Improving the Performance of Conventional Wastewater Treatment Plants

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Abstract

Secondary clarifiers form a crucial component in gravity separation processes mainly in solid-liquid separation. They perform the crucial process of separating the activated sludge from the clarified effluent and also to concentrate the settled sludge. As treatment plants receive increasingly high wastewater flow, conventional sedimentation tanks suffer from overloading problems which result in poor performance. Inlet baffle modification by using an energy dissipating inlet (EDI) was proposed to enhance the performance in the circular clarifiers in Al-Dewanyia wastewater treatment plant. A 3-Dimensional fully mass conservative clarifier model was applied to evaluate proposed tank modification and to estimate the maximum capacity of the existing and modified clarifiers. A Computational Fluid Dynamics (CFD) model was formulated to describe tank performance and design parameters were obtained based on the experimental results. The study revealed that velocity and SS are better parameters than TS, BOD_5, and COD to evaluate the performance of sedimentation tanks. Removal efficiencies of suspended solids, biochemical oxygen demand, and chemical oxygen demand were higher in the EDI (Baffle).

Key Words: Clarifier, Sedimentation, Sludge, Wastewater, Solids, CFD.

تحسين أداء محطات معالجة مياه الصرف الصحي التقليدية

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الخلاصة

أحواض الترسيب الثانوية تشكل مرحلة المعالجة الرئيسية لإزالة المواد الصلبة العالقة و الحماة من مياه الصرف الصحي في محطات المعالجة مياه الصرف الصحي التقليدية. ونتيجة لزيادة كميات التصريف الواصلة إلى محطات المعالجة نتيجة للنمو السكاني أصبحت أحواض الترسيب الكلاسيكية تعاني من قلت كفاءتها في المعالجة. لذلك يتطلب الأمر تحسين أداء أحواض الترسيب. تمت في هذه الدراسة إضافة مصدات عند مدخل مياه الصرف الصحي إلى حوض الترسيب لغرض تحسين الأداء لهذه الأحواض، وتم تطبيق هذا التحسين في محطة معالجة مياه الصرف الصحي في مدينة الديوانية والتي تعاني من زيادة كمية المياه المتدفقة وقلة كفاءة المعالجة. تم تطوير نموذج رياضي ثلاثي الإبعاد لغرض نمذجة أحواض الترسيب وتحسين أداءها وزيادة سعتها. شملت الدراسة قياسات مختبريه للمواد العضوية والصلبة والكيماوية لغرض تحسين أداء محطة المعالجة. بينت النتائج إن كفاءة أحواض الترسيب وبالتالي كفاءة محطة المعالجة تزداد باستخدام المصدات و كذلك سعتها. كشفت الدراسة إن سرعة الجريان و تركيز المواد الصلبة هو أفضل مؤشر لتحسين أداء أحواض الترسيب.

1. Introduction

Secondary clarifier is one of the most commonly used unit operations in conventional wastewater treatment plants. It is customary designed to achieve solids separation from biologically treated

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effluent through clarification of biological solids and thickening of sludge. Many processes depend crucially on the performance of secondary clarifier, particularly in water and wastewater treatment facilities, where they can account for 30% of total plant investment, and non-ideal hydraulics in settlers can be detrimental to solids removal performance [1]. Despite the practical importance of these tanks, current design practice relies heavily on empirical formulae which do not take full account of the detailed hydrodynamics of the system. The determination of the removal efficiency for sedimentation tanks has been the subject of numerous theoretical and experimental studies. The removal efficiency depends on the physical characteristics of the suspended solids (e.g. particle size, density, and settling velocity) as well as on the flow field and the mixing regime in the tank.

Upgrading of existing wastewater treatment plants (WWTPs) may become necessary for a variety of reasons. Growth within the service area, or the desire to serve additional areas, may result in the need to increase the capacity of an existing treatment facility. New, more stringent requirements may be imposed on a treatment facility, resulting in a need to upgrade treatment processes. Older facilities may need upgrading to replace existing equipment that no longer functions as intended or to allow installation of newer, more efficient and cost-effective technology. In this case, the objective of the upgrading may be to improve plant reliability and / or reduce operating cost. Of course, more than one of these reasons may combine for a particular plant. The subject of upgrading existing wastewater plants is particularly important at this time. It is important both because of the large number of existing facilities and because of the increasing stringent requirements imposed on wastewater treatment facilities. Studies have investigated sediment distribution and flow patterns in sedimentation tanks and clarifiers [3]. Several of the studies (Krebs [1], Dahl et al. [2], Krebs et al. [3], Brouckaert and Buckley [4]. Lakehal *et al*. [5], Jayanti and Narayanan [6], Ghawi and Kris [7, 8, and 9], have been carried by use of CFD model.

CFD study of a secondary clarifier at Al-Dewanyia Wastewater Treatment Plant in Iraq was undertaken with a view to improving its capacity to retain sludge under high hydraulic load conditions, which has come under pressure due to the growth in provision of services.

The objective of this study is to examine the possibility of upgrading conventional secondary clarifiers in an operating wastewater treatment plant by applying Energy Dissipating Inlet (EDI) (baffle) for clarifier inlet. Field experiments and mathematical model (CFD model) were conducted in the main wastewater treatment plant in Al-Dewanyia using sedimentation tanks with and without EDI for secondary clarification of activated-sludge mixed liquor.

2. Materials and Methods

Two secondary clarifiers (circular, 30 m diameter by 3.0 m wall deep and centrally fed) at the Al-Dewanyia Wastewater Treatment Plant. Each unit is nominally designed to handle 250 m^3/hr flow, with an equal flow rate of sludge recycled to the activated sludge plant. The clarifiers at these plants are centre-feed and peripheral-overflow clarifiers (Figure 1 and Plate 1) designed for optimum activated sludge secondary clarifier performance. Tank geometry and operating conditions for both clarifiers are summarized below:

- Clarifier diameter = 30 m
- Side wall depth = 3.0 m
- Peak Day Conditions: Influent Flow = 18,000 m^3/d, MLSS = 3,000 mg/L, RAS Flow = 7,500 m^3/d
- Surface Overflow Rate (SOR) = 2.2 m/h
- Solids Loading Rate (SLR) = 222 kg/m^2/day
- “Typical” Settling Characteristics (from an example site with an SVI of approximately 150 mL/g)

The performance and capacity of a centre-feed clarifier is very sensitive to the intensity of influent jets entering into the clarifiers. A centre-feed clarifier naturally generates a strong influent jet due to its small centre-feed area in a circular clarifier tank as shown in Figure 1 and Plate 1. The intensive centre influent often brings significant turbulence into the settling compartment, especially under high flow conditions. To enhance the hydraulic efficiency and capacity of centre-feed clarifiers, one of the most important key issues is to develop a centre-feed apparatus, which could be used to effectively reduce the intensity of the central influent jet and turbulence under high-flow conditions.

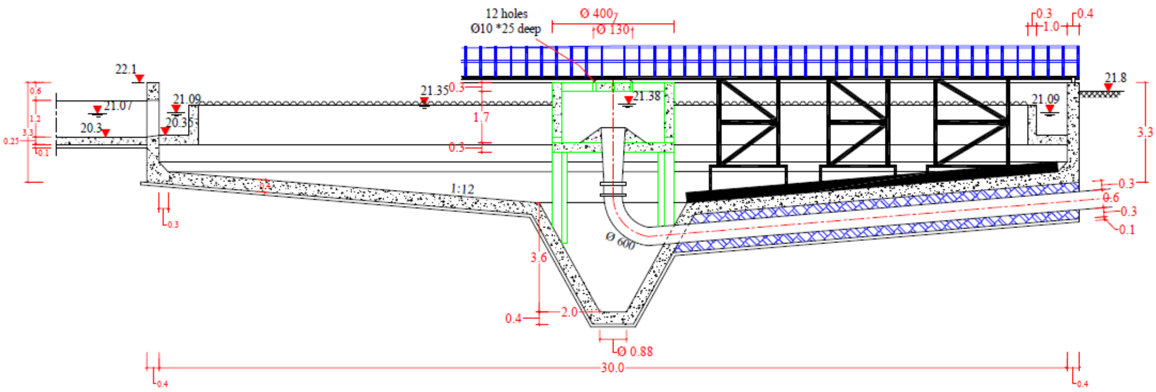

Figure 1. Clarifier scheme in Al-Dewanyia Wastewater Treatment Plant.

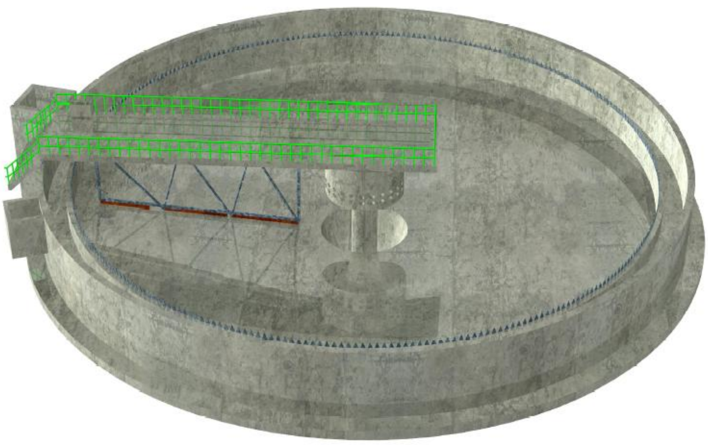

Plate 1. Clarifier scheme in Al-Dewanyia Wastewater Treatment Plant.

To estimate performance enhancements resulting from the use of an energy dissipating inlet (EDI) in a circular clarifier, a pair of computational fluid dynamics (CFD) calculations were performed (Figure 2). In the first simulation, the flow through a clarifier equipped with a centre inlet pipe and open centrewell was calculated. In the second simulation, the centre inlet pipe was replaced with an EDI. Details regarding the development the CFD model are given in the next section.

CFD calculations provide estimates of effluent solids concentrations, return activated sludge (RAS) concentrations, sludge blanket depth and flow distributions in the clarifiers. Performance comparisons were made on the basis of these calculated parameters.

Using the traditional influent structure (as shown in Plate 2), the jet of clarifier influent through a influent slots is very strong due to the very small cross sectional area of the slots. However, if the cross sectional area of the inlet slots is simply enlarged, flow short-circuiting (or unevenly distributed flow) may occur among the slots. For design the EDI, the flocwell diameter was 7.9 m and the depth 1.5 m. Plate 2 shows the actual EDI geometry that was tested.

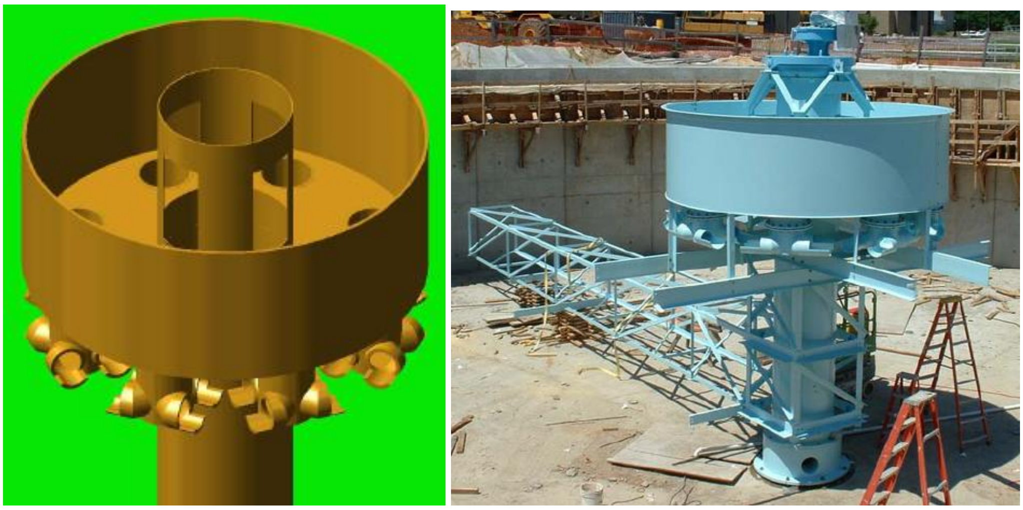

Plate 2. Modified centre inlet structure (EDI).

The wastewater treatment plant was operated at different flow rates to determine the effect of Hydraulic Retention Time (HRT) and Surface Loading Rate (SLR) on the performance of the clarifier. Influent and effluent samples were collected at different operating periods. The liquid temperature ranged between 23-29 °C during the experiment. The samples were analyzed according to procedures outlined in "Standard Methods For The Examination of Water and Wastewater," 17th edition, APHA, (1989) [10] to determine the following parameters: Suspended Solids (SS), Total Solids (TS), Biochemical Oxygen Demand (BOD_5), Chemical Oxygen Demand (COD), Volatile Suspended Solids (VSS), Total Volatile Solids (TVS) and Settleable Solids.

3. CFD Modelling

FLUENT 6.3 and the 3D *k-ε* turbulence model in the Environmental Engineering Module were used [7]. During this study hydraulic CFD modelling began with the definition of settling tank geometry. Secondly fluid characteristics and boundary conditions were defined. The momentum balance including the turbulence model and continuity equations were then solved numerically for the tank using the finite volume method. Finally, the obtained solution was post-processed to be properly visualised. Common mathematical hydraulic model equations used for CFD modelling include the momentum balances for a non-compressible viscous media and the continuity equation [11].

Momentum equation $$\rho\frac{\partial U}{\partial t}-\nabla\left[\left(\mu+\rho C_{\mu}\frac{k^2}{\varepsilon}\right).(\nabla U+(\nabla U)^T)\right]+\rho U.\nabla U+\nabla P=F \quad (1)$$

Continuity equation $$\nabla.U=0 \quad (2)$$

In the settling model an additional scalar equation was added to include the concentration of the solids. This convection-diffusion equation is as follows

$$\rho\frac{\partial C}{\partial t}+\frac{\partial\rho(U+U_S)C}{\partial x_i}=\rho\frac{\partial}{\partial x_i}\left(\frac{v_t}{\sigma_c}\frac{\partial C}{\partial x_i}\right) \quad (3)$$

The settling velocity was modelled using the exponential settling function of Takács 1995, this expression being introduced in the resolution of the concentration equation.

$$U_S=U_{S0}X\exp[-r_h(C-U_{ns})]-U_{S0}X\exp[-r_p(C-U_{ns})] \quad (4)$$

The standard *k*-*ε* eddy-viscosity model is used to account for turbulent effects. The turbulent viscosity is defined as function of the turbulent kinetic energy *k* and its dissipation rate *ε* by the equation

$$\mu_t = \rho C_\mu \frac{k^2}{\varepsilon} \tag{5}$$

The distributions of *k* and *ε* were determined from the following transport equations

$$\frac{\partial \rho k}{\partial t} + \frac{\partial k}{\partial x_i}(\rho k u_i) = \frac{\partial}{\partial x_j}\left((\mu + \frac{\mu_t}{\sigma_k})\frac{\partial k}{\partial x_i} \right) + G_k + G_b - \rho\varepsilon - Y_M + S_k \tag{6}$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial k}{\partial x_i}(\rho \varepsilon u_i) = \frac{\partial}{\partial x_j}\left((\mu + \frac{\mu_t}{\sigma_\varepsilon})\frac{\partial \varepsilon}{\partial x_i} \right) + C_k \frac{\varepsilon}{k}(G_k + C_{sc} G_b) - C_{2\varepsilon}\rho \frac{\varepsilon^2}{k} + S_\varepsilon \tag{7}$$

The model constants (C_μ, $C_{\varepsilon 1}$, $C_{\varepsilon 2}$, σ_k, σ_ε) in the above equations have been determined from experimental data and are set to standard parameters [11]

$C_\mu = 0.09$, $C_{\varepsilon 1} = 0.1256$, $C_{\varepsilon 2} = 1.92$, $\sigma_k = 0.9$, $\sigma_\varepsilon = 1.3$

G_b describes the influence of buoyancy effects and is defined as a function of the suspended solids concentration gradient

$$G_b = \beta g \frac{v_t}{\sigma_c}\frac{\partial C}{\partial x} = \frac{\rho_p - \rho_w}{\rho_p \rho_w} g \frac{v_t}{\sigma_c}\frac{\partial C}{\partial x} \tag{8}$$

The concentration gradient, which reaches maximum values at the interface between the clear fluid and the sludge blanket, hinders turbulence. The source term G_b introduced in turbulence equation addresses this matter. The value of $C_{3\varepsilon}$, usually reported as constant, varies with the ratio of gravity direction parallel flow velocity with respect to perpendicular flow velocity:

$$C_{SC} = \tanh\left|\frac{v}{u}\right| \tag{9}$$

The later expression yields values close to unity for unstable areas, and tends towards zero for stratified sedimentation. A Boussinesq-type approach also implies that the effect of sludge gravity is introduced implicitly as a function of suspended solids concentration. Its implementation in the momentum equations is carried out by means of source terms

$$g(\rho_p - \rho_w) = gC \ \frac{\rho_p - \rho_w}{\rho_p} \tag{10}$$

The dependence of viscosity on concentration is empirically inputted at different concentration ranges. The effect of the scraper blades has been usually either neglected or introduced as uniform constant sources, especially in the modelling of circular sedimentation tank. However, due to the significance of the scraper system for a circular sedimentation tank, an additional sub-model was incorporated to better model the effects of solids transport. The conveying force exerted on the fluid was approximated as a function of fluid velocity including a flow regime dependent drag coefficient

$$F_D = \frac{1}{2} C_D \rho A V_r^2 \tag{11}$$

Different flow rates were used in each continuous experiment during which several samples were collected from influent and effluent of the tank. The samples were analyzed to determine suspended solids, total solids, biochemical oxygen demand and chemical oxygen demand. In addition, some samples were taken from the settled sludge to determine solids concentration.

4. Boundary Conditions

All the boundaries corresponding to concrete surfaces were modelled using the wall functions provided by FLUENT, with a surface roughness parameter set to 0.5 mm. The free liquid surface was represented as a rigid frictionless surface. The flow boundary conditions were set by specifying mass withdrawal rates. Thus the overflow rates were specified at computational cells, and the underflow rate was distributed over a row of cells corresponding to the sludge withdrawal area. The feed inlet to the clarifier was allowed to satisfy the material balance by specifying a fixed pressure at the cells corresponding to the location of the feed slots. Flow rates to be used in the model were determined from measurements conducted on the clarifier on 10th July 2009.

5. Existing Clarifier Performance

The existing secondary clarifiers at Al-Dewanyia Wastewater Treatment Plant, often has experience very high effluent TSS due to the impact of a massive sludge inventory, as shown in Plate 3. In the overloaded clarifiers, the effluent TSS (and BOD_5) is extremely sensitive to any minor variations in plant flow. The overloaded conditions can often cause a large unexpected loss of bio-solids from the secondary treatment process.

Plate 3. Overloaded clarifier operations.

The flow capacity for the two existing clarifiers studied ranges (500 - 750 m^3/hr) due to variations of the process parameters (MLSS). The clarifiers are unable to achieve their expected design flow of 750 m^3/hr due, primarily, to the thickening limitation of clarifiers. The performance and capacity of a centre feed clarifier is very sensitive to the strength of the influent jets into the clarifiers. A traditional centre feed clarifier naturally generates a strong influent jet due to its small centre feed area. Thus, it often brings significant turbulence into the settling compartment, especially under high flow conditions.

The experiments consisted of five runs with different influent flow rates to simulate actual operating conditions of the secondary clarifier in the plant. Each continuous run lasted for a minimum of 5 hours. The influent to the clarifier was the mixed liquor from the second compartment of a high rate aeration tank in Al-Dewanyia sewage treatment plant. The operating conditions during the testing period have no much fluctuation in the influent characteristics, *i.e.* Mixed Liquor Suspended Solids (MLSS), which could affect the performance of the tank during testing period, as shown in Table 1. Similar to SS removal efficiency, the BOD_5 and COD removal efficiencies were more or less constant during the operating period at each flow rate. This confirms that the tank performance was stable during the period of study. Also the relationship between HRT and the removal efficiency of both SS and TS are shown in Table 2 and Figure 2.

Table 1. Operating conditions during experiment of conventional settling tank.

Q	HRT	MLSS	SVI	Temperature, (°C)	
(m^3/hr)	(hour)	(mg/l)	(ml/g)	Liquid	Air
150	2.17	2085	149	29.0	33.8
200	0.87	2170	148	24.8	28.6
250	0.65	2770	130	30.0	33.6
300	0.47	3120	131	30.6	34.3
350	0.33	2390	125	27.0	30.6

Table 2. Performance of conventional settling tank in SS and TS removal.

Q (m^3/hr)	HRT (hour)	SLR (m^3/m^2.hr)	SS removal (%)	TS removal (%)
150	2.17	0.63	94.8	59.6
200	0.87	1.56	94.7	67.4
250	0.65	2.08	94.1	62.0
300	0.47	2.92	93.6	66.0
350	0.33	4.17	94.1	68.1

It is clear from Figure 2 that while the %SS removed is increased as HRT was increased, the %TS did not show a similar trend since %TS was almost constant, if not slightly decreasing, as HRT was increased. This may indicate that biological activities took place in the sedimentation tank especially at longer HRT's thus transforming the biological SS into dissolved solids. Such transformations would ultimately increase the TS concentration at longer HRT, *i.e.* decreases the %TS removal efficiency. This emphasizes the importance of evaluating sedimentation tank performance based on SS (rather than TS) as usually reported in the literature. The effect in the case of the relationship between SLR and removal efficiency of SS and TS is opposite to that observed for HRT as shown in Table 2 and Figure 3.

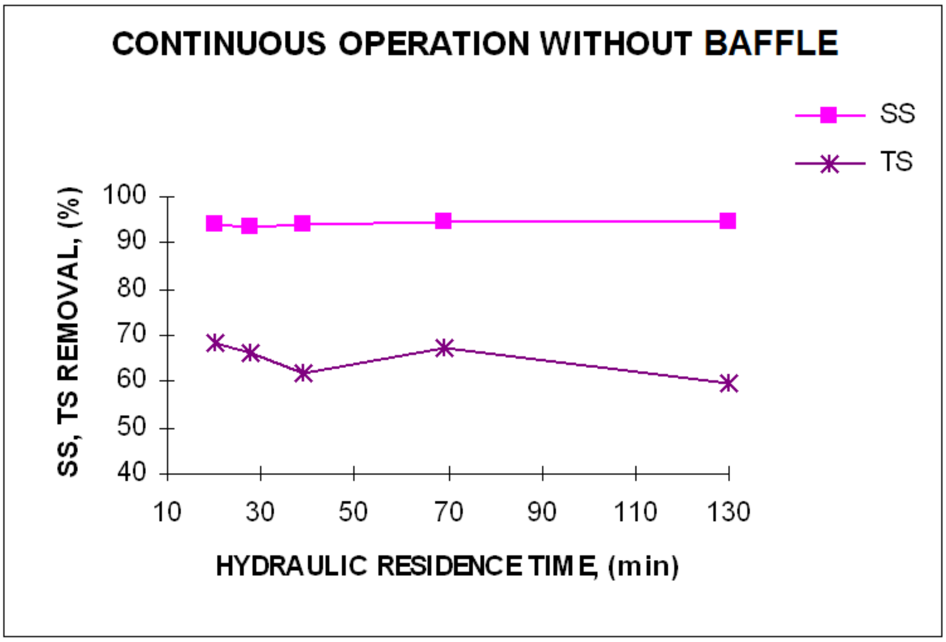

Figure 2. Performance of conventional settler at different hydraulic residence times.

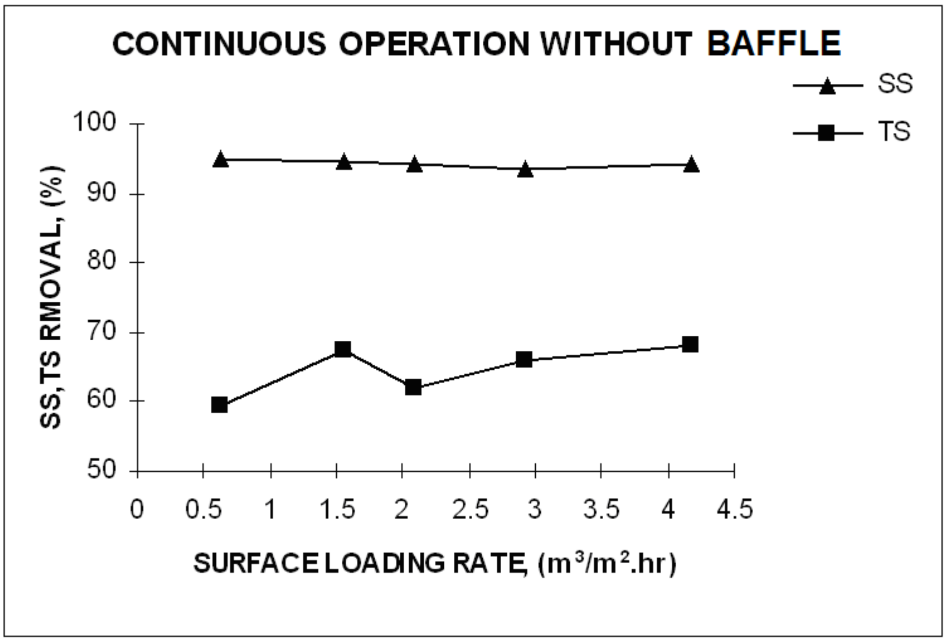

Figure 3. Performance of conventional settler at different surface loading rates.

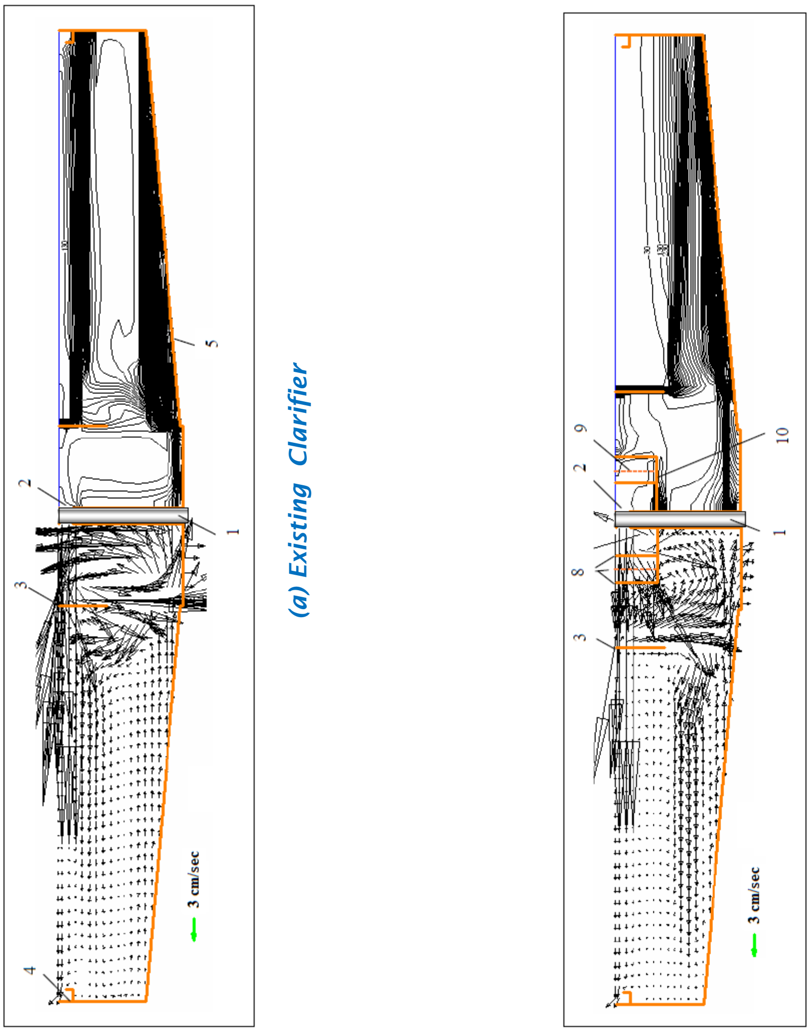

Figure 4. Performance before (a) and after (b) central inlet retrofit.

The good performance of the sedimentation tank during this study is possibly due to the good settleability of the biological solids as indicated by the Sludge Volume Index (SVI) values being in the optimum range of (125-149 ml/g) as presented in Table 1.

6. Results and Discussion

6.1 Performance of Clarifiers with an Optimized Influent Structure

Comparison of the Computational Fluid Dynamic (CFD) modelling results for flow and solids fields between the centre-feed clarifier described in Figure 1 and Plate 1 is present in Figure 4, in which there is no energy dissipating apparatus around the vertical centre-feed pipe.

The velocity and solids fields in a selected vertical slice of the tested clarifiers presented are in Figures 4(*a*) and 4(*b*). In the model predicted velocity fields, each velocity vector originates at a grid point used in the CFD model. The length of each vector is proportional to the magnitude of the velocity determined by the model for the corresponding grid point, and is in accordance with the 3.0 cm/s scale indicated in the figures. The figures also present he simulated solids fields in an identical vertical section of the model. In this figure the contour lines with interval of 100 mg/L indicates the Suspended Solids concentration.

In a centre-feed clarifier, it is not very easy to enforce flow evenly entering the clarifier along the rim of an energy dissipating column unless enough resistance along the radial direction can be created within the device. However, the high resistance along the radial direction cannot be generated through simply reducing the size or number of the inlet ports, which would increase the flow intensity entering into the clarifiers. The EDI is able to simultaneously satisfy both of the energy dissipating principles, i.e. a large accumulative space of inlet ports and a uniform flow distribution among all of the inlet ports due to the multilayer flow impingement.

Figure 4 consists of the two parts of 4(a) and 4(b) with respect to the two tested clarifiers with and without the EDI, respectively.

As shown in Figure 4(*a*), the CFD modelling results for the clarifier equipped with a simple centre influent pipe indicate:

1. The strong influent jet through the inlet ports (2) penetrates the entire radius of the flocculation well (3) and impinges on the inner side of the well (3) due to the lack of effective momentum/energy dissipating facilities within the flocculation well. After impinging on the flocculation well, the influent flow deflects and forms a very strong downward current toward the sludge blanket and clarifier floor (5).
2. Significant reverse flow is predicted underneath the strong surface influent jet due to the shears between them.
3. A pinched clarifier influent flow under the baffle lip (3) can be observed due to the massive sludge inventory in the clarifier. The density forward current is much closer to the water surface than that predicted under a lower flow condition due to the buoyancy impact of the thick sludge blanket.

As shown in Figure 4(*b*), the modelling results for the clarifier equipped with a EDI (8) indicate:

1. The strong influent jet due to the small influent ports (2) continuously impinges with the multilayer perforated columns (8) one after one. The velocities of the influent jets have been substantially reduced before and after going through the ports (9) in the last perforated layer (8). The resistance created by the multiple perforated columns (8) forces the influent jet to

be sufficiently distributed along the vertical and tangential directions before it enters into the flocculation well (3).

2. The downward current due to the deflection of the influent jet on the flocculation well (3) has been significantly reduced, since the momentum of the influent jet is effectively dissipated by applying the EDI. The circular bottom (10) forces all of the influent flow going through the staggered ports (9) and prevents flow short circuiting between the inlet ports (2) and flocculation well (3).
3. The pinched flow underneath the lip of the baffle (flocculation well) (3) has been eliminated and the level of density forward current is much closer to the clarifier floor (5) due to the lowered turbulence and the well-controlled dispersed sludge blanket in the clarifier.
4. The significant reverse flow underneath the surface influent jet predicted in the existing clarifiers has been almost eliminated, since the significantly slowed influent jet generates a much weaker shear influence on the ambient flow.

The existing clarifiers have flow capacities of approximately 1000 (m^3/h) under the normal process condition, which is most of the year. The optimized clarifiers can achieve a flow capacity of around 1300 (m^3/h), which is 30% higher than that of the existing clarifiers.

The performance of the EDI (Baffle) was examined by applying nine different influent flow rates ranging from 150 m^3/hr to 350 m^3/hr in separate mathematical model runs. The duration of each continuous run was at least, 5 hours during which different samples were collected from the influent and effluent of the tank. The main parameters (i.e. SS, TS, BOD_5,...etc.) were determined and the removal efficiencies were calculated at different influent flow rates. The performance was stable during each operating period studied. The values of HRT in the tank were calculated for each mathematical model run as illustrated in Table 3 and the corresponding SLR values are presented in Table 4.

Table 3. Operating conditions during experiment of EDI (Baffle).

Q (m^3/hr)	HRT (hour)	MLSS (mg/l)	SVI (ml/g)	Temperature, (°C)	
				Liquid	Air
150	2.04	1735	116	24.7	25.2
175	1.22	2470	122	28.8	29.3
200	0.82	2172	461	22.2	27.2
225	0.61	1784	476	21.9	27.6
250	0.51	2256	147	22.2	28.0
275	0.44	2308	208	23.5	27.9
300	0.38	1561	547	21.7	28.1
325	0.34	2494	128	24.9	27.9
350	0.31	2093	107	23.8	26.8

Table 4. Performance of EDI (Baffle) in SS and TS removal.

Q (m^3/hr)	HRT (min)	SLR (m^3/m^2.hr)	SS removal (%)	TS removal(%)
150	2.04	0.24	97.7	56.1
175	1.22	0.4	97.5	69.2
200	0.82	0.6	97.9	54.6
225	0.61	0.79	97.5	43.8
250	0.51	0.95	97.1	64.2
275	0.44	1.11	96.7	47.6
300	0.38	1.27	94.7	46
325	0.34	1.43	97.2	64.8
350	0.31	1.59	96.2	66.1

The relationships between HRT and the removal efficiencies of both SS and TS were established as presented in Figure 5, from which it is clear that the removal efficiency increases as HRT increases. Figure 6 shows the relationship between SLR and removal efficiencies for both SS and TS. It is evident that removal efficiency decreases as SLR increases. Such trends are similar to those observed in the conventional sedimentation tank regarding percentage removal of SS and TS in relation to HRT and SLR. In these mathematical model runs on the upgraded sedimentation tank, similar observations to those made during the experiments on the conventional sedimentation tank were evident regarding trends in TS, BOD_5, and COD removal.

6.2 Comparison between Conventional and EDI (Baffle) Sedimentation Tanks

In order to perform such a comparison, the removal efficiency for SS has been determined for both types of settlers at five different influent flow rates ranging from 150 m^3/h to 350 m^3/h. Comparing the results obtained from operating the mathematical model of tank as a conventional sedimentation basin and as a high rate settler (EDI), i.e. without EDI (Baffle) and with EDI (Baffle), it is apparent that during operation with EDI (Baffle) the SS removal efficiency is better than in case of conventional tank by 2% - 3% which is a marginal increase in efficiency. However, the tank with EDI (Baffle) was capable of maintaining high removal efficiencies even when the biological solids had high SVI as shown in Table 1 and 2, knowing that high SVI values (>200 ml/g) are indicative of poor sludge settleability.

The merit with EDI (Baffle) is more apparent when settling rather than thickening is controlling the tank design. This may indicate that application of EDI (Baffle) in secondary clarification of biological sludge may not be as advantageous as their application in primary clarification of wastewater solids. However, when secondary clarifiers are overloaded or suffer from rising sludge problems, upgrading of such clarifiers using EDI (Baffle) is definitely advantageous. This is in addition to savings in costs of land area covered by settlers which is much less in case of EDI (Baffle) than in case of conventional type gravitational settling tanks. Based on the results obtained for EDI (Baffle), a statistical model could be formulated by applying linear regression analysis for the relationship between SLR and %SS removal. Figures 7, 8, and 9 illustrate the relationship obtained which could be expressed by the following equation

$$\%\ SS\ removal = 98.26 - 1.39\ SLR \quad (12)$$

This is a statistical model describing the removal efficiency of SS in the upgraded EDI (Baffle). Similarly the following equations had been obtained for BOD_5 and COD

$$\%\ BOD_5\ removal = 96.20 - 1.01 \quad (13)$$

$$\%\ COD\ removal = 95.50 - 0.8\ SLR \quad (14)$$

7. Conclusion

The following conclusions can be drawn:

1. Effective improving of the performance of secondary sedimentation of biological solids at the studied surface loading rates in the range of 0.2 to 1.6 m^3/m^2.hr was proved by using EDI baffles.
2. Removal efficiencies of suspended solids, biochemical oxygen demand, and chemical oxygen demand were slightly higher in the EDI (Baffle).
3. The EDI (Baffle) is less affected by overloading than conventional settler. If the design surface loading rate criteria for conventional settling tanks are used for designing high-rate settlers, the latter should perform better within the range of surface loading rates normally

used in practical design.

4. The solids removal efficiencies increase with the increase of HRT and decrease of SLR.
5. Suspended solids removal efficiency is a better parameter to describe the performance of sedimentation tanks compared to total solids. Meanwhile, biological transformations of solids in the secondary sedimentation tank could contribute to BOD_5 and COD which results in higher BOD_5/SS and COD/SS ratios in the effluent than in the influent. This emphasizes the uniqueness of SS as a better parameter in performance evaluation.
6. The main advantage of EDI (Baffle) in secondary sedimentation of biological solids lies in their capability of coping with plant overloading conditions. Such settlers could be easily installed in existing rectangular sedimentation tank as a solution to rising sludge problems at minimal cost compared to other solutions such as increasing tank depth, addition of chemical coagulants, etc. Installation or removal of EDI (Baffle) would not interfere with normal operation of existing sedimentation tanks.

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