

SOME PROPOSALS FOR THE DESIGN METHODOLOGY OF TWO-TIER SEDIMENTATION TANKS



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Abstract: The conventional design methodology for two-tier sedimentation tanks has several limitations: some design parameters are assumed, while others, in our opinion, should be calculated. This particularly concerns the depth of the flow section of the sedimentation tank (H_{set}) and the detention time (t_{set}). According to the proposed calculation methodology, achieving a clarification efficiency of 40–65% in two-story settling tanks requires significantly shorter settling times than the currently adopted design values of 5400 s (or 3600 s under low-flow conditions). A clarification efficiency of 42.9% can be achieved with a settling time of only 1630 s. By maintaining a settling-zone depth of 1.2–2.5 m, the methodology enables independent determination of the depths of the cylindrical and conical sections. This design promotes laminar wastewater flow, enhances suspended-solids sedimentation, and reduces both settling-zone and overall tank dimensions while maintaining the required clarification efficiency.

Keywords: two-tier sedimentation tank, sedimentation trough, flow section, design depth, detention time, suspended solids, hydraulic size.

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Introduction

Water resources management plays an important role in maintaining water supply, public health, and environmental protection. Globally, population growth, urbanization, and industrial development have produced large amounts of wastewater, placing significant strain on wastewater treatment facilities and the aquatic bodies that receive treated effluents. Therefore, efficient treatment methods are crucial to reduce pollution, safeguard aquatic habitats, and advance the Sustainable Development Goals (SDGs), especially SDG 6, which aims to ensure the availability and sustainable management of water and sanitation for everyone [1-3].

Before biological treatment, primary treatment significantly reduces suspended particles and organic matter, making it a crucial step in wastewater treatment systems. Sedimentation remains one of the most popular and cost-effective primary treatment techniques for removing settleable particles from wastewater. For sedimentation to be efficient, it must create ideal hydraulic conditions that allow suspended particles to settle under gravity while reducing turbulence and short-circuiting [4-6]. Consequently, the hydraulic and geometric design of sedimentation tanks plays a decisive role in determining treatment performance.

The original design of two-tier sedimentation tanks allows wastewater to enter and leave the sedimentation trough as in horizontal sedimentation tanks, that is, through inlet weirs and collection troughs extending across the entire width of the trough. However, sludge is removed from the digestion chamber from below, as in vertical sedimentation tanks, through a sludge withdrawal pipe under the hydraulic pressure of the water column [7-14]. This unique combination of design features necessitates a comprehensive approach to the hydraulic and structural designs of these facilities [7,15,16].

Because of their simplicity, two-tier sedimentation tanks are widely used to treat domestic wastewater (and wastewater of similar composition), particularly for flow rates up to 10.000 m³/day. These facilities are used for wastewater sedimentation and for digesting and compacting settled sludge. The removal of suspended

solids (up to 60–65%) [4,16,17] occurs in sedimentation troughs, which are designed according to the principles applicable to horizontal sedimentation tanks.

In addition to effective wastewater clarification, the sludge chamber of a two-tier sedimentation tank provides relatively complete sludge digestion. Under the influence of anaerobic bacteria, complex organic substances are first broken down into fatty acids and then decomposed into simpler end products, including methane, carbon dioxide, and, to a lesser extent, hydrogen sulfide [18-23].

Accordingly, this study aims to develop and evaluate a modified design methodology for two-tier sedimentation tanks treating domestic wastewater or wastewater with similar characteristics at flow rates of 10.000–15.000 m³/day. The specific objectives are to: (i) review existing design methodologies for two-tier sedimentation tanks; (ii) develop a procedure for calculating the weighted-average design depth of the sedimentation trough; (iii) establish a methodology for determining the design detention time based on hydraulic relationships and tabulated data; (iv) compare the proposed methodology with conventional design approaches; (v) evaluate the influence of the proposed design parameters on hydraulic characteristics and tank dimensions; and (vi) provide practical recommendations for the design of two-tier sedimentation tanks used in municipal wastewater treatment applications.

The study's scientific novelty lies in proposing to replace the conventionally assumed depth of the flow section of the sedimentation tank (H_{set}), which varies with trough geometry, with a calculated depth (H_p) determined as a weighted-average value. Based on the obtained value of H_p , the structural depth of the two-tier sedimentation tank can be determined using the conventional design methodology.

In addition, instead of adopting a fixed wastewater detention time in the sedimentation trough, namely $t_{set} = 1.5$ h or $t_{set} = 1.0$ h (depending on the daily wastewater flow rate), we propose determining a specific design detention time (t_p).

Materials and Methods

Two-tier sedimentation tanks typically consist of two troughs and are classified as single or twin units based on the number of sludge digestion chambers. In single units (Fig. 1), one sludge digestion chamber serves the entire sedimentation section, whereas in twin units, two digestion chambers serve one sedimentation section.

To design two-tier sedimentation tanks using the conventional methodology, the hydraulic settling velocity is determined first. The depth of the sedimentation section (sedimentation trough) H_{set} is typically assumed within the range of 1.2–2.5 m; the detention time is taken as $t_{set} = 5400$ s, the volume utilization coefficient $K = 0.5$, and the suspended solids removal efficiency (η) is taken within 40–50%. However, in sedimentation tank design, the concentrations of suspended solids in the influent and effluent are typically known. Accordingly, the actual clarification effect can be determined, and based on this indicator, a specific detention time may be selected from the relevant tables as the design value t_p . It is also proposed that the design depth of the sedimentation trough (H_p) should not be assumed, but instead calculated as a weighted-average value.

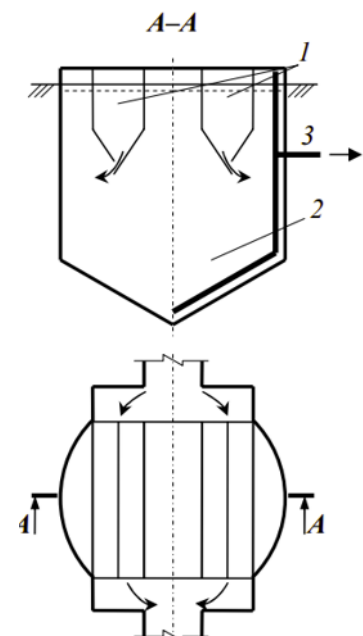


Fig. 1. Two-tier sedimentation tank with two troughs
1 – sedimentation troughs, 2 – sludge septic tank, 3 – sludge removal pipe

By assigning the length of the sedimentation troughs ($L = D = 6, 9, 12$ m), the design flow velocity V_p in the trough can be determined, ensuring that it remains within the range $V_p = 2 - 7 (\leq 10)$ mm/s.

The width of the sedimentation troughs and other parameters can be determined using standard design equations, but with consideration of the obtained calculated values V_p and H_p .

The capacity of the sedimentation troughs is determined based on the maximum hourly wastewater inflow and the water settling time (1–1.5 h). The trough length equals the structure diameter for a circular cross-section or the side length for a square cross-section.

For improved sliding of digested sludge and to facilitate its removal from the tank, the lower part of the structure is designed as a conical section, with the bottom wall slope angle set at $\varphi \geq 30^\circ$.

It is known that the design value of the hydraulic settling velocity (mm/s) should be determined from settling kinetics curves $\varpi = f(t)$, obtained experimentally, by adjusting the laboratory-derived value to a liquid layer height equal to the depth of the flow section of the sedimentation tank, according to the following equation [7,16].

$$U_0 = \frac{1000 \cdot H_{set} \cdot K_{set}}{t_{set} \left(\frac{K_{set} \cdot H_{set}}{h} \right)^n}, \quad (1)$$

where H_{set} is the depth of the flow section of the sedimentation tank (m), that is, the sedimentation trough, typically within the range of 1.2–2.5 m; $K_{set} = 0.5$ is the volume utilization coefficient of the flow section of the sedimentation tank; t_{set} is the settling time (s), corresponding to the required treatment efficiency and obtained from laboratory cylinder tests at a liquid depth h (for municipal wastewater, this value is given in tabulated form); n is an empirical exponent depending on the degree of flocculation (agglomeration) of suspended particles during settling (for municipal wastewater, it is taken from the corresponding design charts).

Accordingly, under the current norms (40-01.03-2022 "Sewage¹ external networks and structures", approved by the construction norms of the Republic of Armenia), primary sedimentation tanks are designed based on the settling kinetics of suspended solids, considering the required clarification efficiency. In contrast, the sedimentation troughs of two-tier sedimentation tanks are still designed using the traditional approach, based on a fixed detention time (1.5 h). At the same time, clarification efficiency is assumed to be 40–50%, depending on the required treated-effluent quality: in some cases, the required removal efficiency may be below 40%, while in others, it may exceed 50%. Therefore, it is more appropriate to design sedimentation troughs based on the settling velocity of specific particle fractions, that is, the hydraulic settling velocity according to Eq. (1).

The design width of a single two-tier sedimentation tank (B) is determined using the conventional equation:

$$B = \frac{1000 \cdot q_{\max}}{N_{tr} \cdot V \cdot H_{set} \cdot N}, m, \quad (2)$$

where $q_{\max}$ is the maximum instantaneous wastewater flow rate, m³/s; V is the design flow velocity, taken as 2–7 mm/s; N is the number of two-tier sedimentation tanks (not less than two); and N_{tr} is the number of sedimentation troughs in each tank, typically taken as two.

The length of the sedimentation troughs L (where $L = D$) is selected as 6, 9, or 12 m. Based on the diameter of the two-tier sedimentation tank, and in accordance with standard design solutions [16], the dimensions of the trough B , h_1 and h_2 are adopted, after which the design depth of the trough is determined.

¹HHSHN 40-01.03-2022. Available at: <https://tinyurl.com/32tdsjjp> (accessed on October 7, 2026).

However, first, the correct number of sedimentation tanks must be verified. For this purpose, the proportion of the surface area of the two-tier sedimentation tank that is free from troughs (A_{free}) should be calculated.

$$A_{free} = 100 \left(1 - \frac{4 \cdot N_{tr} \cdot B}{\pi \cdot D} \right), \% \quad (3)$$

Since a scum layer consisting of light, poorly digestible substances (such as domestic fats) may form in the recesses and sedimentation troughs between the floating disks, the surface area free from scum must be at least 20% of the tank's plan area. If $A_{free} \leq 20\%$, it is necessary to adjust the number of two-tier sedimentation tanks (N), repeat the calculation [12,16]².

Assuming the wastewater detention time in the trough and its flow velocity are specified, the trough design can be carried out (Fig. 2) using the following equations:

$$W_{tr} = q \cdot t; L = V \cdot t; \quad (4)$$

$$A_1 = b \cdot h_1 + b \cdot h_2 / 2 \quad \text{or} \quad A_1 = W_{tr} / L \cdot N \cdot N_{tr}, \quad (5)$$

where W_{tr} is the total volume of all sedimentation troughs (m^3); q is the design flow rate (m^3/s); t is the flow duration of wastewater (s), A_1 is the cross-sectional area of a single trough (m^2) b is the width of the trough (m), h_1 is the height of the rectangular part of the trough (m), h_2 is the height of the triangular part of the trough (m), L is the length of the trough (m), V is the flow velocity (mm/s), N is the number of two-tier sedimentation tanks; and N_{tr} is the number of troughs per sedimentation tank.

However, in our opinion, the depth of the flow section of the sedimentation tank H_{set} , which varies due to the pentagonal shape of the trough (Fig. 3), should be replaced by a design depth H_p , determined as a weighted-average value according to Eq. (1).

$$H_p = \frac{\int_0^{h/2} y^2 dx}{\int_0^{h/2} y dx} = \frac{\int_0^{h/2} (h_1 + x \tan \alpha)^2 dx}{\int_0^{h/2} (h_1 + x \tan \alpha) dx} = \frac{3(3h_1^2 + 3h_1 \cdot h_2 + h_2^2)}{3(2h_1 + h_2)}. \quad (6)$$

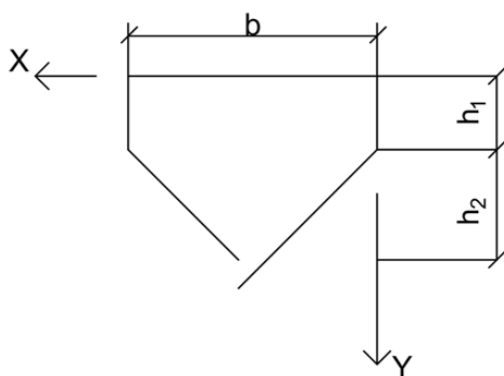


Fig. 2. Sedimentary trough diagram

The calculation should be carried out in the following sequence.

Based on the required clarification efficiency, the settling time t_{set} is determined in a cylinder with a depth of $h = 500$ mm, and then the hydraulic settling velocity of the suspended particles is calculated using Eq. (1).

The flow velocity V of wastewater in the sedimentation trough is determined using the following equation:

$$L = V \cdot H / K \cdot U_0, \quad (7)$$

and the design wastewater flow rate of a single sedimentation tank is determined using the following equation:

$$Q = (h_1 \cdot 0.5 \cdot h_2) \cdot B \cdot V \cdot N_{tr}, \quad (8)$$

where N_{tr} is the number of sedimentation troughs.

²HHSHN 40-01.03-2022. Available at: <https://tinyurl.com/32tdsjjp> (accessed on October 7, 2026).

By dividing the design wastewater flow rate (Q) by the design capacity of a single sedimentation tank (Q_1), the required number of tanks (N) is obtained: $N = Q/Q_1$.

The settled sludge is fully accumulated in the conical part and partially in the cylindrical part of the structure.

The total structural height (H_{st}) of the two-tier sedimentation tanks (Fig. 3) can be determined using the following equation:

$$H_{st} = h_1 + h_2 + h_3 + h_{con} + h_{cyl} + h_4, \quad (9)$$

where h_1 and h_2 are the heights of the cylindrical and conical parts of the flow troughs, respectively; h_3 is the neutral layer between the digestion zone and the trough opening, taken as 0.5 m; h_4 is the freeboard above the water surface of the two-tier sedimentation tank, taken as 0.3 m; and h_{con} and h_{cyl} are the heights of the accumulated sludge layers in the conical and cylindrical parts of the two-tier sedimentation tank, respectively.

The values h_3 and h_4 are standard parameters. The values h_{con} and h_{cyl} can be calculated using the conventional methodology [7,16], whereas h_1 and h_2 are determined using the method proposed in this study.

Results and Discussion

The proposed method significantly reduces the number of required sedimentation tanks. Given the extensive planned construction of small-scale wastewater treatment plants, where two-tier sedimentation tanks can be implemented, this approach may offer considerable engineering and economic advantages.

In the 40-01.03-2022 “Sewage. External networks and structures” on approval of the construction norms of the Republic of Armenia, under the general section “Sedimentation Tanks”, it is stated that the detention time (s), corresponding to the required treatment efficiency and obtained in a laboratory settling column at a depth h_1 may be taken for municipal wastewater from Table 1.

In [9], an example of the design of two-tier sedimentation tanks is presented with the following initial data: daily flow rate of municipal wastewater $Q = 5500 \text{ m}^3/\text{day}$; maximum flow rate $q_{\max} = 0,105 \text{ m}^3/\text{s}$; influent suspended solids concentration $C_{en} = 210$ ($C_{in} = 210$) mg/L; effluent suspended solids concentration $C_{ex} = 120$ ($C_{out} = 120$) mg/L. The per capita wastewater generation rate was $q_0 = 180 \text{ L}/(\text{day} \cdot \text{capita})$. The average winter wastewater temperature is 13°C .

The subsequent section provides a comprehensive design calculation for the two-tier sedimentation tanks. Based on the previously mentioned values C_{en} and C_{ex} , a clarification efficiency of 42.9% was achieved. Nevertheless, as indicated in Table 1 (40-01.03-2022)³ this efficiency level can be attained with a detention time of $t = 1630 \text{ s}$.

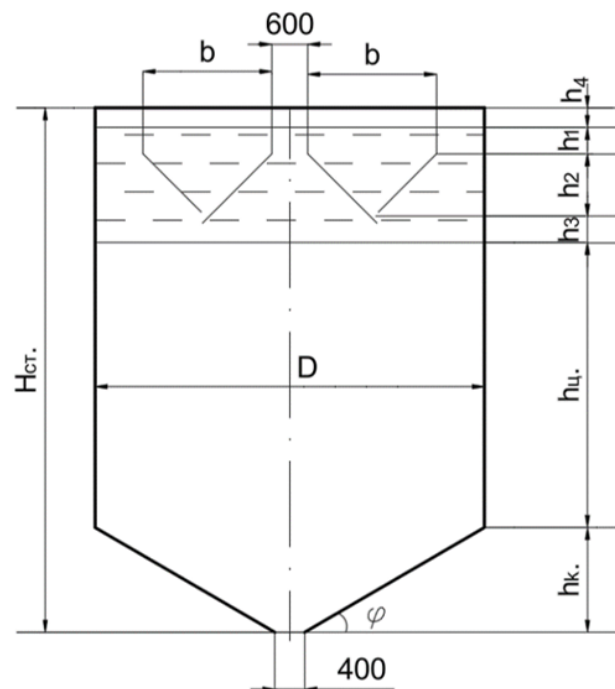


Fig. 3. Schematic diagram of a two-tier sedimentation tank

³HHSHN 40-01.03-2022. Available at: <https://tinyurl.com/32tdsjjp> (accessed on October 7, 2026).

Table 1. Wastewater detention time depending on clarification efficiency

Clarification efficiency	Detention time, t_{set} (s), at a layer depth of $h_1 = 500$ mm and suspended solids concentration, mg/L		
	200	300	400
20	600	540	480
30	960	900	840
40	1440	1200	1080
50	2160	1800	1500
60	7200	3600	2700
70	-	-	7200

To ascertain the hydraulic settling velocity, the depth of the sedimentation section, or sedimentation trough, is considered to be $H_{set} = 2$ m, with the detention time designated as $t_{set} = 5400$ s [9]. It is logical to anticipate a substantially higher clarification efficiency of domestic wastewater at $t_{set} = 5400$ s. Nonetheless, even with the adoption of $t_{set} = 5400$ s, we contend that the sedimentation trough's design depth H_{set} can be determined using the proposed Eq. (6).

Conclusion

Based on the obtained results, the following conclusions can be drawn:

1. In the conventional design methodology for two-tier sedimentation tanks, certain parameters are assumed as design values; however, we believe some of these parameters should be rigorously calculated. Since the channels located in the upper section of the two-tier sedimentation tank function as horizontal clarifiers, according to the data in the provided table, a settling time of $t_{set} = 5400$ s is excessively conservative for achieving a 40–50% suspended solids removal efficiency.
2. A modified design methodology for two-tier sedimentation tanks is proposed, whereby the conventionally assumed depth of the settling zone (H_{set}) is replaced by a calculated depth (H_p), determined as a weighted average value. The proposed approach provides a more rigorous basis for the structure's hydraulic design by incorporating key process parameters into the calculation procedure. Overall, the methodology is suitable for application at the design stage of two-tier sedimentation tanks.
3. Furthermore, it is necessary to introduce the concept of the design detention time (t_p) and determine it either by using a tabular method or by computing it via the formula $t_p = q_{max}/v$, where $v = 2 - 7$ mm/s. Adopt the larger of these two values as the design basis.
4. The equation proposed for determining the weighted-average design depth of a sedimentation trough may also be used to design horizontal grit chambers with circular flow patterns, with the grit chamber design depth determined as a weighted-average value.
5. In conclusion, the conventional design methodology for two-tier sedimentation tanks requires certain refinements.

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Conflict of Interest

The authors declare no conflicts of interest.

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Ethics Statement

The authors confirm that this study was conducted in accordance with the Journal's Research Ethics and Integrity Statement and that all ethical requirements applicable to the study have been fulfilled.

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