by pumping, as it is not heavily compacted (Case Study 6.1).

Case Study 6.1 : Operation of settling-thickening tanks in Dakar, Senegal and Accra, Ghana
(Adapted from Heinss *et al.*, 1998; Badji *et al.*, 2011)

Settling-thickening tanks of different sizes have been in operation in Dakar (Senegal) since 2006 and in the Accra region (Ghana), since the late 1980s. Short loading periods of about one week were adopted for the FS treatment plants in Dakar, where the thickened sludge is mostly removed by pumps, and the most compacted sludge and scum is removed with vacuum trucks. The removal of scum requires powerful vacuum trucks, which are not always available. It is thus crucial to ensure the regular availability of mechanical means to remove the most compacted solid products to ensure the tank's efficiency and sustainability.

Settling-thickening tanks of the Cambérène treatment plant were designed with a nominal HRT of 8.6 hours. Due to initial underestimation of the FS volumes to treat, the settling-thickening tanks were overloaded and operated with an effective HRT of 1.7 h. Thus as discussed in Chapter 2, a preliminary study to assess the volumes and concentrations to be treated is required before designing tanks. Collection and transport activities should be assessed, including area served, the number of households, the frequency of collection from onsite systems, and the type of onsite systems.

Long loading periods of 4 weeks were adopted for the settling-thickening tanks in Accra, where the tanks have a larger volume to allow storage of greater quantities of FS. Due to the size, these types of tank are also referred to as settling-thickening ponds. The loading phase was operated over 4 weeks, with an additional compaction phase where they are not loaded over 3-4 weeks before the sludge removal. In this case, the scum layer is deeper, and the thickened sludge is more compact and therefore more difficult to remove. Front-end loaders have been used to remove both the thickened sludge and the scum, which have a high solids concentration. Large settling-thickening ponds can therefore be more difficult to operate.

6.3.4 Inlet and outlet configuration

Grit screening must be undertaken before the loading of FS into the settling-thickening tanks in order to facilitate maintenance (e.g. removal of coarse waste to avoid potential degradation of pumps). This is explained further in Chapter 5, Overview of Treatment Technologies.

The inlet zone should allow for the uniform and quiescent distribution of the flow in the whole tank and avoid short-circuiting. Therefore, baffles are recommended to help disperse the energy of the inflow, and to reduce the turbulence in the tanks. (Heinss *et al.*, 1998) recommend locating the inlet zone near the deep end of tanks to improve the solids settling. The pumps for the extraction of the thickened sludge must be adapted to remove concentrated sludge. Easy access points should also be included to allow the sampling of sludge in these zones, and to ensure that easy repair of pumps is possible.

The supernatant outlet zone should be located under the scum layer and above the thickened sludge storage layer. Baffles are useful to avoid washout of the scum with the supernatant. To ensure an optimal hydraulic flow, the outlet channel can be extended along the width of the wall (Heinss *et al.*, 1998). It must be at the opposite side of the inlet zone. Outlets that are positioned near to the shallower side of the tank reduce the carry-over of the settled solids from the thickening layer.

6.4 OPERATION AND MAINTENANCE OF SETTLING-THICKENING TANKS

At least two settling-thickening tanks should be operated alternately in parallel, in order to allow for sludge removal as tanks should not be loaded during this time. The loading of FS, and the compaction and removal of the thickened sludge and scum comprise the main phases of an operating cycle. These periods allow for the expected solids-liquid separation and thickening operations. While the tanks are not loaded, additional compaction occurs prior to the removal of thickened sludge and scum, due to the lack of hydraulic disturbance (Heinss *et al.*, 1998). During this time further solids-liquid separation occurs, and the SS concentration increases in the thickened sludge and scum.

6.4.1 Sludge and scum removal

The timing of the removal of sludge and scum as planned for in the design is essential to ensure that the settling-thickening tanks are functioning properly, and that there is adequate depth for the settling of particles, leading to a reduced solids-liquid separation.

Figure 6.5 shows an example of the volume reduction resulting from inadequate sludge removal practices. In this case, the scum layer was not removed during such a long period that as a consequence, weeds are seen growing on the surface. This should be avoided.

If it is observed that a higher volume of thickened sludge has accumulated than what was designed for, this means that the solid load is higher than expected, and operations should be appropriately altered. Sludge removal typically lasts a few hours to a day following the compaction period. Once in operation, detailed monitoring can be done to optimise compaction and sludge removal times based on actual operating conditions.

Figure 6.5 Example of inadequate operation and maintenance of a settling-thickening tank in West Africa. The scum was not removed during a long period, which allowed plants to grow on it. The volume of sludge and scum accumulated does not allow for proper operation of the tank, or for solids-liquid separation (photo: SANDEC).

Figure 6.6 Settling-thickening tank of Rufisque showing the scum layer (photo: SANDEC).

The first step in sludge and scum removal is typically removal of the scum layer. The scum layer generally has a high solids concentration that cannot be easily pumped and can remain after the thickened sludge is removed (Figure 6.6), in which case it needs to be manually removed. If possible, scum can be removed with shovels from both sides of the tank when the tank is narrow enough for access, or by mechanical means such as vacuum trucks with strong pumps. Scum can also be removed manually or sucked by a vacuum tanker after emptying the tank as it is done at the Cambérène treatment plant.

Next, the supernatant layer is frequently removed by pumping or by gravity (depending on the design). It can be pumped to the parallel settling-thickening tank or to the next step in the treatment chain. The thickened sludge can then be pumped or shoveled out of the tank after the supernatant has been removed. When a pump is used for extracting the thickened sludge, the supernatant layer does not need to be removed, as the supernatant layer can facilitate the pumping of thickened sludge as a pressure is maintained. As tanks are frequently over 2 m deep, adequate access for sludge removal (and for tank and pump cleaning) needs to be integrated into the design. The operator knows when it is time for sludge removal based on the loadings and times given in the design, and also by visual observation.

It is possible to design settling-thickening tanks with devices that continuously scrape and pump the thickened sludge out of the tanks, and remove the scum over the supernatant zone. These devices allow easier operation and increase the management flexibility, but increased operating and maintenance costs need to be taken into consideration (Chapter 11).

6.4.2 Start-up period and seasonal variations

As settling-thickening tanks rely mainly on physical processes, there is no special requirement for start-up periods. It is however useful to adjust the load time, assess the depths of the different zones and optimise the compaction time and sludge removal frequency. Seasonal variations of meteorological conditions and FS characteristics may influence the efficiency of the tanks. For example, loss of water through evaporation could increase the solids content of the scum. High temperatures may also increase the anaerobic digestion process, and therefore the height of the scum layer.

Case Study 6.2: Cambérène FST – settling tanks and sludge drying beds

(Adapted from Badji *et al.*, 2011; continued in Case Study 7.2)

Cambérène FSTP, the first treatment plant at scale serving Dakar city, was put in operation in 2006. It is composed of a combination of settling-thickening tanks (two tanks of 155 m^3 each) and unplanted drying beds (10 beds of 130 m^2 each). The thickened sludge is extracted from the settling-thickening tanks and transferred to drying beds by pumping. The effluent from the tank and the leachate from the drying beds are transferred to the wastewater treatment plant. Each week, one tank is used for receiving FS while the other tank is pumped out and cleared from the scum layer. The FS in Dakar is dilute with an average TS of 5 g/L. There is a high groundwater table in Dakar and the majority of sludge is from septic tanks.. The combination of settling/thickening tanks and drying beds was selected to thicken the dilute sludge before drying and in order to reduce the required area for drying beds.

From 2007 to 2009, daily measurements of the pollutant fluxes were conducted at the inlet and outlets of the two treatment stages. Continuous monitoring of sludge characteristics (concentration, dry matter content) in the settling-thickening tanks and drying beds was conducted, and reported by Badji *et al.* (2011), as summarised in Figure 6.7. Although the FSTP was designed for treating 100 m^3 of FS/day and 700 kg TS/day, the plant received 340 m^3 FS/day and 1,700 kg TS/day. The pollutant analysis in the plant in real operational condition is presented in the figure below.

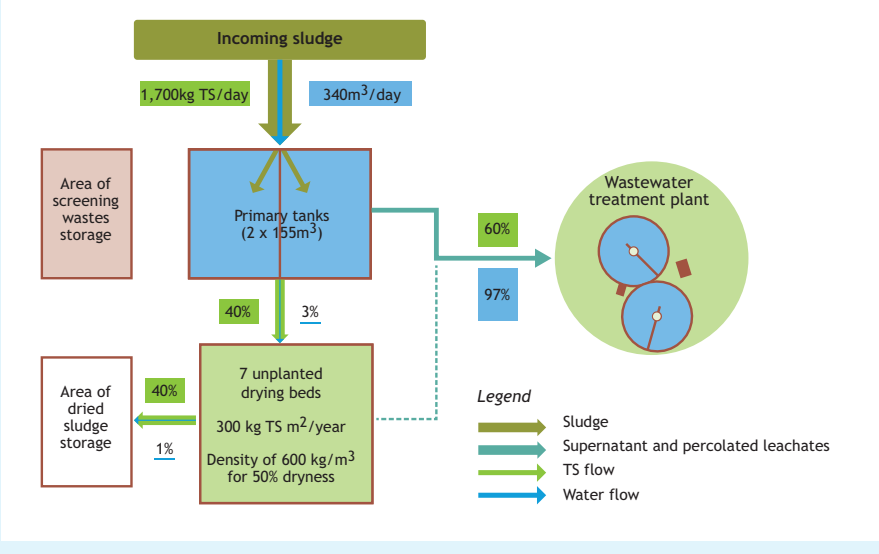

Figure 6.7 Efficiency and fluxes analysis of Cambérène faecal sludge treatment plant in real operational conditions (Badji *et al.*, 2011).

Experiences from Accra reveiled the possibility to obtain a TS concentration of 150 g/L with a similar settling tank. However, it was not known at the time that the influent in Ghana had a higher concentration to start with. Moreover, the Dakar operator left the sludge in the settling-thickening tank for one week only, while the plant in Ghana ran on longer HRTs. As a consequence, a thickened sludge concentration of 60-70 g TS/L was achieved after one week of thickening while 140 g TS/L was envisioned in the design. The achieved removal was far from the designer expectations. This shows the great importance of conducting preliminary studies in order to define sludge characteristics (e.g. concentration, inlet flow and thickening degree) based on local conditions, despite the difficulty – it can save significant amounts of money for the real operation of the plant. Operation and maintenance of the tanks were considered difficult by the operator, in particular entering the tank for scum cleaning. The pumping also required attention as the axle was often blocked by debris and needed to be cleaned. This led to delays in thickened sludge pumping, and as a consequence to an increased overloading in the parallel tank (see Figure 6.7).

6.5 PERFORMANCE OF SETTLING-THICKENING TANKS

The most important consideration in the performance of settling-thickening tanks is the separation of the liquid and solid fractions. The efficiency of the key mechanisms to achieve this are discussed here.

6.5.1 Solids-liquid separation

In the field, the mean settling efficiency of operating tanks and ponds is about 50-60% of SS in the settled volume. This efficiency can reach up to 80% where the tanks have been adequately designed and operated (Heinss *et al.*, 1999).

The concentration of the thickened sludge (C_t) achieved depends on the operating cycle duration and the initial FS characteristics (thickening ability), as presented in Table 6.1. Achieving 60 g SS/L in the thickened zone for a seven day load period seems a reasonable estimate. In Accra, with an operating cycle of about eight weeks, (Heinss *et al.*,1998) observed a total solid content of 150 g TS/L in the thickened layer.

The scum layer thickness and SS content depends mainly on the operating cycle duration, the FS characteristics and the evaporation process. (Heinss *et al.*, 1998) report a scum layer of 80 cm in settling-thickening tanks operated with cycles of 8 weeks. In the Dakar FSTP the observed scum layer had a depth of 10 to 20 cm after one week of loading.

6.5.2 Treatment performance

The main objective of settling-thickening tanks is solids-liquid separation, not stabilisation or pathogen reduction. Further treatment steps are required for both the thickened solids and supernatant. Dissolved organic matter, nutrients, and suspended particles will remain in the supernatant. Examples include 50% of influent COD in the settled sludge, and 50% in the supernatant (Badji *et al.*, 2011), and 10% influent BOD and 25% COD in the supernatant (Heinss, *et al.*, 1998). Total pathogen removal or inactivation is also negligible. Many larger pathogens such as Helminth eggs settle out, and the amounts that are partitioned in the solids will be correlated to SS removal efficiency. (Heinss *et al.*, 1998) observed that 50% of the total Helminth eggs were partitioned in the thickened sludge.

Table 6.2 Results of preliminary studies to determine design parameters

Initial raw FS concentration:	$C_{i(TS)}$= 7 g TS/L $C_{i(SS)}$= 5 g SS/L
FS origin:	Mainly septic tanks (stabilised FS)
Total volatile solids percentage	< 70%
Influent flow:	Q=140 m^3/day
FSTP opening time:	7 h/day 5 days/week 52 weeks/year
Daily peak flow coefficient:	C_p=1.6 (peak flow is often in the morning, after the first trucks rotation)
Concentration of thickened sludge (1 L Imhoff cones)	60 g SS/L
Settling ability (1 L Imhoff cones)	Good (SVI = 23 << 100)

6.6 ADVANTAGES AND CONSTRAINTS OF SETTLING-THICKENING TANKS

Settling-thickening tanks are efficient as a first treatment step as they rapidly achieve solids-liquid separation, they are relatively robust and resilient, and they reduce the volume of sludge for subsequent treatment steps.

Constraints of settling-thickening tanks include:

- lack of experience operating with FS, and lack of empirical data and results on which to base designs on;
- settled sludge still has relatively high water content and requires further dewatering;
- the liquid fraction remains highly concentrated in SS and organics; and
- pathogen removal is not significant, and the endproducts of settling tanks therefore cannot be discharged into water bodies or directly used in agriculture (for more details on appropriate enduse see Chapter 10).

6.7 DESIGN EXAMPLE FOR A SETTLING-THICKENING TANK

As mentioned in the previous sections, the design of settling-thickening tanks involves calculating the basin surface, the zone volumes and the hydraulic configurations.

6.7.1 Initial situation

In a real-life situation, sufficient preliminary studies are needed to allow for the specific design according to the local context characteristics. This example of a design calculation corresponds to a typical situation in which settling-thickening tanks can be implemented and is based on information obtained from preliminary studies as shown in Table 6.2.

6.7.2 Assumptions and design decisions

Based on these preliminary results, the following assumptions and design decisions can be made:

- a final settling velocity of V_c = 0.5 m/h based on SVI tests and experience.;
- the expected settling efficiency (e) is 80% of SS.;

- two parallel tanks are designed to allow the cleaning of one during the loading of the other;
- a loading period of one week (N = 5 = number of treatment plant opening days per week) to minimise anaerobic digestion and gas upflow. This means that each tank is loaded for one week out of every two weeks, while the extraction of thickened sludge and scum is carried out on the other tank;
- a short compaction period of 2-3 days. Hence, the removal of thickened sludge and scum occurs every 10 days by pumping, as the thickened sludge is still sufficiently liquid; and
- the operator has experience in wastewater treatment and therefore the thickened sludge pumping and tank cleaning is likely to be carried out correctly.

6.7.3 Design calculations

The tank surface (S) needed to allow for the selected final settling velocity (V_c) is estimated based on the influent peak flow (Q_p) as shown in the following equations.

Equation 6.4: $Q_p = Q \cdot C_p / 7 = 32\ m^3/h$

Where 7 = number of FSTP opening hours per day

Equation 6.5: $S = Q_p / V_c = 64\ m^2$

Thickening zone volume

The daily SS quantity of FS discharged (M) is calculated from the initial FS concentration (C_i):

Equation 6.6: $M = Q \cdot C_{i(SS)} = 700\ kg\ SS/day$

The daily SS mass of thickened sludge (M_t) is then deduced from the SS settling efficiency (e):

Equation 6. 7: $M_t = M \cdot e = 560\ kg\ SS/day$

Where e = 80%. For a safe design, the value of e should be the maximum expected efficiency (not the mean).

The volume of the thickening sludge storage zone (V_t) is related to the mass of the particles trapped in the thickening zone (M_t) and the SS concentration achieved in the thickened sludge (C_t):

Equation 6.8: $V_t = M_t \cdot N / C_t = 47\ m^3$

Tank configuration

The surface of the tank should be long and narrow and facilitate the distribution of flow. The recommended width to length ratio ranges from 0.1 to 0.2. To reach a surface close to 64 m^2 (see Equation 6.5), the following configuration should be adopted:

Equation 6.9: $S(l \cdot L) = 3 \cdot 22 = 66\ m^2$

Zone depth

The following design characteristics are given for each zone:

- Scum zone: 0.4 m (value assumed to be safe for a 2 week cycle);
- Supernatant zone: 0.5 m (Heinss *et al.*, 1998);
- Separation zone: 0.5 m (Heinss *et al.*, 1998); and
- Thickening sludge zone: 0.75 m (based on 47 m^3 storage in a 66 m^2 tank).

A schematic diagram of the zone depths is shown in Figure 6.8.

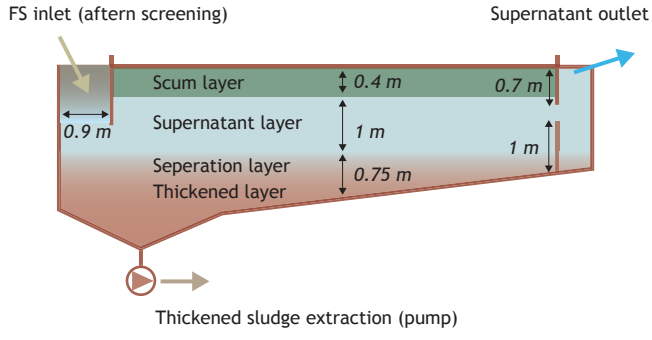

Figure 6.8 Schematic of tank configuration described in design example.

6.7.4 Mass flow analysis of faecal sludge treatment

In this example, the thickened zone was designed based on an 80% SS removal. In order to plan for options to further treat the supernatant, a more realistic settling efficiency (e) of 60% SS should be considered such that the supernatant contains 40% of $C_{i(SS)}$. These mass flows are shown in Figure 6.9, with the estimated SS flows to the treatment options for the supernatant and the thickened sludge.

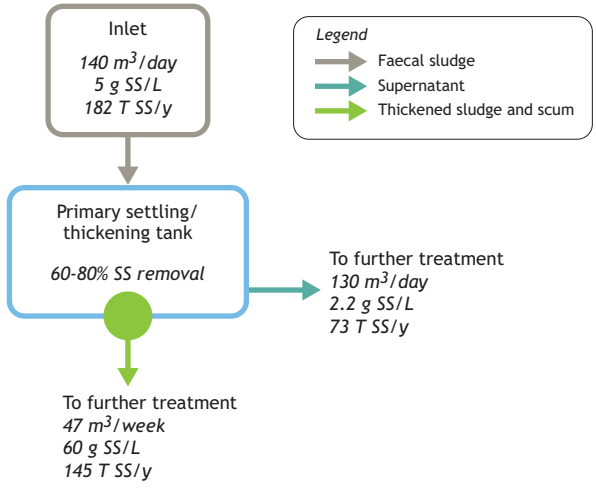

Figure 6.9 Schematic presentations of the treatment and mass flows for the theoretical example.

6.8 BIBLIOGRAPHY

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End of Chapter Study Questions

1. What are three fundamental mechanisms that explain how settling-thickening is achieved? Explain how they work.

2. List three advantages and three disadvantages associated with the operation of settling-thickening tanks.

3. What are the three factors that need to be calculated in order to design settling-thickening tanks?

4. In the design of settling tanks, why is it important to calculate the basin surface, the zone volumes, and the hydraulic configurations?