

Investigation Of An Improved Performance Of Secondary Clarifiers Using Computational Fluid Dynamics Model

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Abstract

Secondary clarifier is one of the most commonly used unit operations in wastewater treatment plants. It is customary designed to achieve solids separation from biologically treated effluent through clarification of biological solids and thickening of 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, based on modern computational fluid dynamic theory, was applied to evaluate the proposed tank modification and to estimate the maximum capacity of the existing and modified clarifiers. A Computational Fluid Dynamic (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 is a better parameter than TS, BOD, COD to evaluate the performance of sedimentation tanks, and Removal efficiencies of suspended solids, biochemical oxygen demand, and chemical oxygen demand were higher in the EDI (Baffle).

Keywords: Clarifier, Sedimentation, Sludge, Wastewater, Solids, CFD.

الخلاصة

ان أحواض الترسيب الثانوية واحدة من أكثر وحدات المعالجة أهمية في محطات معالجة مياه الصرف الصحي. ان أحواض الترسيب مصممة لإزالة المواد الصلبة و المواد العضوية الناتجة من المعالجة الحيوية في أحواض التهوية حيث تتجمع هذه المواد و تترسب في قعر حوض الترسيب على شكل خبث. نتيجة لزيادة كميات التصريف الواصلة الى محطات المعالجة نتيجة للنمو السكاني أصبحت أحواض الترسيب الكلاسيكية تعاني من قلة كفاءتها في المعالجة. لذلك يتطلب الأمر تحسين أداء هزة الأحواض, حيث تم في هزة الدراسة إضافة مصدات عند مدخل مياه الصرف الصحي الى حوض الترسيب لغرض تحسين الأداء لهذه الأحواض, حيث تم تطبيق هذا التحسين في محطة معالجة مياه الصرف الصحي في مدينة الديوانية و التي تعاني من زيادة كمية المياه المتدفقة و بالتالي قلة كفاءة المعالجة. في هذه الدراسة تم تطوير نموذج رياضي ثلاثي الأبعاد بناء على حفظ الكتلة لغرض نمذجة أحواض الترسيب و بالتالي تحسين أداءها و زيادة سعتها. و شملت الدراسة قياسات مختبرية للمواد العضوية و الصلبة و الكيماوية لغرض تحسين أداء محطة المعالجة. و قد بينت النتائج ان كفاءة أحواض الترسيب و بالتالي كفاءة محطة المعالجة تزداد باستخدام المصدات و كذلك سعتها. و ان الدراسة قد كشفت ان سرعة الجريان و تركيز المواد الصلبة هو أفضل مؤشر لتحسين أداء أحواض الترسيب.

Nomenclatures

Symbol	Description
A	The scraper displacement area (m^2)
C	The concentration of solids (mg/l)
C_D	The drag coefficient
C_{ns}	The nonsettleable concentration (mg/l)
C_μ	A model constant
F	A volume force term (N/m^3) which is zero in both the x and y directions.
k	The turbulent kinetic energy (m^2/s^2)
P	The average pressure (Pa)
r_h , r_p	Induce the domination of the first and the second term for the falling and the rising part
t	Time (s)
U	The average flow velocity vector (m/s)
U_s	The settling velocity (m/s)
U_{so}	The reference settling velocity (m/s)
V_t	The blade-to-fluid relative velocity (m/s)
ε	The dissipation of turbulent energy (m^2/s^3)
η	Dynamic viscosity (Pa·s)
v_t	The turbulent viscosity
ρ	Density (kg/m^3)
ρ	The fluid density (kg/m^3)
σ_c	The Schmidt number (0.7)
CFD	Computational Fluid Dynamics
BOD	Biochemical Oxygen Demand
COD	Chemical Oxygen Demand
EDI	Energy Dissipating Inlet
HRT	Hydraulic Retention Time
MLSS	Mixed Liquor Suspended Solids
RTD	Residence Time Distribution
SLR	Surface Loading Rate

SOR	Surface Overflow Rate
SS	Suspended Solids
SVI	Sludge Volume Index
TS	Total Solids
TVS	Total Volatile Solids
VSS	Volatile Suspended Solids

1. Introduction

In wastewater treatment plants as well as in a variety of industrial processes, sedimentation tanks are used to separate suspended solids from water. Sedimentation by gravity is the most common and extensively applied treatment process for the removal of solids from water and wastewater. The increasing concern which is being voiced as to the destruction and pollution of our environment has produced a growing worldwide awareness of the need for more effective wastewater treatment. In addition the contribution of wastewater treated effluents and sludge to the spread of many types of human and animal infection is now being quantified. This has emphasized the vital need for improved water supply and sanitation, especially in developing countries. Operation of wastewater treatment works are thus no longer the exclusive domain of the engineer and chemist; multidisciplinary teams of engineers and scientists are required in order to maximize the benefits to the community which should occur from the installation of sewage treatment. In modern societies proper management of wastewater is a necessity, not an option. Wastewater collected from municipalities and communities must ultimately be returned to receiving waters or to the land. The complex question of which contaminants in wastewater must be removed to protect the environment - and to what extent - must be answered specifically for each case. The answer to this question requires analyses of local conditions and needs, together with the application of scientific knowledge, economic analysis, and engineering judgment based on past experience and consideration of national requirements and regulations.

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. A number of studies have investigated sediment distribution and flow patterns in sedimentation tanks and clarifiers. Several of the studies [1], [2], [3], [4], [5], [6], [7], [8], and [9], have been carried by use of Computational Fluid Dynamic (CFD) model.

The 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 become 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. In order to achieve such objectives, 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 in the activated-sludge unit.

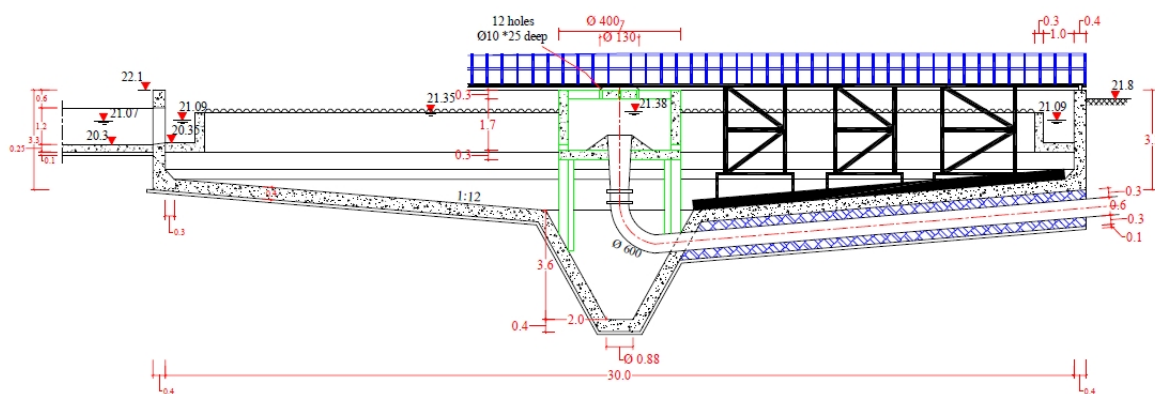
2. Materials And Methods

There are two secondary clarifiers at the Al-Dewanyia Wastewater Treatment Plant. They are circular, 30 m diameter by 3.0 m wall deep and centrally fed. Each unit is nominally designed to handle 250 m³/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) designed for optimum activated sludge secondary clarifier performance. Tank geometry and operating conditions for both clarifiers are summarized below:

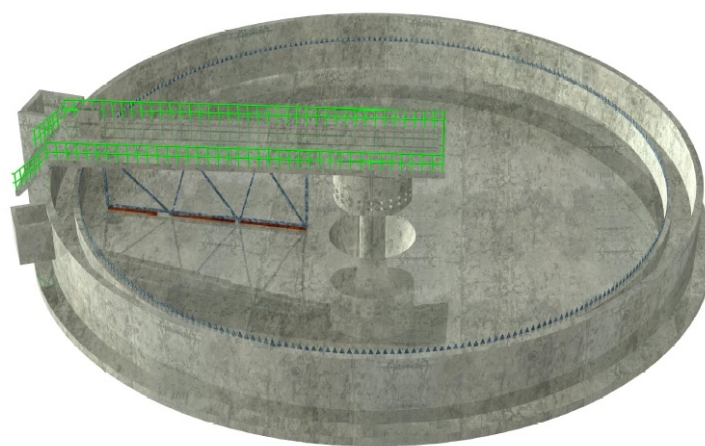
- Clarifier diameter = 30 m
- Side wall depth = 3.0 m
- Peak Day Conditions: Influent Flow = 18,000 m³/d, MLSS = 3,000mg/L, RAS Flow = 7,500 m³/d
- Surface Overflow Rate (SOR) = 2.2 m/h
- Solids Loading Rate (SLR) = 222 kg/m²/day
- “Typical” Settling Characteristics (from an example site with an SVI of approximately 150 mL/g)

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

To enhance the hydraulic efficiency and capacity of the center feed clarifiers, the key is to develop a new center feed structure, which could be used to effectively reduce the strength of the center influent jet under high-flow conditions. 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 center inlet pipe and open centerwell was calculated. In the second simulation, the center inlet pipe was replaced with an EDI.



a) Cross section in clarifier



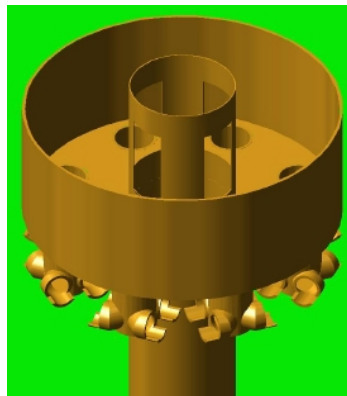
b) Plane of clarifier

Figure 1. Clarifier scheme in Al-Dewanyia Wastewater Treatment Plant (a. cross section in clarifier, and b. plane of clarifier)

The CFD calculations provide estimating the 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 Figures 2), the jet influent through the 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. Figure 2 shows the actual EDI geometry that were tested.

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 experiments. The samples were analyzed according to procedures outlined in “Standard Methods For The Examination of Water and Wastewater” [10] to determine the following parameters: Suspended Solids (SS), Total Solids (TS), Biochemical Oxygen Demand (BOD), Chemical Oxygen Demand (COD), Volatile Suspended Solids (VSS), Total Volatile Solids (TVS) and Settleable Solids.



a) Model of Modified center inlet structure (EDI)



b) Picture of Modified center inlet structure (EDI)

Figure 2. Modified center inlet structure (a, and b)

3. CFD Modelling

In this study FLUENT 6.3 and the 3D k-ε turbulence model in the Environmental Engineering Module were used. During this study hydraulic CFD modelling began with the definition of the 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].

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

$$\nabla \cdot U = 0 \quad (2)$$

In the settling model an additional scalar equation was added to include the concentration of the solids. The convection-diffusion equation in the following form was used:

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

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

$$U_s = U_{s0} X \exp[-r_h (C - U_s)] - U_{s0} X \exp[-r_p (C - U_{ns})] \quad (4)$$

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

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

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

$$\frac{\partial \rho k}{\partial t} + \frac{\partial k}{\partial x_i} (\rho k u_i) = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\sigma_k} \right) \frac{\partial k}{\partial x_i} \right) + G_k + G_b - \rho \varepsilon - Y_M + S_k \quad (5)$$

$$\frac{\partial \rho \varepsilon}{\partial t} + \frac{\partial \varepsilon}{\partial x_i} (\rho \varepsilon u_i) = \frac{\partial}{\partial x_j} \left(\left(\mu + \frac{\mu_t}{\sigma_{\varepsilon}} \right) \frac{\partial \varepsilon}{\partial x_i} \right) + C_k \frac{\varepsilon}{k} (G_k + C_{sc} G_b) - C_{2\varepsilon} \rho \frac{\varepsilon^2}{k} + S_{\varepsilon} \quad (6)$$

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

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

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

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

The concentration gradient, which it 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 $C_{2\epsilon}$, usually reported as constant, varies with the ratio of gravity direction parallel flow velocity with respect to perpendicular flow velocity:

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

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:

$$g(\rho_p - \rho_w) = gC \frac{\rho_p - \rho_w}{\rho_p} \tag{7}$$

The dependence of viscosity on concentration is empirically inputted at different concentration ranges. The effect of the scraper blades has been 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:

$$F_D = C_D \frac{1}{2} \rho A V_r^2 \tag{8}$$

Different flow rates were used in each continuous experiment where several samples were collected from the 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.

3.1 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.

4. Existing Clarifier Performance

As shown in Figure 3, the existing secondary clarifiers at Al-Dewanyia Wastewater Treatment Plant, often experience very high effluent TSS due to the impact of a massive sludge inventory. In the overloaded clarifiers, the effluent TSS, and BOD is extremely sensitive to any minor variations in plant flow. This is because the top of sludge blanket is close to the surface and can easily be carried over the effluent weirs. The overloaded conditions can often cause a large unexpected loss of bio-solids from the secondary treatment process.

The flow capacity for the two existing clarifiers studied ranges from 500 to 750 m³/hr due to variations of the process parameters (MLSS). The clarifiers are unable to achieve their expected design flow of 750 m³/hr due primarily to the thickening limitation of clarifiers. The performance and capacity of a center feed clarifier is very sensitive to the strength of the influent jets into the clarifiers. A traditional center feed clarifier naturally generates a strong influent jet due to its small center feed area. Thus, it often brings significant turbulence into the settling compartment, especially under high flow conditions.



Figure 3. Overloaded clarifier operations

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 are presented in Table 1.

From the above table it is clear that there were no much fluctuations in the influent characteristics, i.e. Mixed Liquor Suspended Solids (MLSS), which could affect the performance of the tank during the testing period. Similar to SS removal efficiency, the BOD and COD removal efficiencies were more or less constant during the operating period at each flow rate. This emphasizes 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 4.

It is clear from Figure 4 that while the percentage of 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 5.

Table 1 Operating conditions during experiment of conventional settling tank

Q (m ³ /hr)	HRT (hour)	MLSS (mg/l)	SVI (ml/g)	Temperature, (°C)	
				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

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 Table1.

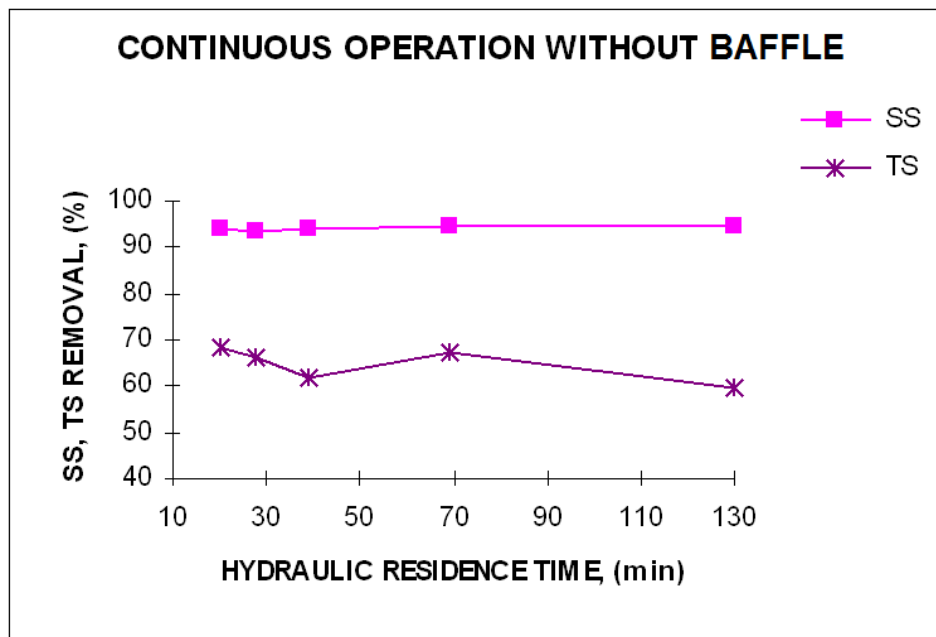


Figure 4. Performance Of Conventional Settler At Different Hydraulic Residence Times.

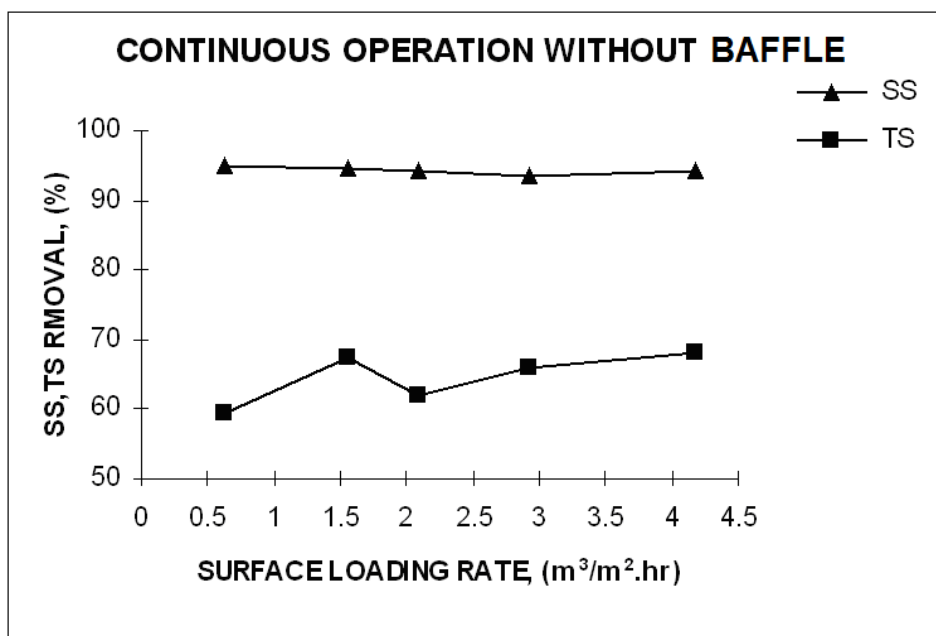


Figure 5. Performance Of Conventional Settler At Different Surface Loading Rates.

5. Result And Dissociation

5.1 Performance of Clarifiers with an Optimized Influent Structure

Figure 6 presents comparison of the Computational Fluid Dynamic (CFD) modelling results for flow and solids fields between the centre-feed clarifier described in Figure 1, in which there is no energy dissipating apparatus around the vertical centre-feed pipe.

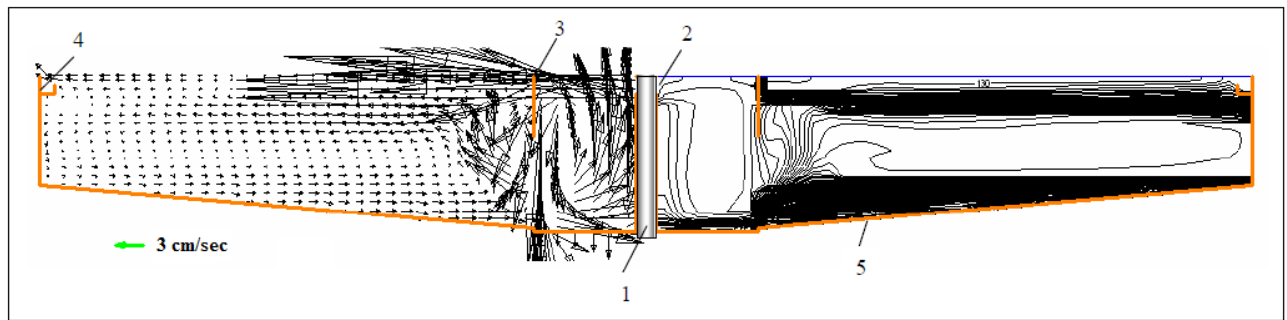
Figures 6(a) and 6(b) present the velocity and solids fields in a selected vertical slice of the tested clarifiers. In the model predicted velocity fields, each velocity vector originates at a grid point in the CFD model. The length of each vector is proportional to the magnitude of the velocity determined 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 the 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 easy to enforce flow evenly to enter 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 can not be generated through simply reducing the size or number of the inlet ports, which would increase the flow intensity entering into the clarifier. 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.

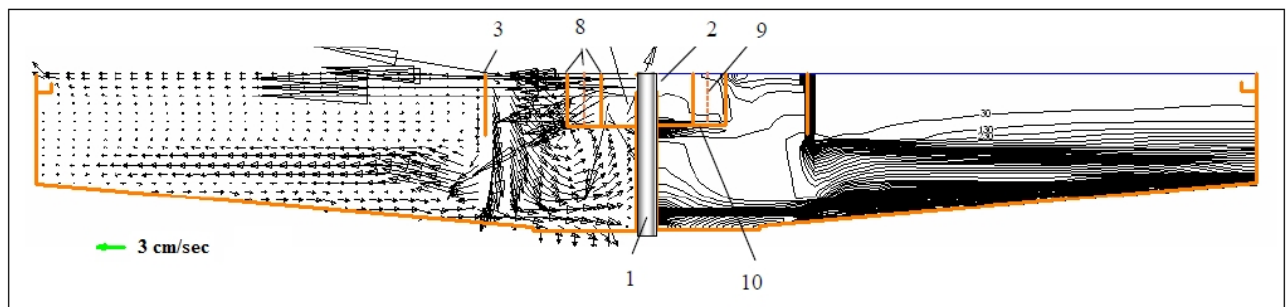
Figure 6 consists of the two parts of 6(a) and 6(b) with respect to the two tested clarifiers with and with no the EDI, respectively.

Figure 6(a), the CFD modelling results for the clarifier equipped with a simple centre influent pipe indicating shows:

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.



a) Existing Clarifier



b) Modified Clarifier

Figure 6. Performance Before (A) And After (B) Central Inlet Retrofit

As shown in Figure 6(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 (m³/h) under the normal process condition, which is most of the year. The optimized clarifiers can achieve a flow capacity of around 1300 (m³/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 m³/hr to 350 m³/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,...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 (hour)	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 7, from which it is clear that the removal efficiency increases as HRT increases.

Figure 8 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, and COD removal.

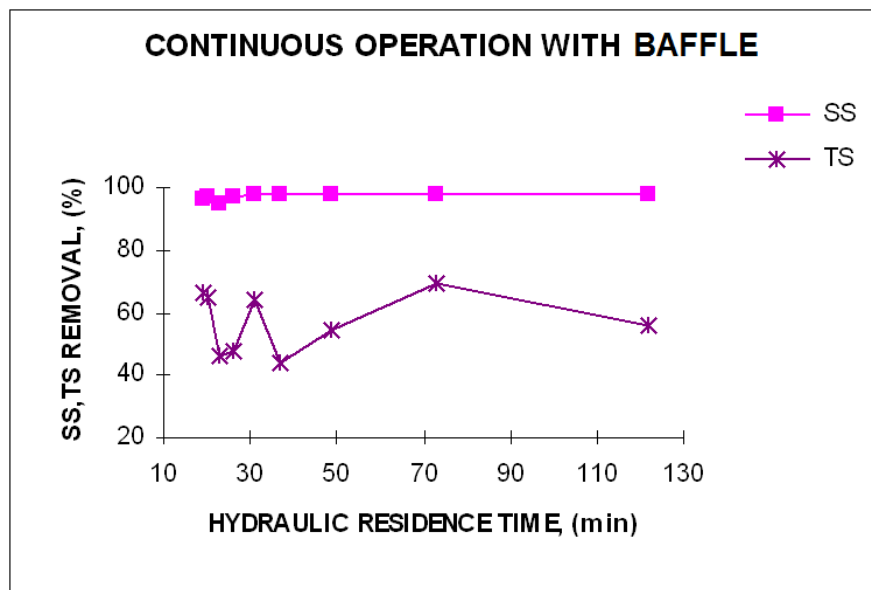


Figure 7. Performance Of EDI (Baffle) At Different Hydraulic Residence Times.

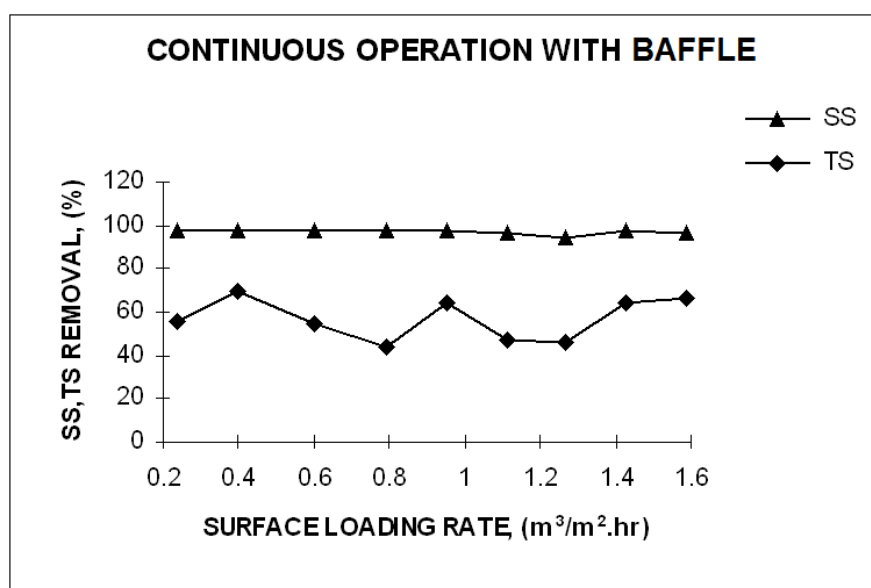


Figure 8. Performance Of EDI (Baffle) At Different Surface Loading Rates.

5.2 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 m³/h to 350 m³/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 the 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, BOD and COD removal. Figures 9, 10, and 11 illustrate the relationship obtained which could be expressed by the following equation 9, 10, and 11:

$$\% \text{ SS removal} = 98.26 - 1.39 \text{ SLR} \quad \dots\dots\dots (9)$$

$$\% \text{ BOD removal} = 96.20 - 1.01 \text{ SLR} \quad \dots\dots\dots (10)$$

$$\% \text{ COD removal} = 95.50 - 0.8 \text{ SLR} \quad \dots\dots\dots (11)$$

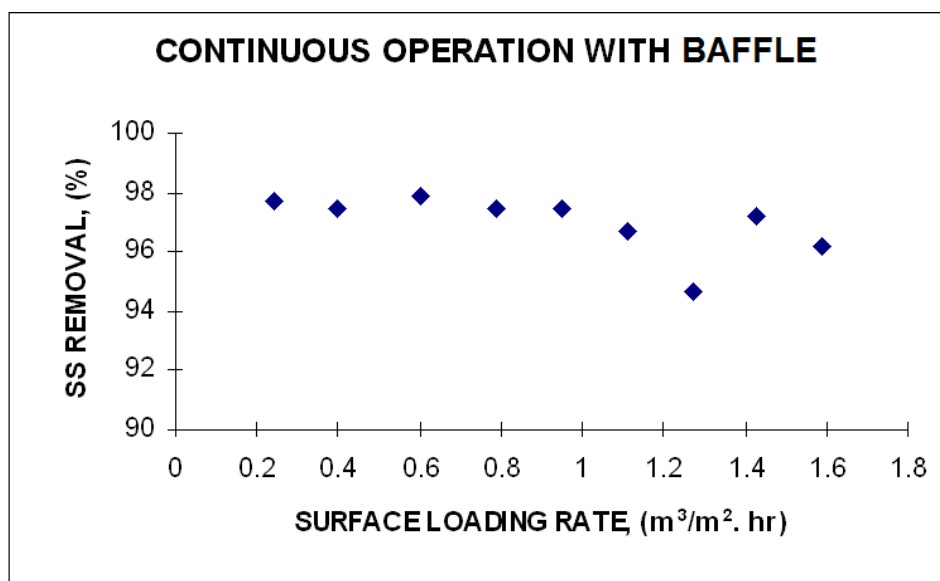


Figure 9. Effect Of Surface Loading Rate On SS Removal Of EDI (Baffle).

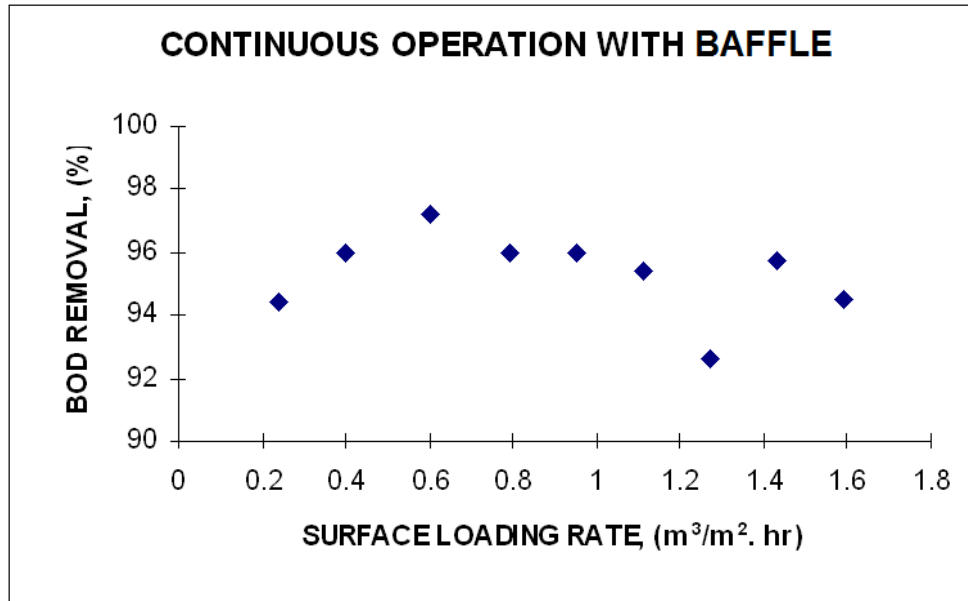


Figure 10. Effect Of Surface Loading Rate On BOD Removal Of EDI (Baffle).

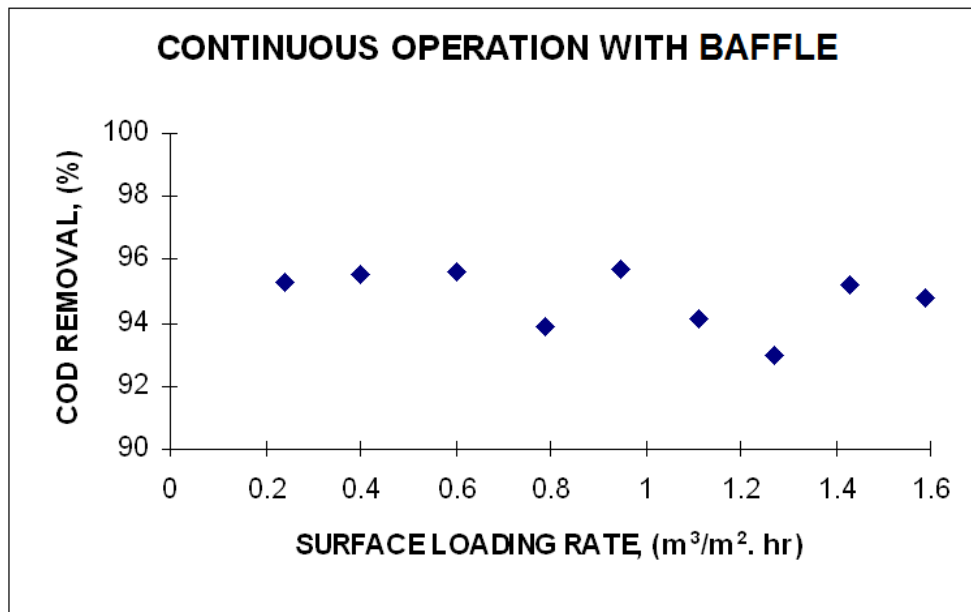


Figure 11. Effect Of Surface Loading Rate On COD Removal Of EDI (Baffle).

6. Conclusions

The following conclusions can be drawn:

1. The EDI (Baffle) has proved effective in improving the performance of secondary sedimentation of biological solids at the studied surface loading rates in the range of 0.2 to 1.6 m³/m².hr.
2. Removal efficiencies of suspended solids, biochemical oxygen demand, and chemical oxygen demand were slightly higher in the EDI (Baffle).
3. In comparison with conventional settler, the EDI (Baffle) is less affected by overloading. If the design surface loading rate criteria for conventional settling tanks is used for designing high-rate settlers, the latter should perform better within the range of surface loading rates normally used in practical design.
4. 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 and COD which results in higher BOD/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.
5. 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 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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