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An experimental sedimentation tank for enhancing the settling of solid particles

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Abstract

Sedimentation tanks have a vital role in the overall efficiency of solid particles removal in treatment units. Therefore, an in-depth study these tanks is necessary to ensure high quality of water and increasing the system efficiency. In this work, an experimental rectangular sedimentation tank has been operated with and without a baffle to investigate the system behaviour and effectiveness for the reduction of solid particles. Turbid water was prepared using clay, which was collected from the water treatment plant of Al Maqal Port (Iraq), mixed with clear water in a plastic supply tank. Raw and outflow samples were tested against turbidity after plotting a calibration curve between inflow suspended solids versus their corresponding turbidity values. The key objective was to assess the impact of different flow rates, particle concentrations, heights and positions of the baffle on the system efficiency. Findings showed that the tank performance was enhanced significantly ($p < 0.05$) with the use of a baffle placed at a distance of 0.15 of tank length with height equal to 0.2 of tank depth. Higher removal efficiency (91%) was recorded at a lower flow rate (0.015 $dm^3 \cdot s^{-1}$) and higher concentration (1250 $mg \cdot dm^{-3}$), as the treatment efficiency enhanced by 34% compared with the operation without a baffle. Placing the baffle in the middle of the sedimentation tank produced the worst results. System efficiency for solids removal reduced with increasing baffle height. Further research is required to evaluate the efficiency of an inclined baffle.

Key words: *baffle, clay, secondary settling basin, solid particles, treatment plant, turbid water*

INTRODUCTION

Solid particles are one of the most persistent contaminants in wastewater [Kowalczyk *et al*. 2019; Malczewska, Biczyński 2017], and the reduction of these pollutants is considered an important step in water and wastewater treatment plants. Sedimentation using primary and secondary settling tanks separates suspended particles from water by gravity [Jawecki *et al*. 2017]. This method has been widely used over the years for the purification of turbid water. Treatment occurs when solid particles settle down along the tank due to the low flowing rate of turbid water [Ghawi, Al-Jeebory 2010; Shahrokhi *et al*. 2013].

Sedimentation basins account for around thirty percent of the total cost of any treatment unit, and as a result, enhancing the efficiency of these tanks is the desired target for designers and operators [Shahrokhi *et al*. 2013]. The performance of settling basins is affected clearly by functions of these systems. Therefore, much attention is needed in terms of key functions that affect the process of settling. These factors mainly include tank dimensions, flow rate, settling velocity [Mall, Shriram 2014], type of flow, particles characteristics and concentration, flow pattern, angle between the baffle and the system bed [Saady 2012], and finally baffle position and height [Tamayol *et al*. 2010].

Previous research on sedimentation tank treatment systems provided valuable information about the impact of tank dimensions on the settling efficiency [Mall, Shriram 2014]. Regarding the impact of the baffle, Yoon and Lee [2000] mentioned that the baffle in settling basins is capable to spread out the flow over the whole tank, squander the inflow kinetic energy, and enhance the circulation time (to inhibit short-circuiting). Therefore, many researchers have focused on the use of baffle either experimentally [Goula *et al*. 2008] to assess the impact of the baffle on the flow pattern or numerically [Al-Sammarraee, Chan 2009; Tamayol *et al*. 2010] to examine the impact of different baffle configurations. Shahrokhi *et al*. [2012] concluded that increasing the number of baffles boosted the tank performance, but the authors ignored the cost of these baffles compared with the resulted enhancement. Recently, different modelling approaches have been used to study the effect of the settling area [NGUYEN *et al*. 2019] and particles distribution [FAN *et al*. 2020] on the system efficiency. However, it has been noticed that the full impact of the main operation variables on the efficiency of sedimentation tanks is still limited. Apart from ASGHARZADEH *et al*. [2011], no investigations have been reported to assess the efficiency of settling basins depending on the particles removal or outflow concentrations, as these two parameters are very important to evaluate the basin performance. ASGHARZADEH *et al*. [2011] have focused on the efficiency of a settling tank used to treat kaolin at concentration of 400 and 1000 mg·dm^{-3} depending on velocity profile and outlet concentrations. However, the impact of different flow rates and wider range of inlet concentrations have not been observed. In addition, the system was operated to examine the impact of a baffle placed in two positions only, which were not enough to evaluate the performance of an eight meter channel. Thus, this research will be the first to focus on the impact of different factors, in detail, based on the profile of particles distribution and the efficiency of settling tank in particles removal in one full study. These factors include baffle height (H_b), baffle position, inflow rate (Q), and inflow concentration (C_{in}). This could create an opportunity to increase the tank efficiency and to provide more understanding about the tank performance.

In this work, findings of experimental studies are discussed to assess the performance of a lab-scale secondary sedimentation tank designed to eliminate particles. The objectives are to examine the impact of the: presence and absence of a baffle, its position and height, low and high inflow particulate concentrations, and low and high inflow rates (reflecting the contact time) on the system efficiency for the removal of solid particles.

MATERIALS AND METHODS

EXPERIMENTAL PROTOCOL

A laboratory-scale experimental sedimentation tank was operated at the university using a stainless steel rectangular tank of 120 cm in length (L), 30 cm in width (W), and 40 cm depth in (D). System dimensions were as recommended by MALL and SHRIRAM [2014]. These authors mentioned that the preferable length to width ratio of rectangular settling tank ranges between a ratio of 3:1 and 5:1, and higher settling efficiency achieved at a ratio equal to 3:1 or 4:1. They also founded that the lower basin depth is preferable. Hence, in this research a ratio of 4L:1W was used with a depth of 40 cm – which was enough for sludge storage. Figure 1 demonstrates a schematic diagram of the system. The slope of the tank bed was zero, and the inlet at the height of 13 cm has a rectangular cross-section. The height of the sharp-edged outlet weir is 38 cm, and the total depth of flow was 40 cm.

The system was operated several times with and without a baffle placed in the system bed. The bed baffle was

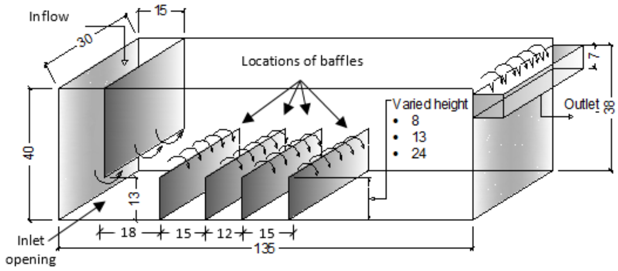

Fig. 1. A schematic diagram of the settling tank used in this study (all dimensions are in cm); source: own elaboration

selected instead of the surface baffle for enhancing the settling tank efficiency [TAMAYOL *et al*. 2010], due to the fact that it efficiently interrupts the extreme rapid jet and decreases the speed of flow within the tank bed [HEYDARI, MEHRZADEGAN 2014]. In the first case, the tank was operated without a baffle. In cases from 2 to 5, a single baffle was used and placed in the system bed at distances of 18, 33, 45 and 60 cm from the inlet opening. At each distance, three baffles of 8, 13, and 24 cm in height were examined, which were below, equal and above the height of the inlet, respectively. The tank was operated in separate runs using two different concentrations (low: 250 ±5.45, and high: 1250 ±4.49 mg·dm^{-3}) and inflow rates (low: 0.015 and high: 0.06 dm^3·s^{-1} reflecting contact time of 9600 s and 2400 s, respectively), which have not been studied before. These selected values were within the design guideline recommended by JOVER-SMET *et al*. [2017]. Each run exceeded the contact time needed to collect enough data on inflow and outflow samples. The results of each run were repeated three times under the same conditions to make sure that all results are reliable. All cases were examined using Reynold number of 0.0508. Table 1 summarises each case of operation. The Q was fixed at the desired value using a flow valve, and measured by a flow meter installed between the supply tank and the inlet.

TURBID WATER PREPARATION AND MEASUREMENT

The turbid water was prepared as a settling suspension of clay to examine the basin efficiency (specific gravity of 2.65, D_{50} = 1.7 mm), which was collected from the water treatment plant of Al Maqal Port (Iraq) and mixed with clear water in a plastic supply tank. A supply tank of 250 dm^3 is placed at a distance of 40 cm above the ground. It contained a mixer to ensure that no particles settle down in the supply tank. To evaluate the tank efficiency, raw and outflow samples were tested for turbidity after plotting a calibration curve between the inflow suspended solids versus their corresponding turbidity values. Turbidity was measured using a turbidity meter (LP2000-11 Precision Bench, HANNA). Suspended solids were tested according to the method stated by APHA 2005 [EATON *et al*. (eds.) 2005]. Treatment efficiency (TE, %) of the sedimentation tank has been investigated as defined below (C_{in} and C_{out} are inflow and outflow particle concentrations, respectively):

$$TE = [(C_{in} - C_{out})/C_{in})]\ 100 \qquad (1)$$

Table 1. Studied cases of the experimental sedimentation tank (inflow concentrations 250 and 1250 mg·dm^{-3}, inflow rate 0.060 and 0.015 dm^3·s^{-1}, over flow rate 0.0001670 and 0.0000416 m·s^{-1} high and low values, respectively)

Case	Baffle	Distance[1] (cm)	Baffle height (cm)
1	no baffle	–	–
2	single baffle	18	8, 13, 24
3	single baffle	33	similar to case 2
4	single baffle	45	similar to case 2
5	single baffle	60	similar to case 2

[1] Distance from the inlet opening.
Source: own elaboration.

DATA ANALYSES

The resulted data was analysed using Microsoft Excel 2016. Statistical analysis using IBM SPSS 23 was conducted with the non-parametric Man–Whitney U test, to compare the difference between two independent samples. The Shapiro–Wilk test was computed to examine the normality of data.

RESULTS AND DISCUSSION

PROFILE OF PARTICLES CONCENTRATIONS

The profile of particle concentrations at varying depths (0, 5, 10, 15, 20, 25, and 30 cm) along the tank and in different distances (15, 30, 40, 55, 75 and 100 cm) from the inlet opening with and without a baffle are discussed below.

Case of 'no baffle'. Results clearly showed that particle concentrations at a distance of 15 cm from the inlet opening in case no baffle is ued (Tab. 1, case 1) were scattered along the tank depth (Figs. 2a and g for cases of high and low inflow rates, respectively). Subsequently, most particles are accumulated within the middle parts of the basin depth for both studied inflow concentrations and inflow rates. This was interpreted by the pattern of jet flow through the inlet as mentioned by ASGHARZADEH *et al*. [2011]. A similar particles distribution was found in Figures 2b and h, showing values at a distance of 30 cm from the inlet, indicating that the flow pattern was also similar. However, the vertical profile of solids at distances of 40, 55, 75, and 100 cm from the inlet showed a different path, as presented in Figures 2c, d, e, and f (high flow rate), and Figures 2i, j, k, and l (low flow rate), respectively. Particles concentrate on the tank bed with their gradually reduced presence in upper layers, especially near to the end of the tank. These results are explained by the fact that particles move towards the system bed and settle down after a specific distance of more than half of the channel length, especially the heavier ones [ASGHARZADEH *et al*. 2011].

Case of a baffle placed at 0.15 of the tank length. When the baffle was fitted at a distance of 18 cm (Tab. 1, case 2), results showed that the profile of particles at 15 cm from the inlet (before the baffle) and using a plate of 8 cm height were scattered, which was due to the pattern of inlet jet (Figs. 3a and g in case of low and high inflows, respectively). These scatterings were dissimilar if compared with the case of 'no baffle' (Figs. 2a and g). It was because particles had reduced concentration in the mid-depth of the tank and increased concentration in the other parts. However, in case 1, the particles were scattered randomly along the tank height with some accumulation in the mid-depth only. These results were explained by the impact of the baffle, which works as a barrier accumulating particles in front of it [AL-SAMMARRAEE, CHAN 2009]. The degree of accumulation was also affected by the plate height. Behind the baffle, at distances of 30 and 40 cm from the inlet, particle concentrations were gradually decreasing (with length) in the top layers to increase again in the tank bed (Figs. 3b, c, h, and i) because of particle re-suspension [ASGHARZADEH *et al*. 2011]. At distances of 55, 75 and 100 cm from the inlet, the particles distribution was very uniform and concentrations increased clearly towards the system bed (depending to the baffle efficiency) as shown in Figures 3d–f (high Q), and Figures 3j–l (low Q). A trend of particle distribution was found when 13 cm and 24 cm baffles were used (data not shown).

Case of a baffle placed at 0.275 of the tank length. In case the H_b 8 cm baffle is placed at a distance of 33 cm from the inlet (Tab. 1, case 3), at a distance of 15 cm (before the baffle) particles were dispersed and highly concentrated (similar to case 2). Solids accumulation near to the inlet in case 3 (Figs. 4a and g) was higher than in case 1 (Figs. 2a and g) due to the impact of the baffle. However, the accumulation was lower in comparison with case 2 (Figs. 3a and g) due to the baffle position. However, the trend of particles distribution was similar. At a distance of 30 cm from the inlet, most particles accumulated in the middle part of the tank depth, with some reduction in particles concentrations (Figs. 4 b and h). This may indicate that solids started to move towards the system bed. After the baffle, at a distance of 40 cm, a clear reduction of particles concentrations was noticed (Figs. 4 c and i). Then, the concentrations decreased sharply in the upper parts comparing with these at the system bed (Figs. 4d–f, case of high Q and Figs. 4j–l, case of low Q) depending on baffle effectiveness. A trend of particles distribution was noticed using 13 cm and 24 cm plate heights (data not shown).

Case of a baffle placed at 0.375 of the tank length. Figure 5 shows particulates profile when the 8 cm baffle placed at a distance of 45 cm from the inlet (Tab. 1, case 4). In this trial, the vertical profile of particles at a 15 cm for all inflow rates exhibited equivalent distribution to the corresponding profile of case 2 (Figs. 3a and g) and case 3 (Figs. 4a and g). However, particles showed lower accumulation in this case (Figs. 5a and g) due to the impact of the baffle position on treatment efficiency, which was lower than in cases 2 and 3. Following on from that, at distances of 30 cm (Figs. 5b and h) and 40 cm (Figs. 5c and i) a small reduction was noticed in the concentration of particles as solids started to move down. However, particle concentration at a distance of 55 cm (directly after the baffle) decreased in top layers of the sediment tank and significantly increased in the system bed. This can be interpreted by the effect of the baffle (Figs. 5d and j). Then, the concentrations showed a sharp decrease at top layers of the settling tank (Figs. 5e and f, and k and l). This trend of particles distribution was similar using 13 cm and 24 cm baffles (data not shown).

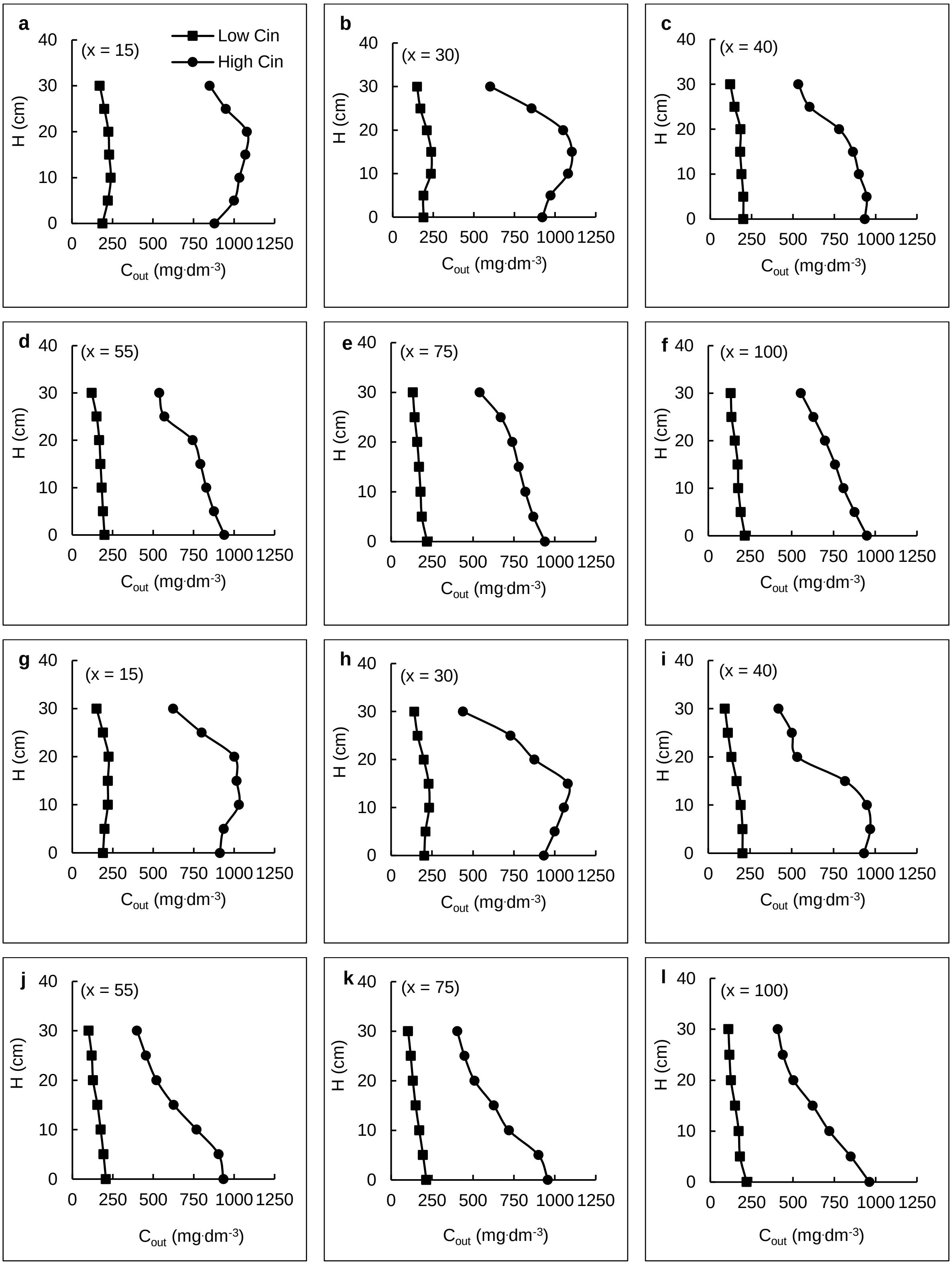

Fig. 2. Profile of particles in case of 'no baffle': a)–f) flow rate of 0.06 dm^3·s^{-1}, g)–l); flow rate of 0.015 dm^3·s^{-1}; *H* = tank depth, *x* = distance from the inlet (cm), C_{in} and C_{out} = inflow and outflow concentrations of particles (mg·dm^{-3}); source: own study

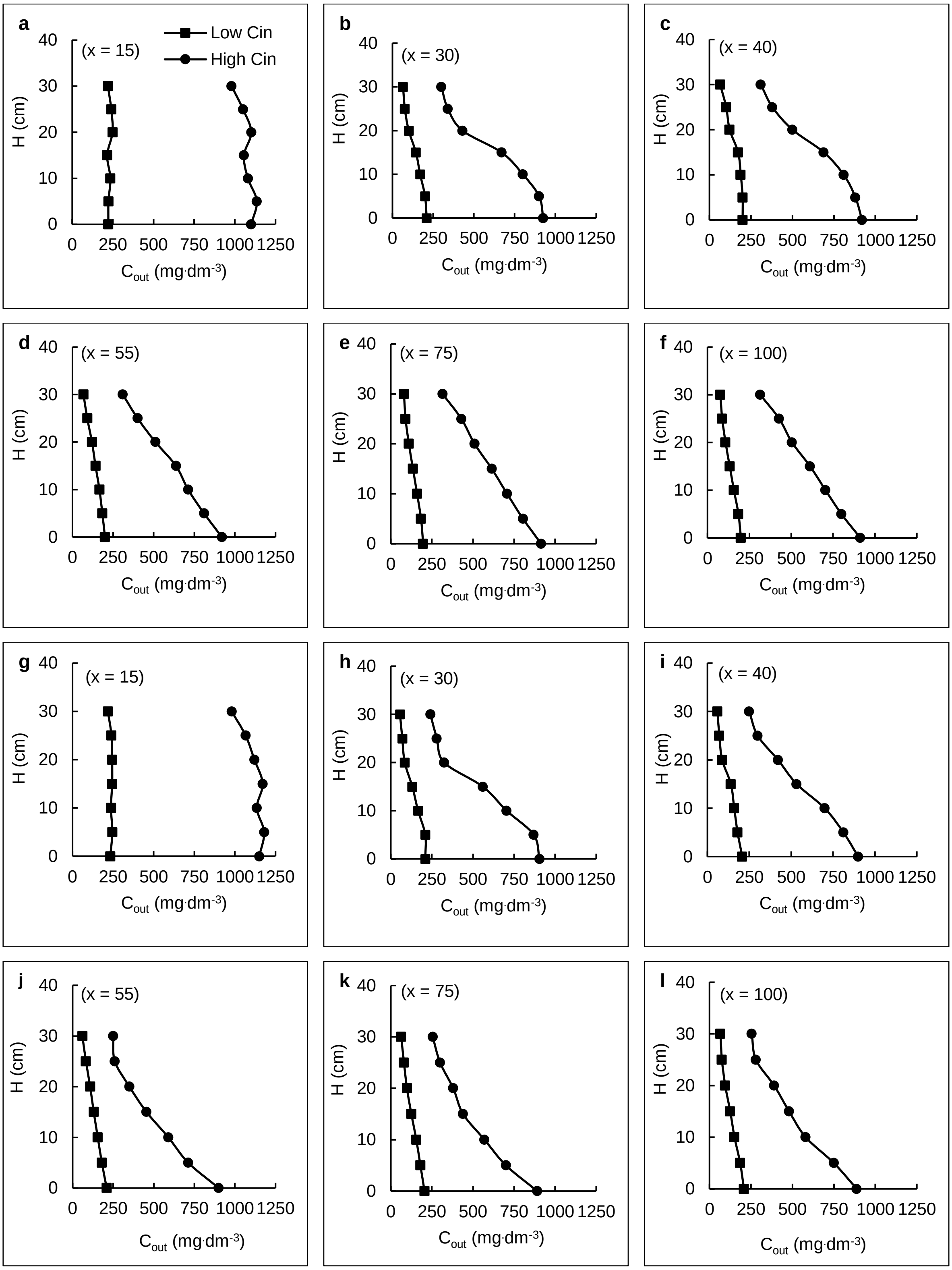

Fig. 3. Profile of particles in case of 8 cm baffle placed at 18 cm: a)–f); flow rate of 0.06 $dm^3 \cdot s^{-1}$, g)–l) flow rate of 0.015 $dm^3 \cdot s^{-1}$; explanations as in Fig. 2; source: own study

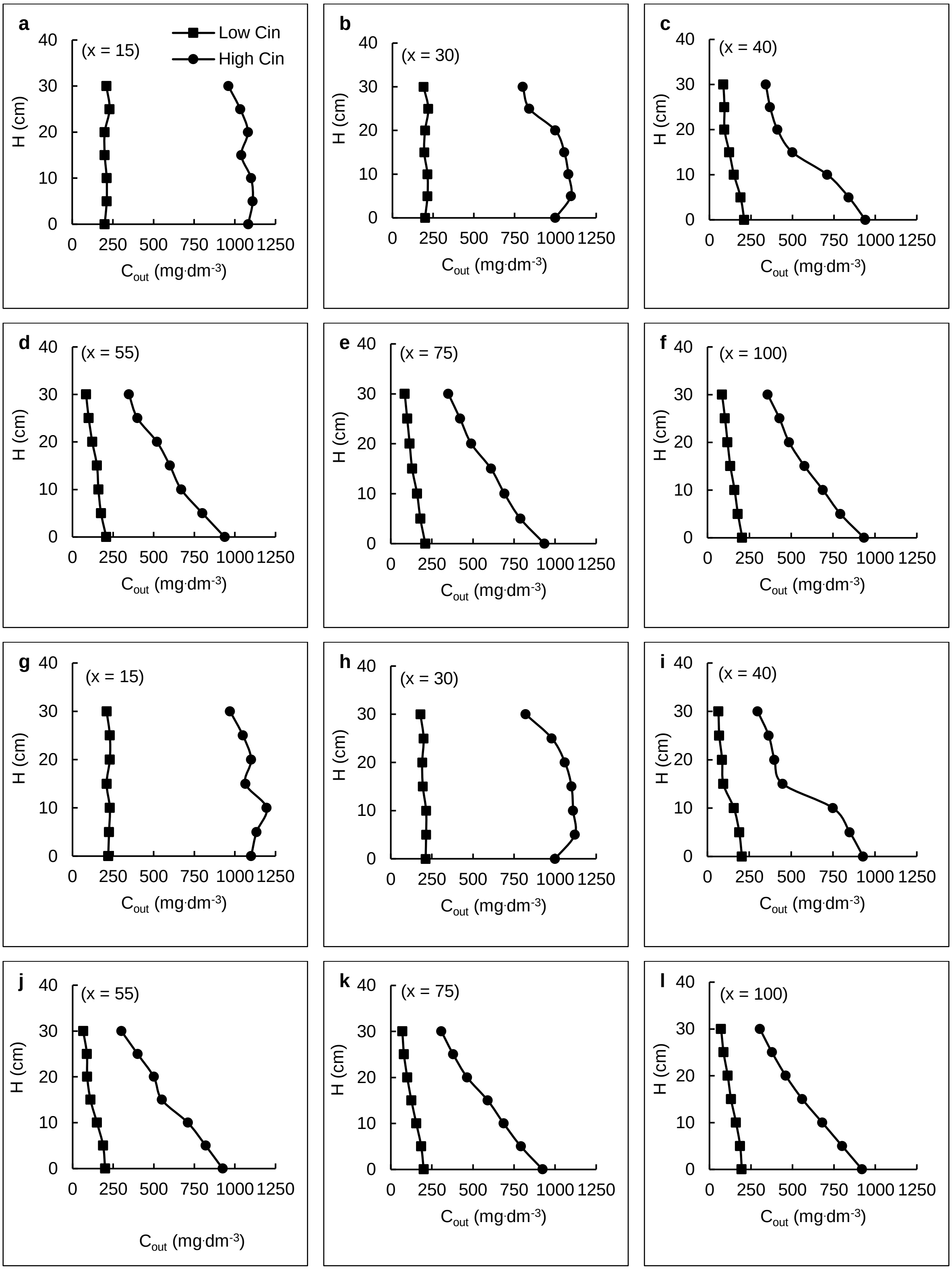

Fig. 4. Profile of particles in case of baffle placed at 33 cm with a height of 8 cm: a)–f); flow rate of 0.06 $dm^{3} \cdot s^{-1}$, g)–l); flow rate of 0.015 $dm^{3} \cdot s^{-1}$; explanations as in Fig. 2; source: own study

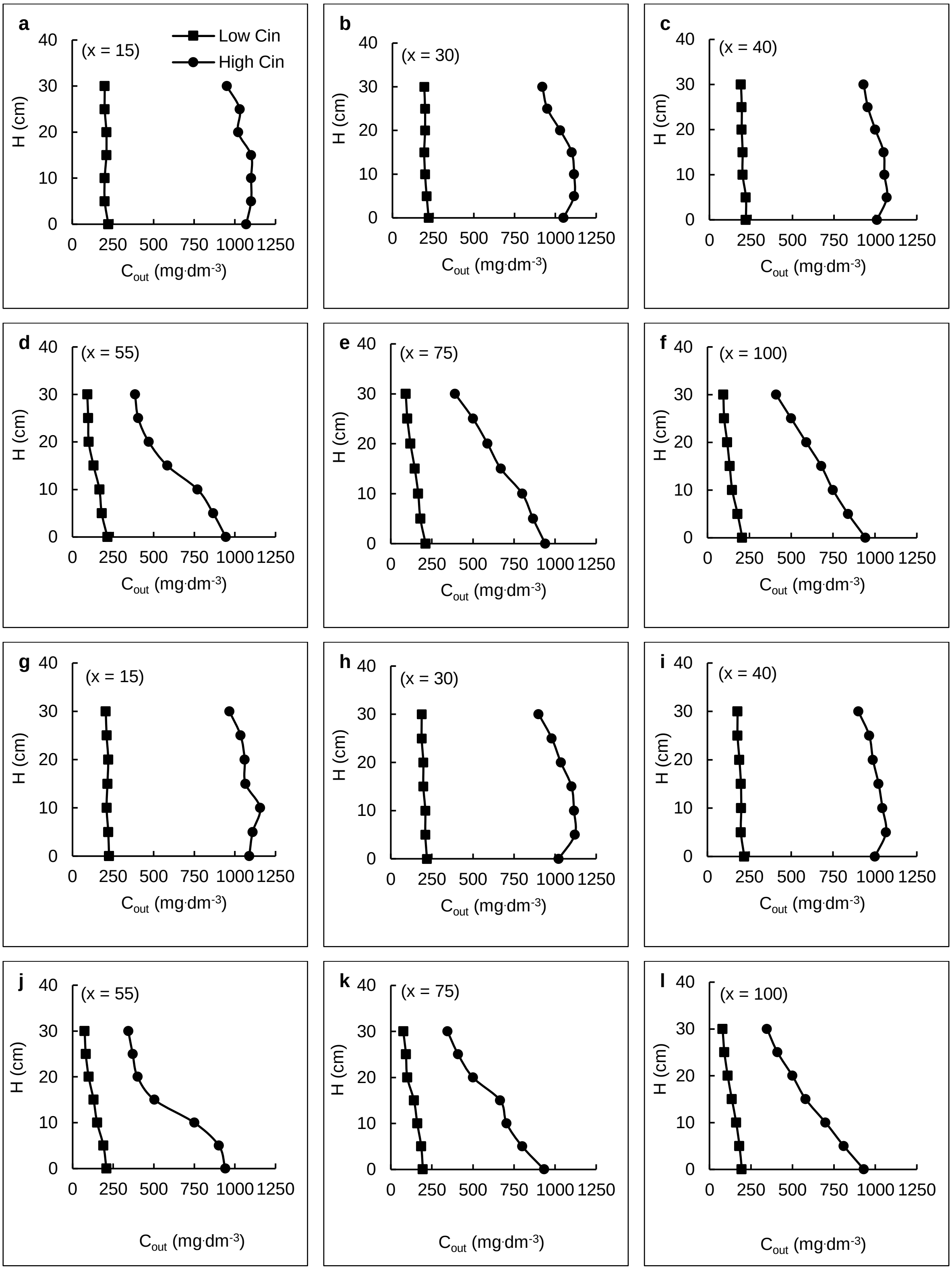

Fig. 5. Profile of particles in case of baffle placed at 45 cm with a height of 8 cm: a)–f); flow rate of 0.06 $dm^3 \cdot s^{-1}$, g)–l) flow rate of 0.015 $dm^3 \cdot s^{-1}$; explanations as in Fig. 2; source: own study

Case of a baffle placed at 0.5 of the tank length. Figure 6 shows the profile of particles when the 8 cm baffle is fitted in the middle of the tank length, 60 cm from the inlet (Tab. 1, case 5). Particles showed vertical distribution within the distance of 15 cm from the inlet (Figs. 6a and g), and their concentration was higher than in the case of 'no baffle' and lower than the other cases. This may indicate low efficiency in the system performance. Then, the concentrations reduced progressively, and a remarkable reduction was found within the area behind the baffle (Figs. 6e, f, k and l), as particles concentrations reduced in top parts and increased in lower parts of the system depth. This reduction was lower than in other cases of using baffles and the case of 'no baffle'. The profile of particles showed similar trend using 13 cm and 24 cm baffle heights (data not shown).

According to the above, it is clear that the impact of C_{in} on particles distribution for all studied cases (with and without baffle) was to some extent similar for both studied concentrations (Figs. 2–6). However, the accumulation of particles in the system bed was higher using 1250 mg·dm^{-3} inflow values. This was due to the sedimentation which increased with growing concentrations and could contain much heavier and larger flocs as mentioned by SAADY [2012]. The author confirmed that the collision force between particles increased at higher concentrations and lead to the formation of larger and heavier flocs that settle down in the system bed. Interestingly, AL-SAMMARRAEE *et al*. [2009] concluded that the settling process of larger particles in sedimentation channels occur rapidly compared with smaller ones. These outcomes indicate that the C_{in} affect particles accumulation in the system bed, but does not affect the vertical distribution of particles along the settling tank.

Regarding the impact of Q on particles distribution, results confirmed that a lower rate of flow corresponded to higher particle accumulation in the tank bed and smaller concentrations at the top parts of the settling tank (higher removal efficiency). These results are observed for all studied cases (with and without baffle), as presented in Figures 2, 3, 4, 5, and 6a to f (Q = 0.06 dm^3·s^{-1}) versus to Figures 2, 3, 4, 5, and 6g to l (Q = 0.015 dm^3·s^{-1}). This is because the kinetic energy is affected by the flow rate, and at low levels of flow this energy decreases leading to higher sedimentation efficiency [JOVER-SMET *et al*. 2017; PATZIGER, KISS 2015]. These results reflected the impact of particles retention time in the channel, as a lower flow rate means more and enough time for particles to settle down. This consequently translates into higher removal efficiency, and vice versa. Although, authors have treated activated-sludge using a circular sedimentation tank, these findings confirmed that the Q affects the system performance, at different levels, regardless the system is supported by a baffle or not.

The impact of baffle configurations showed a similar trend in particle profiles for all baffle heights. However, particles settling at the end of the tank when baffle placed at a distance of 18 cm from the inlet (for both studied flow rates) was better in case of H_b = 8 cm (Fig. 3) followed by the case of H_b = 13 cm, and the lower settling corresponded to H_b = 24 cm. These outcomes were noticed for all baffle positions of 33, 45 and 60 cm, although the values were not the same. Therefore, the best height of a baffle is 8 cm and 13 cm, which represent 20% and 32.5% of the system depth. These findings indicated that the best settling efficiency is achieved when H_b is less or equal to the height of the inlet opening, and this efficiency decreases with growing H_b. In terms of a baffle position and comparing it with the case of 'no baffle', the settling of particles is high in the system bed when the baffle is placed at a distance of 18 cm from the inlet for all studied inflow values, flow rates, and baffle heights (Fig. 3), except the case of H_b = 24 cm as an ineffective (data not shown). The same profile of particles distribution, with less efficiency, was found in the case of a baffle located at 33 cm, followed by 45 cm, and then 60 cm from the inlet.

TREATMENT SYSTEM EFFICIENCY

The efficiency of the studied sedimentation tank for particles removal according to particle concentrations in inflow and outflow water is shown in Table 2.

Impact of inflow concentration. Results revealed that the system performance was affected by the C_{in}, as all studied cases showed higher treatment efficiency (*TE*) linked with C_{in} of 1250 mg·dm^{-3} than 250 mg·dm^{-3} (Tab. 2). This is because at C_{in}, a significant proportion of particles is flocculated and settled down in the tank bed [JOVER-SMET *et al.* 2017]. Many authors have confirmed these outcomes [LIU, GARCIA 2011]. Note that the differences were significant (p < 0.05) for both high and low flow rates in cases of H_b = 8 cm, except when the baffle was placed in the mid-length of the tank.

Impact of flow rate. Treatment efficiencies (TE) were higher when the system operated at a lower flow rate (Tab. 2). This is due to the fact that a lower Q means longer retention time for particles in the system and consequently, a higher *TE* as mentioned before. Statistically, the differences between the treatment efficiencies at high and low rate of flow were significant (p < 0.05) for all studied cases (except the cases of un-efficient baffle).

Impact of baffle. Table 2 shows that the *TE* is significantly affected by baffle height and location. The removal efficiencies were higher when the baffle was placed at distances of 18, 33, and 45 cm from the inlet and the baffle height was 8 cm and 13 cm, if compared with 'no baffle' treatment. Therefore, only these cases were effective for improving the settling tank performance, and the H_b of 8 cm was the best case. HEYDARI and MEHRZADEGAN [2014] concluded that for enhancing the trap efficiency in the channel and decreasing the dead zones size and turbulent flow in the system, the H_b should be between 0.2 and 0.4 of water depth. In this study, effective baffle heights were within this range, which reflected the enhancement of the system efficiency. Statistically, significant differences (p < 0.05) were found between the case of 'no baffle' versus a baffle placed at 18 cm and 33 cm from the inlet and a baffle height of 8 cm as the best height, for both studied flow rates. Treatment efficiencies at H_b of 24 cm were lower than the case of 'no baffle', which indicated that higher baffle reduces the efficiency of the settling tank. It is because already settled particles tend to re-suspend due to the strong jet flow and higher

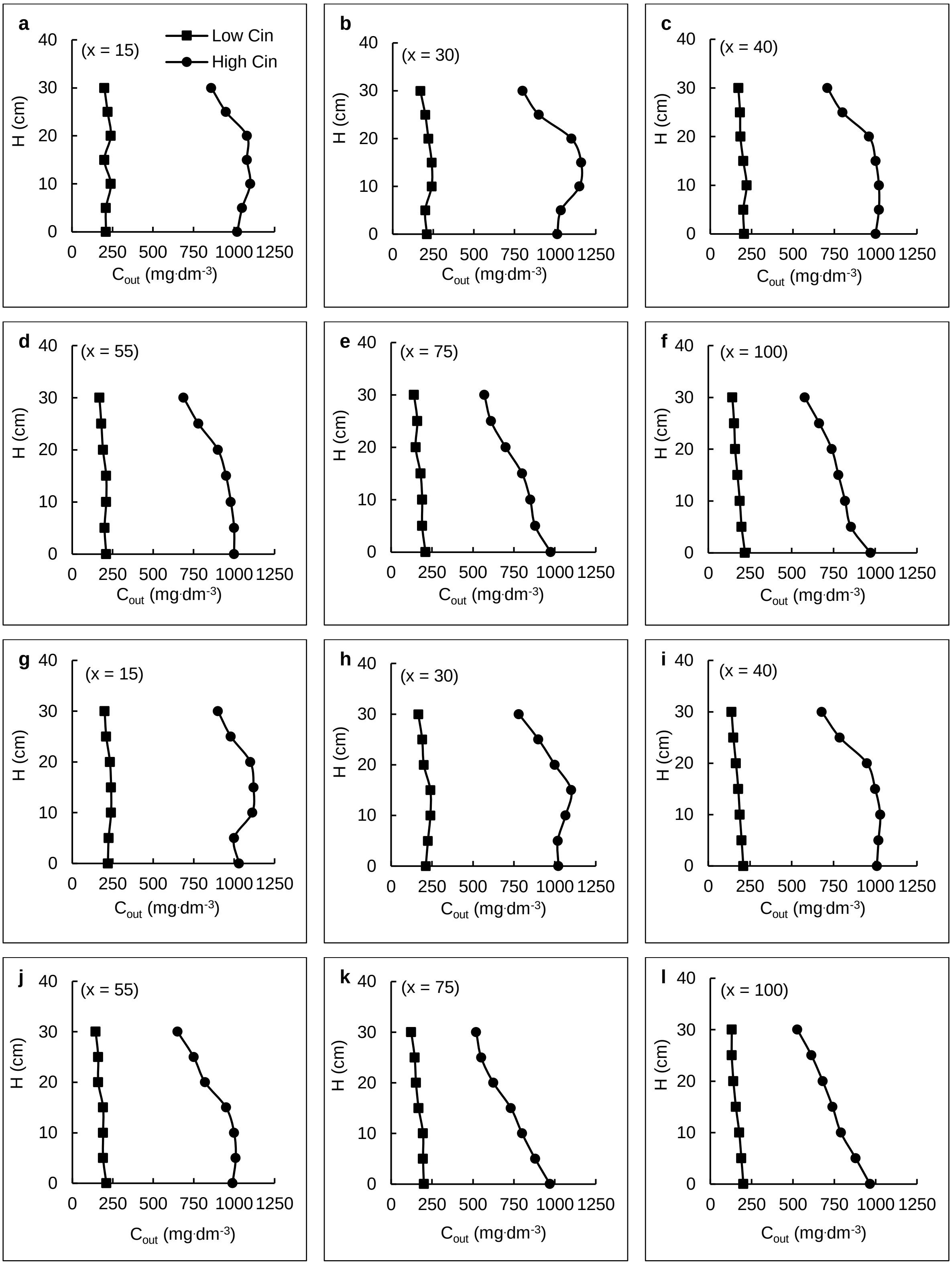

Fig. 6. Profile of particles in case of baffle placed at 60 cm with a height of 8 cm: a)–f) flow rate of 0.06 dm^{3}·s^{-1}, g)–l) flow rate of 0.015 dm^{3}·s^{-1}; explanations as in Fig. 2; source: own study

Table 2. Treatment efficiency of secondary sedimentation tank for particles removal

Case	Baffle height	Flow rate: 0.06 dm^3·s^{-1}		Low rate: 0.015 dm^3·s^{-1}	
		C_{in} = 1 250 mg·dm^{-3}	C_{in} = 250 mg·dm^{-3}	C_{in} = 1 250 mg·dm^{-3}	C_{in} =250 mg·dm^{-3}
Case 1: no baffle	–	58	51	68	60
Case 2: single baffle x = 18 cm	8	75	65	91	79
	13	69	59	80	69
	24	53	46	65	58
Case 3: single baffle x = 33 cm	8	72	60	85	72
	13	62	54	75	64
	24	52	44	60	54
Case 4: single baffle x = 45 cm	8	66	58	76	65
	13	60	52	72	60
	24	49	39	58	48
Case 5: single baffle x = 60 cm	8	48	40	56	46
	13	41	34	50	40
	24	39	32	48	36

Explanations: x = distance from inlet opening, C_{in} = inflow concentration of particles.
Source: own study.

flow velocity that occurs when higher baffles are used. This also increases the recirculation zone and finally reduces the settling efficiency [ASGHARZADEH *et al*. 2011].

Regarding the baffle location, the *TE* was higher in case of a baffle placed at 18 cm, followed by 33 cm, and then 45 cm from the inlet if compared with the case of 'no baffle' (Tab. 2). Statistically, a significant dissimilarity ($p < 0.05$) was found between the case of 'no baffle' and a baffle placed at 18 cm and 33 cm from the inlet with a baffle height of 8 cm. Thus, the system performance improved when the baffle was located between 0.15 and 0.375 of tank length, and a higher *TE* was achieved when the baffle was located between 0.15 and 0.275 of the tank length. These results nearly match investigations by RAZMI *et al.* [2013] confirming that higher performance of a settling channel can be achieved by placing a baffle between 0.1 and 0.2 of the tank length, i.e. near to the entrance jet.

However, when the baffle was located in the middle of the tank length, the *TE* was lower than the case of 'no baffle' and other studied cases with the use of a baffle. These findings do not match those of ASGHARZADEH *et al*. [2011] who concluded that the removal efficiency of particulates was higher when a single baffle was placed in the middle of the tank length. However, SHAHROKHI *et al*. [2013] confirmed that a baffle located at 0.125 of the tank length provided higher performance, and the efficiency of treatment decreased with length. They also showed that a baffle located in the middle the tank length represented the worst case of treatment, which corresponded with findings of this study. These findings can be interpreted by the fact that high removal is achieved when the baffle is placed in the middle of the circulation area. This is because the baffle reduces the circulation volume (dead zone size) to small parts and the turbulent kinetic energy in comparison with inefficient cases.

According to the above, it is clear that a baffle with a height of 8 cm located 18 cm from the inlet (0.15 of tank length) was the best for the improvement of the system performance. As the removal efficiency increased by 29% and 27% using a flow rate of 0.06 dm^3·s^{-1} at high and low inflow concentrations, in that order, and by 34% and 30% using a flow rate of 0.015 dm^3·s^{-1} at high and low inflow concentrations. Similar results have been reported previously, but the baffle increased the removal of particles by 9% [GOULA *et al*. 2008] and 11% [HUGGINS *et al*. 2005] only. This may be due to the impact of operating conditions.

CONCLUSIONS

1. Higher concentration increases the system efficiency.
2. The flow rate affects the system performance, as the higher flow rate decreases the system efficiency, whether supported by a baffle or not.
3. Baffle height and location significantly affect the settling process.
4. The best settling efficiency is achieved when a baffle height is less than or equal to the height of the inlet opening, and this efficiency decreases with the increasing baffle height. This is very important to avoid extra cost related to higher baffles.
5. Baffle located within the circulation zone highly improves the treatment, and it is not acceptable to place a baffle (of any height) far from the circulation zone.
6. System efficiency without a baffle (51–68%) is better comparing with corresponding values in case of a baffle placed in the middle of the tank length (32–56%).
7. Baffle depth of 0.2 of the tank height located at 0.15 of the tank length is the best case for improving the system performance.
8. Removal efficiency increased by 29% and 27% using a high flow rate at high and low inflow, respectively, and by 34% and 30% using a low flow rate at high and low inflow.

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REFERENCES

AL-SAMMARRAEE M., CHAN A. 2009. Large-eddy simulations of particle sedimentation in a longitudinal sedimentation basin of a water treatment plant. Part 2: The effects of baffles. Chemical Engineering Journal. Vol. 152 p. 315–321. DOI 10.1016/j.cej.2009.01.052.

AL-SAMMARRAEE M., CHAN A., SALIM S.M., MAHABALESWAR U.S. 2009. Large-eddy simulations of particle sedimentation in a longitudinal sedimentation basin of a water treatment plant. Part I: Particle settling performance. Chemical Engineering Journal. Vol. 152 p. 307–314. DOI 10.1016/j.cej.2009.04.062.

ASGHARZADEH H., FIROOZABADI B., AFSHIN H. 2011. Experimental investigation of effects of baffle configurations on the performance of a secondary sedimentation tank. Scientia Iranica. Vol. 18 p. 938–949. DOI 10.1016/j.scient.2011.07.005.

EATON A.D., CLESCERI L.S., RICE E.W., GREENBERG A.E., FRANSON M.A.H. (eds.) 2005. Standard methods for the examination of water and wastewater. 21st ed. Washington DC. American Public Health Association/American Water Works Association/Water Environment Federation. ISBN 0875530478.

FAN L., XU N., DONG Q., LIU Q., DING A. 2020. Investigation of activated sludge behavior in secondary sedimentation tanks by two models. Environmental Engineering Science. Vol. 37 p. 120–131. DOI 10.1089/ees.2019.0090.

GOULA A.M., KOSTOGLOU M., KARAPANTSIOS T.D., ZOUBOULIS A.I. 2008. A CFD methodology for the design of sedimentation tanks in potable water treatment: Case study: The influence of a feed flow control baffle. Chemical Engineering Journal. Vol. 140 p. 110–121. DOI 10.1016/j.cej.2007.09.022.

HEYDARI M.M., MEHRZADEGAN H.R. 2014. Effect of baffles on the flow and hydrodynamics of settling basins: A review. Journal of Agricultural Research. Vol. 52 p. 137–150.

HUGGINS D.L., PIEDRAHITA R.H., RUMSEY T. 2005. Analysis of sediment transport modeling using computational fluid dynamics (CFD) for aquaculture raceways. Aquacultural Engineering. Vol. 31 p. 277–293. DOI 10.1016/j.aquaeng.2004.05.007.

JAWECKI B., PAWĘSKA K., SOBOTA M. 2017. Operating household wastewater treatment plants in the light of binding quality standards for wastewater discharged to water bodies or to soil. Journal of Water and Land Development. No. 32 p. 31–39. DOI 10.1515/jwld-2017-0004.

JOVER-SMET M., MARTÍN-PASCUAL J., TRAPOTE A. 2017. Model of suspended solids removal in the primary sedimentation tanks for the treatment of urban wastewater. Water. Vol. 9, 448. DOI 10.3390/w9060448.

KOWALCZYK A., SMOROŃ S., KOPACZ M. 2019. Influence of runoff of suspended solids on quality of surface water: Case study of the Szreniawa River. Journal of Water and Land Development. No. 41 (IV–VI) p. 83–90. DOI 10.2478/jwld-2019-0031.

LIU X., GARCÍA M.H. 2011. Computational fluid dynamics modeling for the design of large primary settling tanks. Journal of Hydraulic Engineering. Vol. 137 p. 343–355. DOI 10.1061/(ASCE)HY.1943-7900.0000313.

MALCZEWSKA B., BICZYŃSKI A. 2017. Comparison between different models for rheological characterization of sludge from settling tank. Journal of Water and Land Development. No. 34 p. 191–196. DOI 10.1515/jwld-2017-0053.

MALL A.K., SHRIRAM. 2014. Design modification of sedimentation tank. International Journal for Scientific Research & Development. Vol. 2(9) p. 821–825.

NGUYEN T.-A., DAO N.T. M., TERASHIMA M., YASUI H. 2019. Improvement of suspended solids removal efficiency in sedimentation tanks by increasing settling area using computational fluid dynamics. Journal of Water and Environment Technology. Vol. 17 p. 420–431. DOI 10.2965/jwet.19-052

PATZIGER M., KISS K. 2015. Towards a hydrodynamically enhanced design and operation of primary settling tanks–Results of a long term in situ measurement investigation program. Water and Environment Journal. Vol. 29 p. 338–345. DOI 10.1111/wej.12125.

RAZMI A.M., BAKHTYAR R., FIROOZABADI B., BARRY D.A. 2013. Experiments and numerical modeling of baffle configuration effects on the performance of sedimentation tanks. Canadian Journal of Civil Engineering. Vol. 40 p. 140–150. DOI 10.1139/cjce-2012-0176.

SAADY N.M. 2012. Effects of inclined plates and polyelectrolyte on the performance of settling tanks. Journal of Applied Sciences in Environmental Sanitation. Vol. 7 p. 35–42.

SHAHROKHI M., ROSTAMI F., SAID M.A.M. 2013. Numerical modeling of baffle location effects on the flow pattern of primary sedimentation tanks. Applied Mathematical Modelling. Vol. 37 p. 4486–4496. DOI 10.1016/j.apm.2012.09.060.

SHAHROKHI M., ROSTAMI F., SAID M.A.M., YAZDI S.R.S. 2012. The effect of number of baffles on the improvement efficiency of primary sedimentation tanks. Applied Mathematical Modelling. Vol. 36 p. 3725–3735. DOI 10.1016/j.apm.2011.11.001.

TAMAYOL A., FIROOZABADI B., ASHJARI M.A. 2010. Hydrodynamics of secondary settling tanks and increasing their performance using baffles. Journal of Environmental Engineering. Vol. 136 p. 32–39. DOI 10.1061/(ASCE)EE.1943-7870.0000126.

YOON T.H., LEE S.O. 2000. Numerical modeling of sedimentation basins with a baffle. KSCE Journal of Civil Engineering. Vol. 4 p. 227–232. DOI 10.1007/BF02823970.