

# Evaluating the Use of Tube Settlers and Lamella Plates in Increasing the Efficiency of Sedimentation Tanks

Hanan A. Fouad<sup>1\*</sup>, Rehab M. Elhefny<sup>1</sup> and Ahmed I. Marei<sup>1</sup>

<sup>1</sup>Sanitary and Environmental Engineering, Faculty of Engineering at Shoubra, Benha University, Egypt.

## Authors' contributions

This work was carried out in collaboration between all authors. All authors read and approved the final manuscript.

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## ABSTRACT

**Aims:** The main purpose of this study is to evaluate the use of tube settlers and Lamella plates in increasing the efficiency of sedimentation tanks in removing the turbidity, bacteria, and algae from water in water treatment plants.

**Study Design:** Evaluating the use of tube settlers and Lamella plates in increasing the efficiency of sedimentation tanks.

**Place and Duration of Study:** Sample: Department of Civil Engineering and Department of Sanitary and Environmental Engineering, between June 2012 and July 2016.

**Methodology:** Egypt's governorates are enriched with various water treatment facilities. More than 7 full-scale WTPs of discharges ranged between  $1,25 \times 10^5$  and  $9 \times 10^5$  m<sup>3</sup>/day located in Cairo and Giza in Egypt were assessed. The evaluation has been done through the laboratory analyses that include the average summer and winter turbidity, bacteria and algae and the average removal efficiency have been deduced for seven water treatment technologies to be assessed.

**Results:** A comparison was done during the period of winter and summer 2015. The evaluation was done on the basis of removal efficiency of turbidity, bacteria and algae. The results have

\*Corresponding author: E-mail: [ahmed.marei@feng.bu.edu.eg](mailto:ahmed.marei@feng.bu.edu.eg);

shown that tube settler clarifiers are more efficient than lamella plate clarifiers and other clarifying systems with higher SLR (surface loading rates). Application of these plates has not caused any interruption of daily operation of treatment plants and could be achieved at minimal cost. Results indicated that the tube settler clarifiers have achieved the highest removal efficiency in terms of turbidity, bacteria and algae. Which were between (84.45%, 89.64%), (98.24%, 99.36%) and (94.31%, 98.86%) respectively. On the other hand, lamella plate clarifiers have achieved turbidity removal efficiency between (69.59%, 74.11%), its bacterial removal efficiency was between (98.28%, 99.11%) and its algae removal efficiency was between (89.48%, 92.94%).

**Conclusion:** The tube settler clarifiers have achieved the highest removal efficiency in terms of turbidity, bacteria and algae. It is better than the other clarifying systems.

*Keywords: Tube settler clarifiers; lamella plate clarifiers; turbidity and algae.*

## 1. INTRODUCTION

McKean [1] stated that sedimentation is one of the most popular systems used in water and wastewater treatment plants in order to remove the turbidity, bacteria and algae. Lamella plates are used in WTP in place of conventional settling tanks. They use inclined plates to provide a large effective settling area for a small footprint. Solid particles settle on the plates and slides down in collection hoppers at the bottom. The sludge is drawn off at the bottom of the hoppers and the clarified water exits at the top over a weir [1].

Therefore, where site footprint limitations are of concern a lamella clarifier system is favored. The small required area provides the opportunity for the clarifiers to be located and operated inside, decreasing some of the general problems of algae growth, clogging due to blowing debris accumulation and odor control, that occur when the machinery is outdoors [2]. Lamella clarifiers are better than the other clarifying systems due to the large effective sedimentation area caused by the use of inclined parallel plates, which enhances the operating conditions of the clarifiers. The system is smaller and needs only 65-80% of the area of clarifiers of the conventional systems. The inclined parallel plates indicate that the clarifier can be operated with overflow rates equal to (2–4) times of the conventional clarifiers which allow a higher influent flow rate [3]. Shevidi et al. [4] offered a new arrangement of tube settlers in series. A two-stage tube settler is used to remove turbidity from water. In their design, the diameter of tubes of the first stage was wide as the conventional tube settlers; while in the second stage, the diameter of the tubes was narrow to enhance the performance. They showed that the two-stage tube settler was more effective than the single-stage one. Lamella clarifiers can be combined into the treatment process or separated units can

be used to improve the flow through existing water treatment plants [5]. Lamella clarifiers are supposed to be one of the best possibilities for pre-treatment ahead of membrane filters [6].

Michael [7] illustrated that the surface overflow rate for lamella plate clarifiers is in between (10–25)  $\text{m}^3/\text{m}^2/\text{h}$ . For these overflow rates, the detention time in each lamella clarifier is low, at around 20 minutes or less. The angle of slope of lamella plates should be inclined at a 50-70° from the horizontal direction to allow for self-cleaning. The projected plate area of the lamella clarifier will be approximately 50% of the space of the conventional clarifier [8]. Sarkar et al. [2] showed that the inclination angle of 45 degrees for parallel systems is optimal [9]. Results of tube settler studies showed that for settling flocculent particles optimum inclination was found to be 55° and the optimum settling velocity for flocculent settling was 2.76 mm/min during which 81 percent turbidity removal was observed (Turbidity < 3 NTU) [10]. The World Health Organization has indicated that the best solutions to increase the capacity of a water treatment plant from 3600  $\text{m}^3/\text{hour}$  to 9000  $\text{m}^3/\text{hour}$  and increase the quality of the treated water is by adding square tube settlers to the existing conventional clarifiers with dimensions (5 cm \* 5 cm) and water velocity 0.15 m/min. It is an alternative solution for the construction of additional clarifiers with low cost [11]. Martin et al. [4] noted a design method to add hexagonal tube settlers from plastic in settling clarifiers with an easy way to make it easy for the particles to be settled and angle of inclination is 60°. The idea of this design is to reduce the water velocity to give the solid particle the time to be settled inside the tube settlers [12]. An evaluation for the efficiency of conventional clariflocculator units with tube settlers within the compact units in Mosul Unified Water Project was made. The results indicated that the tube settlers are more efficient than conventional

clariflocculator units in removing turbidity and phytoplankton algae at a low turbidity level. Results also showed that the conventional clariflocculator units are more efficient than tube settlers at a high turbidity level [13].

## 2. METHODOLOGY

Egypt's governorates are enriched with various water treatment facilities. More than 7 full-scale WTPs of discharges ranged between  $1,25 \times 10^5$  and  $9 \times 10^5$  m<sup>3</sup>/day located in Cairo and Giza in Egypt were assessed. The evaluation has been done through the laboratory analyses that include the average summer and winter turbidity, bacteria and algae and the average removal efficiency have been deduced for seven water treatment technologies to be assessed.

All data concerned with the WTP in this research are listed as:

The first WTP is located in Giza with a design capacity of  $1,25 \times 10^5$  m<sup>3</sup>/day and serves about  $6,25 \times 10^5$  capita. The clarifiers used are Tube settler clarifiers. They consist of one train made up of three clarifying tanks. Each class has 37.00 lengths, 8.40 m wide and the water depth is 6.10 m. The detention time is about 60 minutes per clarifier and the surface loading rate is  $5.96$  m<sup>3</sup>/m<sup>2</sup>/h. The height of the tube package is 1.50 m.

The second WTP is located in Cairo with a design capacity of  $6,60 \times 10^5$  m<sup>3</sup>/day and serves about  $3,30 \times 10^6$  capita. The clarifiers used are Tube settler clarifiers. They consist of 12 trains made up of one clarifying tank. Each one has 36.80 lengths, 8.40 m width and the water depth is 5.20 m. The detention time is about 0.70 hours per clarifier tank and the Surface loading rate is  $7.50$  m<sup>3</sup>/m<sup>2</sup>/h. The height of the tube package is 1.50 m.

The third WTP is located in Giza with a design capacity equal to  $2 \times 10^5$  m<sup>3</sup>/day and feeds about  $1 \times 10^6$  capita. The clarifiers used are Tube settler clarifiers. They consist of 3 clarifiers only. Each clarifier has 50 m length, 15 m width and the water depth is 7 m.

The fourth WTP is located in Cairo with a design capacity of  $4 \times 10^5$  m<sup>3</sup>/day and serves about  $2 \times 10^6$  capita. The clarifiers used are lamella plate clarifiers. They consist of two stages. Each stage made up of 4 clarifiers only for each side. Each clarifier has 13.50 m length, 10.20 m width. The width of the plate

is 1.222 m, the length of the plate is 2.770 m, the angle of the slope of each plate is 55° and the spacing between each two plates is 80 mm.

This fifth WTP is located in Giza with a design capacity of  $9 \times 10^5$  m<sup>3</sup>/day and serves about  $4,50 \times 10^6$  capita. The clarifiers used are Pulsator clarifiers. They consist of two stages (A and B). Stage "A" consists of 8 clarifiers. The capacity of each pulsator clarifier is  $40,000$  m<sup>3</sup>/day and its dimensions are 28 m length, 24 m width and the water depth is 4 m. Stage "B" consists of 12 clarifiers. The capacity of each pulsator clarifier is  $50,000$  m<sup>3</sup>/day and its dimensions are 28.5 m length, 24 m width and the water depth is 5 m.

This sixth WTP is located in Cairo with a design capacity of  $2 \times 10^5$  m<sup>3</sup>/day and serves about  $1 \times 10^6$  capita. The clarifiers used are Pulsator clarifiers. They consist of four clarifiers with the length of 24 m, width 24 m and the water depth is about 6 m.

This seventh WTP is located in Cairo with a design capacity of  $6,50 \times 10^5$  m<sup>3</sup>/day and serves about  $3,25 \times 10^6$  capita. The clarifiers used are square clariflocculators. They consist of ten clarifiers with the length of 35 m, width 35 m and the water depth is about 6.40 m.

The study was conducted using collected samples from the influent and effluent flow of the WTPs, Samples were collected from the WTPs during both summer and winter.

## 3. RESULTS AND DISCUSSION

As mentioned above, the assessment has covered the laboratory analyses which include the average summer and winter turbidity, bacteria and algae, and the average removal efficiency deduced for seven water treatment technologies to be assessed.

### 3.1 The Effect of Different Types of Clarifiers on the Turbidity Removal Efficiency

Fig. 1 shows that the efficiency of turbidity removal of the tube settler clarifiers of the first and the second WTPs in the summer and winter seasons are (89.64%, 84.45%) and (86.80%, 86.11%) with SLR equal to  $5.96$  m<sup>3</sup>/m<sup>2</sup>/h and

7.50 m<sup>3</sup>/m<sup>2</sup>/h respectively. The efficiency of the tube settlers is higher than the efficiency of the Lamella plate clarifiers of the fourth WTP which is equal to (74.11% and 69.59%) in the summer and winter seasons respectively with SLR equal to 8.36 m<sup>3</sup>/m<sup>2</sup>/h. It is also more efficient than the Pulsator clarifiers that used in the fifth and sixth WTPs which have efficiency equal to (67.75%, 86.29%) and (47.37%, 87.11%) in the summer and winter seasons with SLR 2.80 m<sup>3</sup>/m<sup>2</sup>/h, 3.10 m<sup>3</sup>/m<sup>2</sup>/h respectively, although the sixth WTP has a removal efficiency higher than the tube settlers of the second WTP during summer and winter and the first WTP during winter, it can be explained as the SLR of the tube settler clarifiers is higher than it for Pulsator clarifiers, and the difference in efficiency is insignificant, amounting to only 0.31% for the first WTP in winter and 1.84%, 1.00% for summer and winter for the second WTP respectively. The efficiency of the tube settler clarifiers of the first and second WTPs during summer and winter is higher than the efficiency of the square clariflocculators of the seventh WTP in summer and winter since the prior has an efficiency of 77.36% and 77.53% and SLR equal to 2.21 m<sup>3</sup>/m<sup>2</sup>/h.

The efficiency of the tube settler clarifiers of the third WTP is 53.91% and 22.99% during summer and winter respectively so it is rather low compared to the efficiency of other systems due to some issues related to the design and construction of the clarifiers. It is not washed since it was constructed because these clarifiers need gates to separate the tube settler clarifiers away from the feeder channel. All tube settler clarifiers are continuously open and if they want to wash anyone, they will need to stop the WTP from working so it makes the efficiency of the WTP very low. The cross section of the tube settlers becomes narrower and this increase the velocity of water so the particles don't have the time required to be settled and escapes with the water. The constructed company will make new gates for the tube settler clarifiers.

Although the SLR of lamella plate clarifiers of the fourth WTP is the highest of all seven WTPs, its efficiency is very low, as opposed to the pulsator and square clariflocculators which are more efficient. The least efficient of the seven WTPs is the tube settler clarifiers of the third WTP due to the errors that became clear during the working.

Finally, the performance of the tube settlers is very good as expected and recorded 87.05% and

86.45% as average turbidity removal efficiency during summer and winter respectively. The efficiency of the tube settler clarifiers in summer and winter are approximately the same and not affected with the weather conditions unlike lamella plate clarifiers since the difference between its efficiency in summer and winter is 4.52%. The turbidity removal efficiency of tube settlers is close to the standard efficiency values which equal to (90 – 95%) (Bruce, 2006) so it is better than the efficiency of the lamella clarifiers, pulsator clarifiers and the square clariflocculators.

### 3.2 The Effect of Different Types of Clarifiers on the Bacterial Removal Efficiency

Fig. 2 illustrates that the efficiency of the tube settler clarifiers of the first and the third WTPs in the summer and winter seasons are (99.13%, 99.36%) and (98.90%, 98.79%) respectively. The efficiency of the tube settlers is higher than the efficiency of the Lamella plate clarifiers of the fourth WTP which equal to (99.13% and 98.28%) in the summer and winter seasons respectively. The efficiency of the second WTP in the summer and winter is (98.50% and 98.24%) respectively. Although the efficiency of tube settlers of the first and second WTPs may be higher than the efficiency of the lamella plates of the fourth WTP, the lamella plate clarifiers are better than tube settler clarifiers because it has higher SLR and the chlorine dose that used is smaller.

It is also more efficient than the Pulsator clarifiers that used in the fifth and sixth WTPs which have efficiency equal to (99.30%, 99.40%) and (98.82%, 99.82%) in summer and winter respectively. Although it has a higher efficiency than it for the tube settlers and lamella plate clarifiers during summer and winter, tube settler and lamella plate clarifiers are the best because it has higher SLR than Pulsator clarifiers and the chlorine dose are approximately the same that lies in that range (4 to 7.60 PPM).

The efficiency of the square clariflocculators of the seventh WTP in summer and winter is the highest at all and it is equal to 99.50% and 99.45% in summer and winter respectively but the tube settler and lamella plate clarifiers are the best because they have the highest SLR and the difference between the efficiency values is insignificant as shown in Fig. 2.

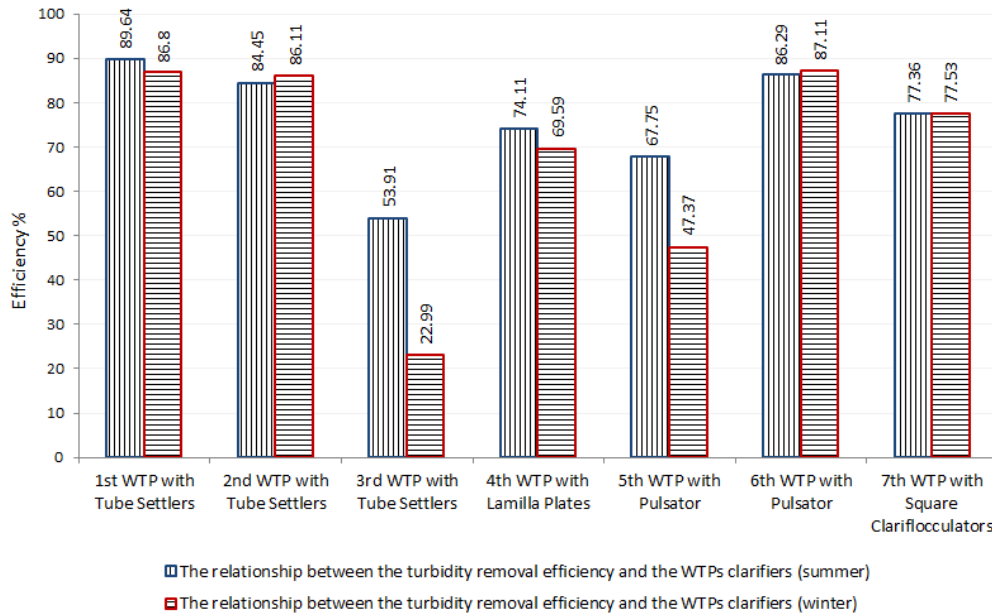


Fig. 1. The turbidity removal efficiency for the different WTPs clarifiers

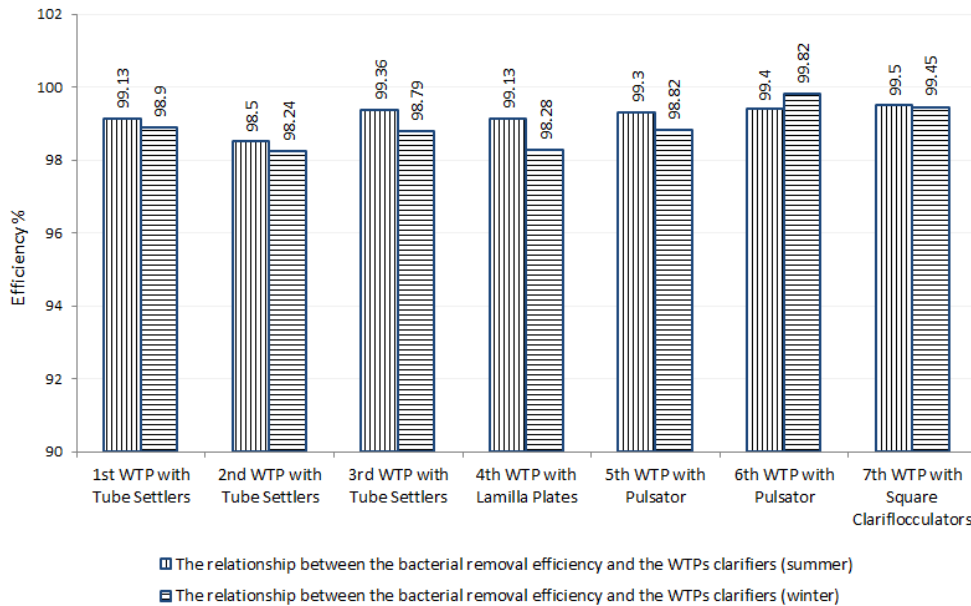
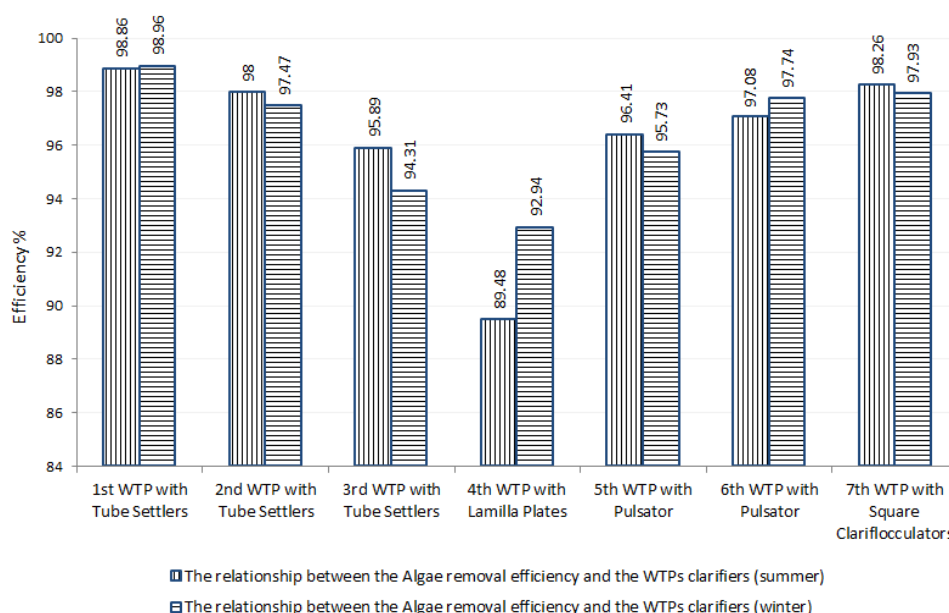


Fig. 2. The bacterial removal efficiency for the different WTPs clarifiers

Finally, the performance of the tube settlers and lamella plate clarifiers is very good as expected and recorded (99.00%, 99.13%) and (98.65%, 98.28%) as the average bacterial removal efficiency during summer and winter for tube settler clarifiers and lamella plate clarifiers respectively. This means that the efficiency of the

tube settlers and lamella plate clarifiers in summer and winter are approximately the same and not affected by the weather conditions since the difference between its efficiency in summer and winter is 0.65% for tube settler clarifiers and 1.15% for lamella plate clarifiers.



**Fig. 3. The bacterial removal efficiency for the different WTPs clarifiers**

### 3.3 The Effect of Different Types of Clarifiers on the Algae Removal Efficiency

Fig. 3 explains that the efficiency of the tube settler clarifiers of the first, second and the third WTPs in the summer and winter seasons are (98.86%, 98.00%, 95.89%) and (98.96%, 97.47%, 94.31%) respectively. The efficiency of the tube settlers is higher than the efficiency of the Lamella plate clarifiers of the fourth WTP which equal to (89.48% and 92.94%) in summer and winter respectively. Lamella plate clarifiers are also very good in removing bacteria because it has good efficiency with the highest SLR but tube settlers are the best because it has the best efficiency with high SLR.

The Pulsator clarifiers of the fifth and sixth WTPs have efficiency equal to (96.41%, 97.08%) and (95.73%, 97.74%) in the summer and winter seasons respectively, although the efficiency of the pulsator clarifiers is higher than the efficiency of tube settler clarifiers of the third WTP (that has the lowest efficiency of tube settlers), the tube settler clarifiers are the best as the maximum difference in the efficiency values is insignificant, amounting to only 1.19% in summer and 3.43% in winter and the tube settler clarifiers have higher SLR that may be equal to 2.5 times of the pulsator clarifiers.

The efficiency of the square clariflocculators of the seventh WTP in summer and winter is 98.26% and 97.93%. It is lower than the efficiency of tube settler clarifiers of the second and the third WTPs but the maximum difference in the efficiency values between it and the third WTP (that has the lowest efficiency of tube settlers), is insignificant, amounting to only 2.37% in summer and 3.62% in winter and the tube settler clarifiers have higher SLR that may be equal to 3 times of the square clariflocculators.

Finally, the performance of the tube settlers is the best as expected and recorded 97.58% and 96.91% average algae removal efficiency during summer and winter respectively. The efficiency of the tube settlers in summer and winter are approximately the same and not affected with the weather conditions.

At the end, the tube settler clarifiers are the best clarifying system can be used in removing turbidity, bacteria and algae. It is the best system can be used to increase the efficiency of the existence sedimentation tanks with higher surface loading rate as explained.

## 4. CONCLUSION

The present study collected laboratory test results of different type of clarifiers for seven

WTPs. Lamella plate, Tube settler, pulsator and square clariflocculators were used in the considered WTPs. After analyzing and comparison of the collected data, the tube settler clarifiers have achieved the highest removal efficiency in terms of turbidity, bacteria and algae. It is better than the other clarifying systems. And the following conclusions were reached:

1. Lamella plate clarifiers have very good efficiency in all WTPs except the fourth one.
2. Tube settler clarifiers have better efficiency than Lamella plate clarifiers.
3. The mistakes in the design and the construction works make terrible problems in the steps after the construction and this appear during the time of operation such as the problems in the third water treatment plant clarifiers as we explained before.
4. With the comparison of efficiency of the Lamella plates and tube settler clarifiers, we find that the tube settler clarifiers is more effective in increasing the efficiency of the sedimentation tanks in removing the turbidity except the efficiency of the tube settler clarifiers in the third water treatment plant as we explained but for efficiency of it in removing the bacteria and the algae we find that they are effective because of the high efficiency.
5. The efficiency of the Lamella plate clarifiers in removing the turbidity is less than the efficiency of the other sedimentation systems such as Pulsator clarifiers and the Square Clariflocculators but it has a high surface overflow rate that maybe equal to about more than 4 times of it for Pulsator clarifiers and the Square Clariflocculators.
6. The efficiency of the Lamella plate clarifiers in removing the bacteria and the algae is very good and it is approximately equal to it for the other sedimentation systems such as Pulsator clarifiers and the Square Clariflocculators although it has a higher surface overflow rate than it for Pulsator clarifiers and the Square Clariflocculators.
7. The efficiency of the tube settler clarifiers in removing the turbidity is better than that of the other sedimentation systems such as Pulsator clarifiers and the Square

Clariflocculators because the difference between them is not high. The efficiency of tube settler clarifiers may be higher or less than the efficiency of the other sedimentation systems but the difference still very small number although it has a high surface overflow rate that maybe equal to about more than 2.5 times of it for Pulsator clarifiers and the Square Clariflocculators. Except the efficiency of the tube settler clarifiers in the third water treatment plant as we explained.

8. All clarifier types have very good overall efficiency in removing bacteria and algae.

### COMPETING INTERESTS

Authors have declared that no competing interests exist.

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