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Design parameters for implementing inclined plate settlers in sedimentation tanks

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Abstract

This study evaluates the hydraulic and operational performance of inclined plate settlers (IPS) as an enhancement to conventional sedimentation tanks in wastewater treatment. IPS, also known as lamella clarifiers, increase effective settling surface area within a compact footprint, addressing the space and retention-time limitations of traditional tanks. A laboratory-scale pilot was constructed to investigate the effects of plate inclination, spacing, vertical height, and surface texture on the removal of total suspended solids (TSS). Synthetic wastewater (200–250 mg/L clay suspension) was tested through five configurations of flat and corrugated PVC plates under varying geometries, with hourly sampling over six-hour runs. Results showed that plate inclination was the most influential factor, with efficiencies improving from 45° to 65°; narrower spacing (2.5 cm) outperformed wider spacing (5cm); taller plates (15cm) improved capture of slower-settling particles; and corrugated surfaces enhanced removal by increasing surface area. The optimized configuration (15cm corrugated plates, 2.5 cm spacing, 65° inclination) achieved up to 99% TSS removal. Comparative analysis with global case studies confirmed the scalability and practicality of IPS for compact, cost-effective retrofitting. Overall, IPS are validated as a robust technology bridging theory and application, offering significant improvements in sedimentation efficiency for modern wastewater treatment.

Keywords: Compact design, Inclined plate settlers, Lamella clarifiers, Pilot study, Sedimentation, TSS removal, Wastewater treatment.

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1. Introduction

Over the last century, rapid urban development and industrial activities have led to the deterioration of global water resources. The presence of pollutants such as suspended solids, organic matter, and microbial contaminants has made wastewater treatment an essential practice. Among treatment stages, sedimentation serves as a primary step for removing settleable solids and reducing organic load [1].

Conventional sedimentation tanks rely on gravitational settling of particles, requiring significant surface area and retention time. However, this poses challenges for densely populated regions or retrofit applications. Inclined plate settlers, also known as lamella clarifiers, offer a solution by increasing the effective settling surface within a compact footprint [2, 3]. These systems operate based on Hazen [4] surface overflow theory, which emphasizes surface area over height for effective particle removal.

Sedimentation is a gravity-driven process central to both primary and secondary wastewater treatment stages. The core objective is to reduce TSS prior to biological treatment or discharge. Traditional tanks often fall short in performance due to flow short-circuiting, turbulence, or inadequate retention time.

To address these limitations, inclined plate settlers were introduced. Hazen [4] first proposed the concept in Hazen [4] emphasizing the benefit of increasing surface area to enhance sedimentation. By inserting inclined plates into tanks, the settling distance for particles is minimized, resulting in faster and more efficient solids separation.

The American Water Works Association (AWWA) provides key design recommendations, notably maintaining laminar flow (Re < 800) and optimizing plate spacing and inclination. Studies confirm that inclination angles between 45° and 65° yield optimal results [5]. Plate materials like polypropylene, HDPE, stainless steel, and fiberglass offer various advantages in terms of cost, durability, and chemical resistance [5, 6].

Corrugated surfaces can improve TSS removal by increasing effective area and reducing flow turbulence. Computational fluid dynamics (CFD) and empirical studies show improved particle capture with structured plates versus smooth plates [7-9].

Further, several authors have explored the relationship between hydraulic loading rates and removal efficiency, noting that increased surface area allows higher loading without compromising effluent quality. A key metric used in IPS design is the surface overflow rate (SOR), which should remain below the settling velocity of the slowest-settling particles to ensure effective capture [6].

Globally, IPS systems have been implemented in potable water and wastewater treatment. In Egypt, Gabal El Asfar and Nubaria treatment plants report significant operational improvements with IPS integration [10-12]. These systems also reduce the physical footprint, operational costs, and sludge handling burden.

In North America and Europe, IPS are used in both municipal and industrial settings, including food processing and mining. Their adaptability and performance make them a viable retrofit solution, particularly in space-constrained facilities [13].

Comparative studies in Brazil, China, and South Africa indicate similar performance benchmarks, with consistent TSS reductions of 85–98%, even in variable climatic or hydraulic conditions. The universal success of IPS is attributed to their scalability, low energy requirements, and ease of maintenance [7, 14, 15].

Despite widespread use, most previous studies focus on theoretical analysis or full-scale modelling. This research contributes empirical data from a lab-scale pilot, enabling direct performance comparisons across varied IPS configurations. It fills a critical gap between theory and practice by validating design parameters under tightly controlled experimental conditions.

2. Study Objectives

The main objectives of this work are:

1. To investigate the influence of key design parameters—including plate spacing, inclination angle, vertical plate height, and surface texture—on sedimentation performance and the effectiveness of inclined plate settlers (IPS) in enhancing total suspended solids (TSS) removal under controlled laboratory conditions.
2. To validate the experimental findings against hydraulic theory and established IPS design equations, in order to identify the optimal IPS configuration for maximizing TSS removal efficiency.
3. To compare the experimental results with global case studies and propose best practices for practical and scalable applications in compact wastewater treatment systems.

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3. Materials and Methods

The experimental study was conducted in the Sanitary Engineering Laboratory using a lab-scale pilot setup, as detailed in Chapter 3. A series of controlled test runs were performed, with each run designed to isolate and evaluate the impact of a single design parameter while keeping other variables constant. This approach allowed for a focused assessment of how each factor such as plate inclination angle, Plate Vertical Depth, spacing, and surface texture affects the sedimentation performance of inclined plate settlers.

A lab-scale pilot system included six transparent tanks (35×25×40 cm), fed from a 200-liter elevated tank containing synthetic water. The water was prepared by mixing 20 g of clay to simulate a TSS concentration of 200–250 mg/L.

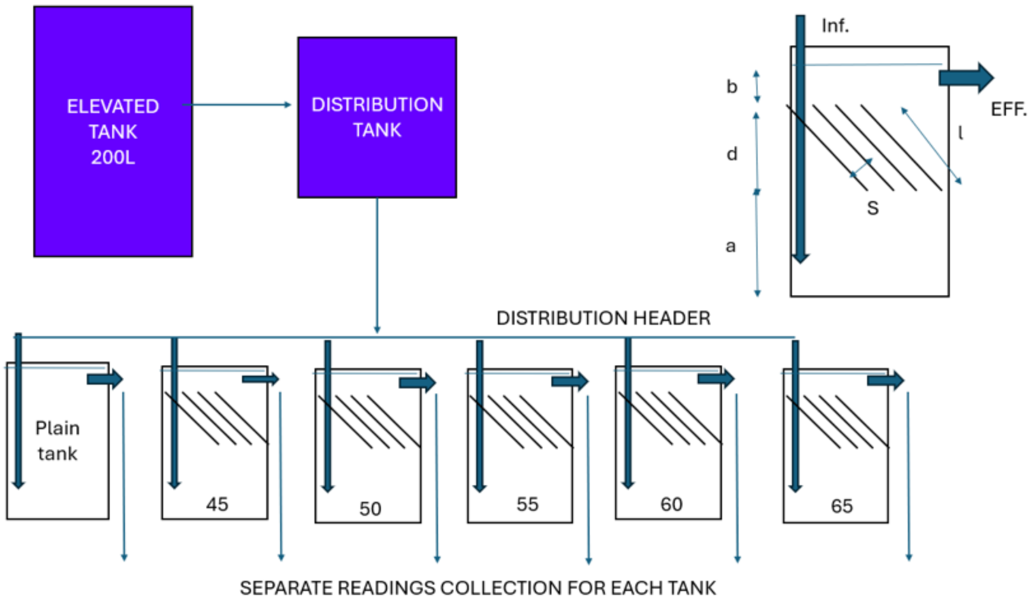

Figure 1.
Lab Pilot Diagram.

Figure 2.
Lab pilot during operation.

Table 1.
Experimental configurations for Runs 1–5.

Run	Description	Plate Height (cm)	Plate Spacing (cm)	Plate Type	Inclination (°)
1	Base Case	10	2.5	Flat PVC	45–65
2	Double Spacing	10	5.0	Flat PVC	45–65
3	Shorter Plates Layer	5	2.5	Flat PVC	45–65
4	Longer Plates Layer Height	15	2.5	Flat PVC	45–65
5	Corrugated Long Plate	15	2.5	Corrugated PVC	45–65

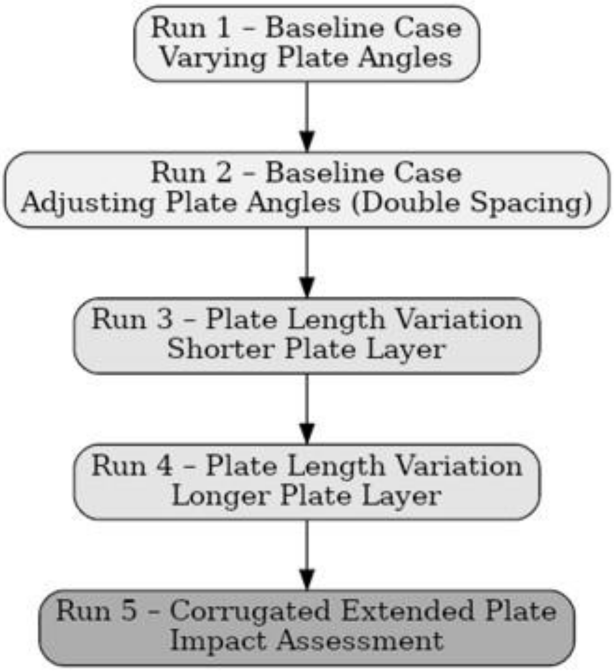

Figure 3.
Flow Chart: Experimental Runs.

Each run involved a 6-hour continuous flow test. 100 ml samples were collected hourly from inflow and outflow points, filtered, dried at 105°C, and weighed to determine TSS. Removal efficiency was calculated by comparing inlet and outlet concentrations.

Instruments used included a digital precision balance (±0.001g), drying oven, and ceramic plates. Water inflow was regulated through 1/4-inch PVC pipes connected to a copper header for equal distribution.

The experimental system was tested over a 30-day period to ensure hydraulic stability and calibration. All tanks received equal inflow through a copper header with identical PVC piping.

Plate settler configurations were arranged within tanks using removable racks to allow easy substitution between runs. Corrugated plates were fabricated from textured PVC sheets. Digital balances with 0.001 g precision were used for TSS measurements.

To analyse trends, data were averaged over 10-day periods for each run. Each data point represents a daily of six hourly measurements per tank.

Flow visualization confirmed laminar flow within the tank boundaries, and care was taken to avoid short-circuiting. Visual inspections and photographic documentation were maintained throughout the study for quality assurance.

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The chosen methodology ensured repeatability of results, minimized measurement errors, and provided a reliable basis for comparing the influence of different plate configurations. This systematic approach strengthens the validity of the experimental outcomes and facilitates the translation of findings into practical design recommendations for full-scale applications.

4. Results and Discussion

As mentioned in the introduction, plate settlers are a good option in sedimentation tanks for settling suspended solids. Study aimed to determine the design parameters that achieved highest removal efficiency of suspended solids in the plate settlers clarify.

The optimum values for the previous parameters were discussed here in this chapter according to the achieving of the highest removal ratio for TSS in the tank during all runs studied cases.

4.1. Run 1: Base Case – Variation of Plate Angles

In this setup, all tanks had flat PVC plates with 10 cm vertical height and 2.5 cm spacing. Plate inclination varied from 45° to 65° in 5° increments, with one control tank left without plates.

Results showed significant TSS removal improvements with increasing inclination. At 65°, average TSS dropped to 6.0 ppm, compared to 44.5 ppm in the plain tank. Removal efficiency exceeded 97% for 60° and 65° configurations, highlighting plate angle as a primary performance driver.

The results from Run 1 emphasize the vital role of plate inclination angle in optimizing sedimentation. As shown in run 1 results, TSS removal increased progressively with plate inclination from 45° to 65°, with 65° achieving the peak efficiency at 98%. This trend corroborates earlier studies indicating that steeper angles reduce the effective settling distance for particles and minimize re-entrainment due to flow disturbance [6, 15, 16]. as shown in Figure 2.

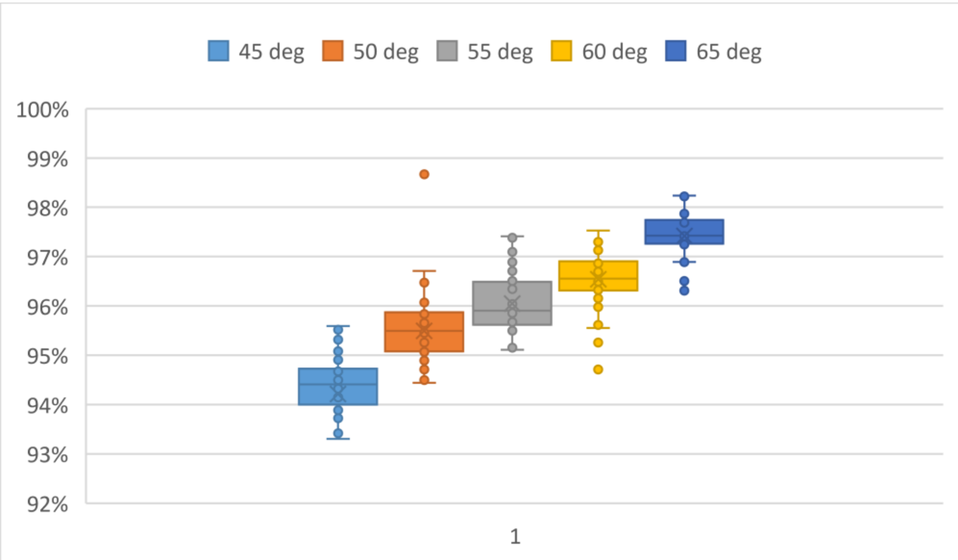

Figure 4.
Effect of Plate Inclination Angle on TSS Removal Ratio from half plating case.

Importantly, the performance of all tanks equipped with inclined plates significantly outperformed the plain sedimentation tank. On average, the plain tank showed TSS concentrations above 44 ppm, while the 65° plate configuration reduced TSS to under 6 ppm. This reflects a reduction of over 85%, confirming that inclined plate settlers greatly enhance sedimentation efficiency by increasing the effective surface area and encouraging laminar settling conditions [7, 9, 15] as in Figure 3.

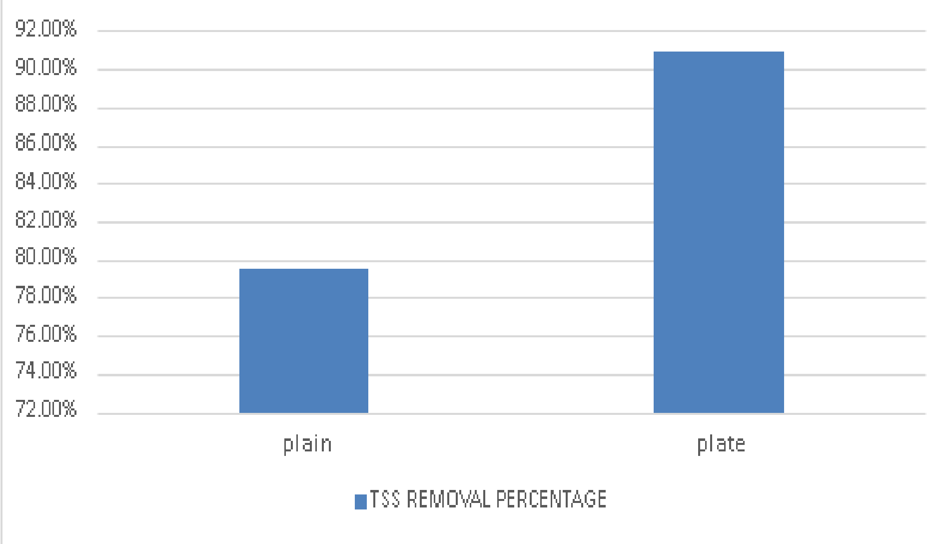

Figure 5.
Plate Settlers Effect on TSS Removal Efficiency from half plating case vs plain.

The inclination impacts the trajectory of particle settling and surface contact probability. As inclination increases, the horizontal projection of each plate shortens, yet the effective vertical settling path is enhanced. Therefore, a balance is required to maintain optimal plate density and sediment capture. A 65° angle emerged as the best compromise, enhancing laminar flow and minimizing horizontal settling lag, in line with Hazen [4] and Metcalf & Eddy [6] classical theory [4, 6].

4.2. Run 2: Effect of Double Spacing

Doubling the spacing to 5 cm reduced plate density, keeping height at 10 cm. TSS removal efficiency decreased across all angles. At 65°, TSS averaged 17 ppm (≈91–92% removal), significantly lower than the 6 ppm achieved in Run 1 with 2.5 cm spacing (≈97% removal). The data confirmed that reduced plate density diminishes settling efficiency due to reduced surface area and increased flow velocity between plates. Overall, doubling the spacing between plates (from 2.5 cm to 5 cm) resulted in a reduction in TSS removal efficiency of about **5–6%**. While larger spacing facilitates easier sludge removal and reduces the risk of clogging [6] it also reduces the number of sedimentation units per tank volume, thus lowering the total available settling surface [16] as shown in Figure 4.

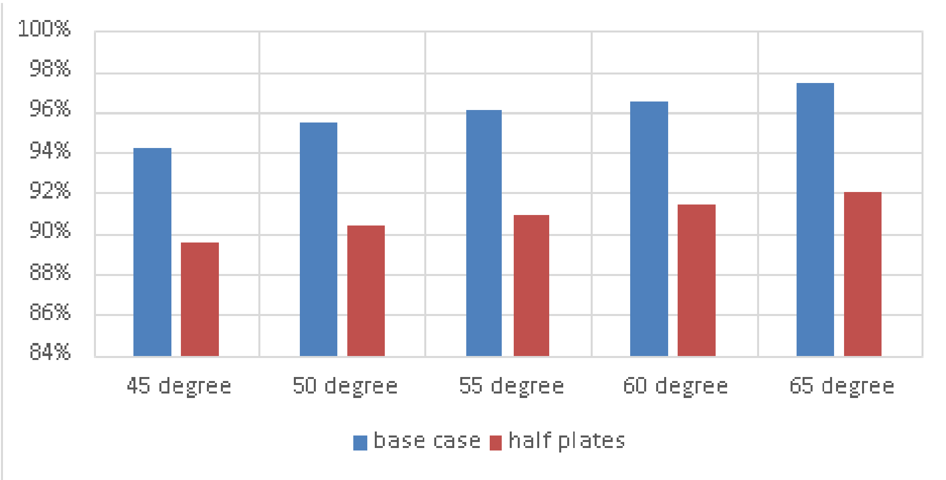

Figure 6.
Plate Settler Spacing Effect on TSS Removal Ratios.

The optimal performance of 2.5 cm spacing supports the recommendation of maintaining tight but manageable plate arrangements. Such configurations maximize particle interception opportunities without inducing excessive head losses or flow short-circuiting [6, 17]. Importantly, the inclination angle still dominated performance, with 65° outperforming others even at wider spacing, suggesting that inclination is a primary design parameter, with spacing as a secondary constraint.

4.3. Run 3 & 4: Impact of the Layers with Shorter & Longer Plates

In Run 3 reducing plate vertical height to 5 cm aimed to test the importance of surface contact time. While trends were similar to Run 1, performance declined slightly.

Average TSS for 65° was ~15 ppm, indicating that reduced height compromises performance. The shorter path offers less opportunity for particle capture.

In run 4 plates were extended to 15 cm vertical height, maintaining 2.5 cm spacing.

This run yielded superior results across the board. The 65° plate achieved 2.5 ppm average TSS (98.9% removal), outperforming all previous configurations. Deeper plates increased surface area and sedimentation contact time.

Comparative tests of varying plate vertical heights showed that longer plates (15 cm in Run 4) achieved higher TSS removal than shorter ones (5 cm in Run 3), with an improvement of ~2–3%. The deeper plates allowed greater contact time and provided a more substantial barrier to unsettled particles. As in Figure 5.

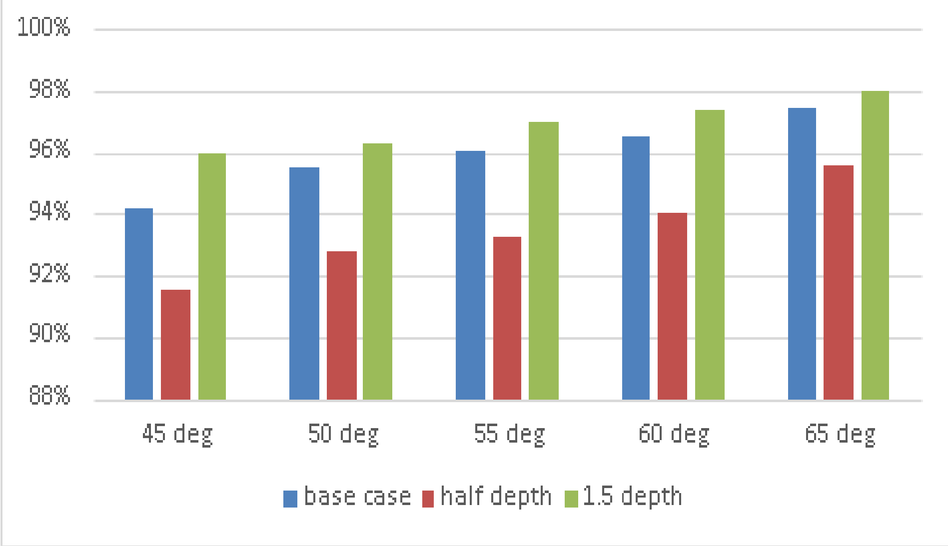

Figure 7.
TSS Removal Efficacy with Different Plate Layer Heights.

This observation indicates that the vertical height of IPS plates should be proportionally scaled to the tank height. A recommended ratio of plate height to water height lies between 1:3 and 1:4. Shorter plates (Run 3) yielded decent performance but lacked stability in removal ratios, likely due to insufficient interaction time for slower-settling particles. a finding that aligns with the general principles of sedimentation theory particularly regarding the importance of maximizing effective surface area for improved particle capture [6, 16].

4.4. Run 5: Impact of Corrugated Long Plate

Corrugated PVC plates (15 cm height, 2.5 cm spacing) were tested in Run 5. At 65°, average TSS fell below 2.5 ppm.

The corrugated surface increased effective surface area and disrupted boundary layers, enhancing settling. Results showed the highest and most consistent performance across 10 days.

The final configuration tested involved corrugated plates, which demonstrated marginal but consistent gains in removal efficiency—up to 1–2% compared to flat plates. Corrugations increased the effective surface area and disrupted flow patterns slightly, enhancing the particle settling process.

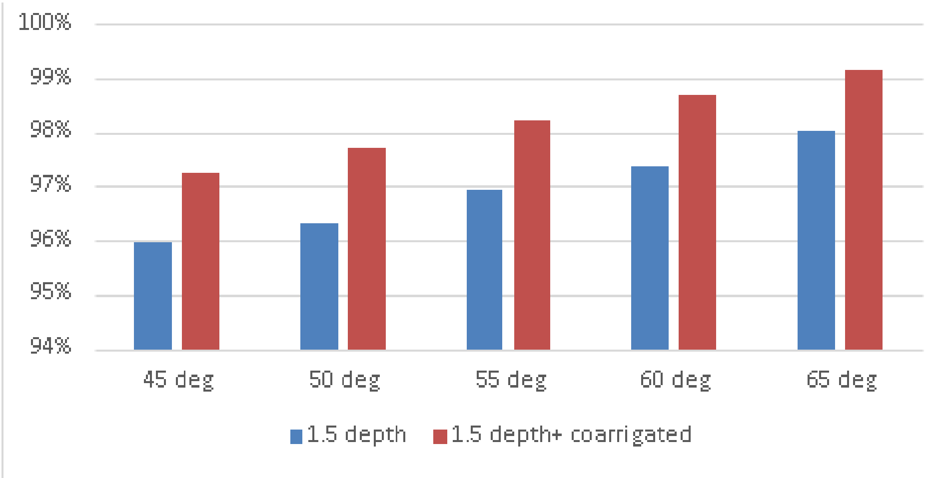

Figure 8.
TSS Removal Efficiency with Plate Surface Shape

More importantly, the corrugated surface prevented the buildup of boundary layers, reducing particle re-suspension and enhancing sediment capture. The best result—99–100% TSS removal—was achieved using 15 cm corrugated plates at

65° inclination. These findings validate the hypothesis that surface structuring aids in turbulence damping and increases hydrodynamic stability near the plate boundary [16].

5. Summary of Performance

Across all runs, the 65° inclined corrugated plate at 15 cm height consistently produced the lowest TSS levels. A plain tank averaged 44–59 ppm TSS, while optimized IPS units reached 2–6 ppm. The relationship between geometry and performance was linear for inclination and height but nonlinear for spacing due to fluid dynamics.

This experimental validation confirms that geometric optimization—particularly inclination angle and surface enhancements—can significantly improve sedimentation efficiency in compact IPS systems.

From previous discussions and the detailed laboratory results, the optimal design parameters for inclined plate settler systems can be summarized as follows:

Table 2.
Recommended Design and Performance Parameters for Plate Settlers.

Parameter	Value / Range
TSS Removal Efficiency	94–99% = 5% range between angles
TSS Removal Ratio	97–99% in 65 Degree
Design Retention Time	0.5–1.5 h
Layer Height : Tank Water Height Ratio	1 : 3/4
Plate Inclination Angle	60–65° from horizontal
Submergence Height	5–30 cm
Plate Spacing	5–20 cm
Plate Settler Height	Lab: 10–15 cm; Prototype: 0.75–1.5 m
Plate Surface Type	Corrugated, wave height 0.5–2 cm

Demonstrating their robustness under changing flow and geometry conditions. The performance was found to be highly sensitive to plate inclination and surface area per tank volume, echoing global standards in IPS system design.

6. Conclusion

This research successfully demonstrated the superior performance of inclined plate settlers (IPS) over conventional plain sedimentation systems in enhancing TSS removal efficiency. Laboratory experiments revealed that the optimal configuration—65° inclined corrugated plates with 2.5 cm spacing and 15 cm vertical height—achieved up to 99% TSS removal efficiency. These results were consistent across multiple trials, confirming the robustness and reliability of the selected parameters.

The implementation of IPS significantly shortened settling times and increased surface area within the same tank volume, resulting in higher treatment efficiency. Furthermore, the experimental study identified the key design parameters that govern IPS performance:

- Plate Inclination Angle: Increasing the angle from 45° to 65° consistently improved TSS removal. A 65° inclination minimized the horizontal settling path and enhanced laminar flow, making it the most effective in reducing re-entrainment and maximizing particle capture.
- Plate Spacing: Narrower spacing (2.5 cm) provided higher removal efficiency compared to wider spacing (5 cm), as it increased surface density and reduced flow velocity between plates, leading to improved settling conditions.
- Plate Height: Taller plates (15 cm) allowed longer particle contact time and greater surface area per unit volume. This significantly improved removal efficiency compared to shorter plates (5 cm), which were less effective in retaining slower-settling particles.
- Surface Texture: Corrugated surfaces enhanced removal by disrupting boundary layers and increasing effective surface area, which reduced particle resuspension and improved hydrodynamic stability. Corrugated plates outperformed flat ones by 1–2%.

In conclusion, inclined plate settlers are a powerful enhancement to sedimentation-based water treatment, offering scalability, efficiency, and economic viability [15, 16]. This study provides a practical, experimentally validated framework for future applications in both retrofit and new-build projects, especially where space, cost, and performance are critical factors. Beyond validating laboratory-scale performance, the results also highlight the potential for IPS integration in diverse wastewater and potable water treatment contexts. Future work should extend these findings to pilot and full-scale systems under variable loading and climatic conditions, allowing for broader generalization of the design parameters. Ultimately, this research underscores the role of IPS as a sustainable and adaptable technology that can support global efforts in improving water quality and resource management.

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