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Experimental investigation of the effect of inlet baffle position on the flow pattern, oil concentration, and efficiency of rectangular separator tank

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ABSTRACT

Oil and water separation due to gravitation is extensively applied in water and wastewater treatment to get rid of the oil droplets. Optimum inlet baffle configuration may facilitate the formation of favorable flow fields and heighten the separator tank's removal efficiency. Experimental tests were carried out to ascertain appropriate position for an inlet baffle in a rectangular separator tank. There are four parts in the experimental measurements. First of all, measured velocity fields make use of an acoustic Doppler velocimeter. Second of all, the uniformity of flow is measured by drawing a comparison of the standard deviation of the velocity profile. The oil concentration at both inlet and outlet points was later on assessed. Finally, the separation tank's removal efficiency was evaluated. The results provide an indication that a uniform flow pattern improved when the inlet baffle position gave a minimum standard deviation value. In this case, the minimum concentration of oil at the outlet and the highest removal efficiency have been obtained.

Keywords: ADV; Inlet baffles; Gravity separator tanks; Oil concentration; Removal efficiency

1. Introduction

Issues concerning fat, oil, and grease (FOG) in sewer systems have not been given much attention, although in the long run, this might hint at (*inter alia*) blockages and sanitary overflows [1]. FOG deposits are the main cause of 40–50% of sewer overflows all across the country and the secondary cause of another 10–25% of sewer overflows. Statistics point to the fact that 138,000 sanitary sewer overflows (SSOs) occur annually, resulting from the pipe blockages due to hardened and insoluble FOG deposit accumulations [2,3]. These waste materials include source waste from petroleum and petrochemical refining and processing; tramp oil from mechanical repair stores, utility operations, and various others [4].

The removal of (FOG) from water and wastewater by the gravity separation rectangular tank is one of the most popular methods in treatment units. Floating is defined as the separation of oil droplets that is lighter than water via the gravitational effect. The main factors that leave an impact on the separation process are the criteria of oil droplets and water phases that are linked with the floating process and

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hydraulic condition of the flow pattern inside the separator tank. A uniform flow is fundamentally significant to the efficiency of oil and water separation inside the rectangular tanks. Thus, flow pattern adjustment increases the coalescing oil droplets, and as an effect, enhances the rate at which oil droplets reach the water surface of the separation tanks (Stokes' law). In reality, there is a scarcity of scientific studies that have been conducted to establish design guidelines for oil and water separator tanks.

Morrow and Dodget [5] had elaborated on an installed flat platform in front of the internal flow at a number of locations and they showed that the inlet liquid flow of oil and water in a separator tank has a remarkable effect on separation performance. Experiments were run in a rectangular tank measuring 1.83 m long and 0.46 m wide. The measured axial velocity values at the centerline were validated with the aid of computer predictions, and there was a good agreement. Chu and Ng [6] illustrated that an 8–10% improvement in removal efficiency can be obtained for oil and grease by adding tube settlers inside the separator tank. Aziz et al. [7] studied the results of numerical and experimental models (in various restaurants) and the alternative inlet geometry as well as outlet and baffle wall designs for FOG mixtures with water, where they studied the removal efficiency in gravity separator compartments by measuring FOG concentration in the influent and effluent of a grease abatement device via the sample collection. The relation between inlet velocity values and oil diameter in the oil and water separator tanks using computation fluid dynamics (CFD) is examined, and the results show that the mixture velocity of 0.5 m/s had more benefit than that of 1.0 m/s, and that the oil diameter of 1 mm had given the best results in comparison to 0.5 and 0.25 mm [8].

The main aim of the present study is to confirm on the most preferred optimum of an inlet baffle in the rectangular oil and water separator tank. As far as the experiment goes, water and palm oil was mixed to ensure the floating tank and the velocity fields were measured using an acoustic Doppler velocity (ADV). The oil concentration at influent and effluent and the tank's removal efficiency were then measured. The effects of different baffle positions on the efficiency of the water and oil separator tank were examined by performing an assessment over the concentration of oil, velocity values, uniformity of flow, and removal efficiency in the flow field of each case concerned.

2. Experimental setup and methods

A set of laboratory measurements is tested for six inlet baffle positions in a rectangular oil and water separator tank (with water depth to tank length ratio of 0.31) [9,10]. Fig. 1 shows the experimental setup and measurement system. This figure illustrates a rectangular oil and water separator tank with the length $L = 130$ cm, width $W = 50$ cm, height $H = 42$ cm, height of inlet opening $H_{\mathrm{in}} = 10$ cm, height of weir $H_{\mathrm{w}} = 40$ cm, and height of end baffle $H_{\mathrm{b}} = 31.8$ cm. The distance from the tank bottom to the inlet opening is $H_1 = 15$ cm. The end structure baffle was constructed on the distance $d_{\mathrm{e}}/L = 0.77$ [11]. A submerged pump (model pond-150) inside a big storage tank discharged flow to the flume. The laboratory experiments were conducted for six cases for inlet baffle positions at a flow rate equal to $Q = 120$ L/min. In case 1, there was no inlet baffle; cases 2–6 had inlet baffle located at various distances from the inlet to tank length ratios, that is, $d/L = 0.04$, 0.11, 0.15, 0.23, and 0.30, respectively. The ratio of the inlet baffle height to water depth $H_{\mathrm{in}}/H = 0.24$. For all cases, the Froude number inside the tank was $F = 0.0047$ and in the inlet $F_{\mathrm{in}} = 0.04$, an inlet Reynolds number at 27°C was read as $R_{\mathrm{in}} = 4{,}652$.

Between each case, the channel was drained and cleaned two times to ensure all oil droplets that pasted on the flume walls were removed and filled again with a tap water from the reservoir. Experimental measurements of the cases were conducted, and the measured values of dimensionless x- and z-velocity profiles were recorded.

In this research, a palm oil was used (density = 910 kg/m^3) to test the removal efficiency of the water and oil gravity separator tank. Mix 5% volume of oil with 95% volume of water inside a 50-L container. The emulsion mixed for about 20 min [12] using WiseStir Lab Mixer (Model No. HS-30D) at 1,200 revolution per minute (rpm), prior to the initiation of the experiment to ensure all the droplet interface between oil and water would be broken [6]. Within mixing, the emulsion was pumped by a silicone tube to the main tank using a digital Masterflex pump (Model No. 7519-06) at a constant discharge rate of 1,000 ml/min. The inner diameter of the tube was 0.6 cm and it released the emulsion at the centerline of the bottom of the inlet slot. The time injection of the synthetic emulsion for each case to the tank was about 5 min. While injecting, samples were taken from the tank (three samples from inlet and three samples from the outlet) and each sample is an average of nine points (section A-A).

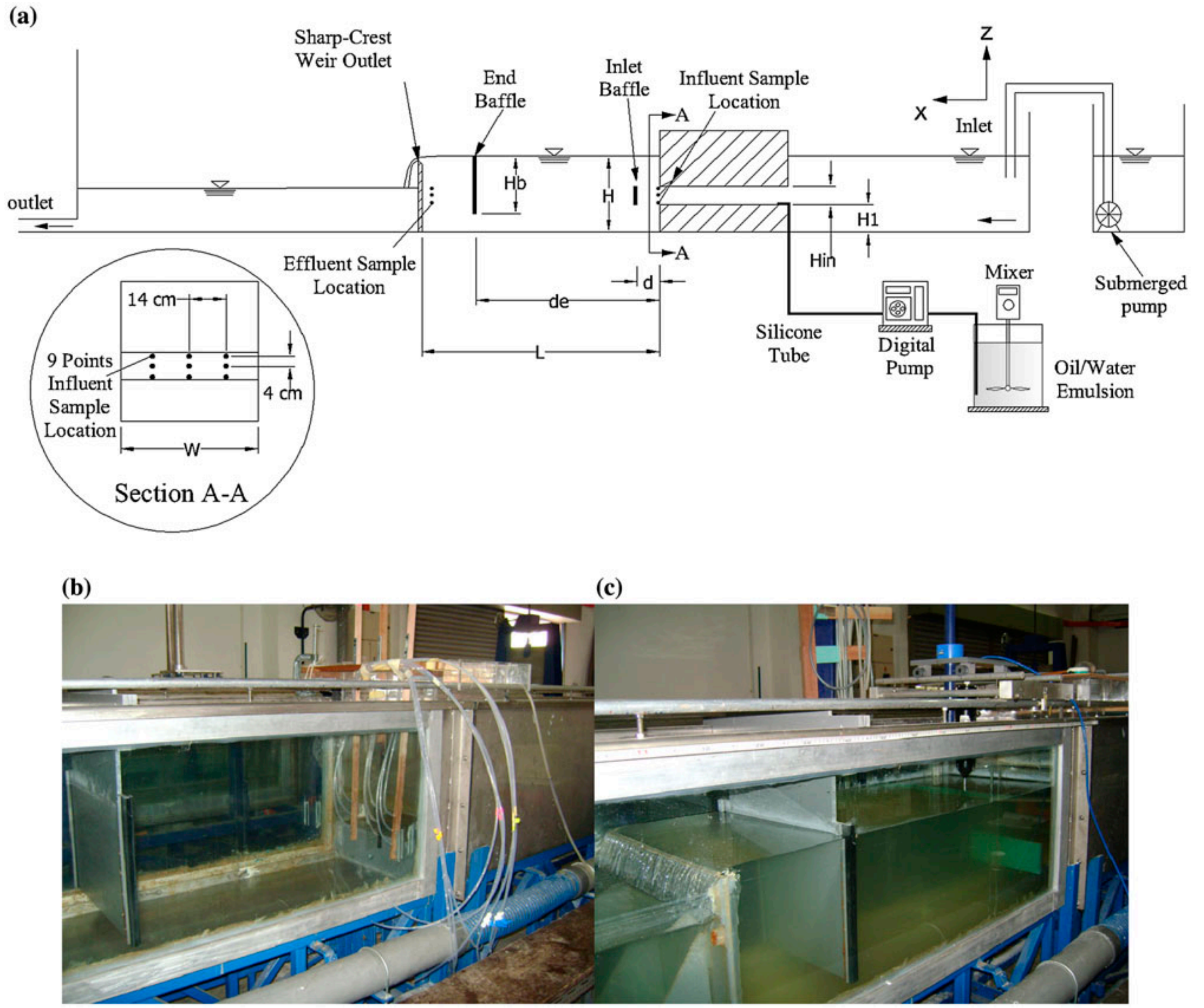

Fig. 1. (a) Schematic diagram of the tank, (b) Photo of intake samples, and (c) Photo of inlet baffle, end baffles, and ADV.

2.1. Velocity measurements device

The three velocity components were measured using an ADV. This device, which is an intrusive remote sensing system, can serve the functions of other flow meters, including electromagnetic current meters, propeller meters, hot films, and hot wire probes [13]. The ADV is relatively rugged, easy to operate, and can be readily mounted and maneuvered with the flow field [14]. A 10-MHz Nortek ADV meter (Nortek AS, Norway) is used to measure the instantaneous velocities of liquid flow at different points in the oil and water separator tank. The velocity of particles was measured in a remote sampling volume based on the Doppler shift effect [15,16]. The probe head includes one transmitter and four receivers. In this study, the remote sampling volume was located 5 cm from the tip of the transmitter. However, several studies have shown that the distance might change slightly. The probe was inserted into the flow, while the sensing volume was away from it. The presence of the probe generally does not affect the measurement. The accuracy of the measured data does not exceed ±0.5% of the measured value ±1 mm/s [17]. After measuring the velocity with ADV device, the post-processing process should be evaluated on collected data before calculating the flow characteristics. In steady flows, the first step of signal processing is the elimination of all data samples with communication errors, average correlation below 80% and signal-to-noise ratio (SNR) below 15 dB. According to the manufacturer, the SNR is a function of turbidity, i.e. the quantity of particulate material in the flow. For high-frequency measurements (>25 Hz), SNR > 15 decibels (db) is recommended. In this study, six profiles are used to measure the velocity in the centerline of the separator tanks for each case of inlet baffle location. The velocity of each profile was then measured at eight points along the vertical line.

2.2. *Analysis of oil concentration using the gravimetric method*

Oil and grease are characterized by their poor solubility in water which causes difficulties in their transportation through pipelines, their degradation in biological treatment system, and their disposal into natural water bodies. In this study, the gravimetric method [18] was used to determine the palm oil concentration in wastewater. Palm oil/water sample of 400 ml was collected from the separator tank. Before measuring the concentration, a 500-ml conical flask was washed and dried in an oven and the dried flask was weighed after cooling to room temperature. Two separatory funnels were attached to a retort stand and one was positioned above the other. Wastewater sample was added at the top separatory funnel and to ensure all the samples had been collected and transferred to the separatory funnel, the measuring beaker was rinsed with some distilled water, followed by the addition of a little (10 ml) 40/60 petroleum ether repeatedly. Five drops of methyl orange and several drops of sulfuric acid were added to the sample until the indicator color in all sample changed to red, then 100 ml 40/60 petroleum ether solvent was poured into the separatory funnel. After capping the funnel, the sample was then rigorously shaken for about 60 times by opening the funnel tap from time to time to release the pressure through shaking. After mixing, the separatory funnel was left still for approximately 2 min so the solvent phase and aqueous phase could separate. Then, the lower aqueous layer was drained into the bottom separatory funnel, leaving behind the solvent layer at the top separatory funnel. 100 ml 40/60 petroleum ether was added to the aqueous layer at the bottom separatory funnel again and it was shaken for another 60 times. Next, the lower layer was released into the beaker. The organic layer was transferred from the top funnel into the bottom funnel, and the top funnel was washed with petroleum ether to make sure that all organic materials were collected. Distilled water of 300 ml was added to the bottom separatory funnel by way of shaking it gently. Then, the lower layer was drained. Five drops of methyl orange indicator were then added. The red mixture shows that acid is still present and the step of washing with distilled water has to be repeated until all the redness disappears. The separated layer was passed through a filter paper into a dry 500-ml conical flask. To make sure no water will escape into the conical flask, a little anhydrous sodium sulfate was added onto the filter paper. After collecting the filtrate in the flask, the contents were evaporated on water bath at 70°C for about 1 h. Then, the conical flask was oven-dried at 100°C for about a minute and weighed after placing it in a dessicator that was cooled at room temperature.

The following equation is used to calculate oil and grease concentration in the sample [19]:

$$\text{mg oil and grease/L} = W_r/V_s \tag{1}$$

where W_r is the total weight of flask and residue, minus tare weight of flask in milligram, and V_s is the initial sample volume in liter.

The performance of the baffle location in the oil and water separator tank was evaluated by calculating the percentage removal of the influent flow concentration at the outlet concentration. The following equation was used to assess the performance [7]:

$$\text{Removal efficiency}\,\% = \left(\frac{C_{\text{in}} - C_{\text{out}}}{C_{\text{in}}}\right) \times 100 \tag{2}$$

where C_{in} is the inlet oil concentration, mg/L, and C_{out} is the outlet oil concentration, mg/L.

3. Confidence of experimental results

The standard deviation indicates the flow uniformity by quantifying the discrepancy of velocity from the average velocity. The following equation is used to calculate the standard deviation, σ:

$$\sigma = \left[\frac{1}{n-1}\sum_{i=1}^{n}(u_i - \bar{u})^2\right]^{0.5} \tag{3}$$

where n is the number of observation, u_i is the x-velocity measured, and $\bar{u}$ is the average value determined as follows:

$$\bar{u} = \frac{1}{n}\sum_{i=1}^{n} u_i \tag{4}$$

4. Results and discussion

4.1. Velocity laboratory measurement

The x and z direction velocity at the varying sections of 10, 25, 45, 60, 75, and 90 cm from the inlet tank was shown in Fig. 2. In Fig. 2(a) at section $x = 10$ cm near the inflow entrance where the baffle was placed (the inlet to tank length ratios) $d/L = 0.15$, 0.23, 0.3, and without the inlet baffle, the value of the x-velocity profile is approximately near, because in this section, these baffle positions could not be affected on the flow field. However, when the baffle was constructed at $d/L = 0.04$ (before section at $x = 10$), the affected baffle on the value of x-velocity, especially the velocities in the middle of profile, were noticeably reversed, while the top and bottom of the velocity profile had positive values. In the baffle placed in $d/L = 0.12$, there was a limited effect on the flow field. In another section at $x = 25$ cm, the maximum velocity occurred after the baffle position was $d/L = 0.15$ on the top of the tank and this region close to the water surface is very important for oil droplet stability in the surface, hence whenever the velocity of flow achieves to the minimum, oil droplets coalesce with other droplets and to rise rapidly toward the separator surface. In all other sections at $x = 45$ to 90 cm in Fig. 2(a), the x-direction velocity in all baffle cases are approximately of the same values, in comparison with the case with no inlet baffle where the maximum velocity was near the middle profile, because all baffle cases were constructed before these sections.

The main objective to place the inlet baffle in the oil and water separator tank is to contribute to energy dissipation, thereby more uniformity could be produced to allow the oil droplet to coalesce with other droplets and floating to the tank surface. On the other

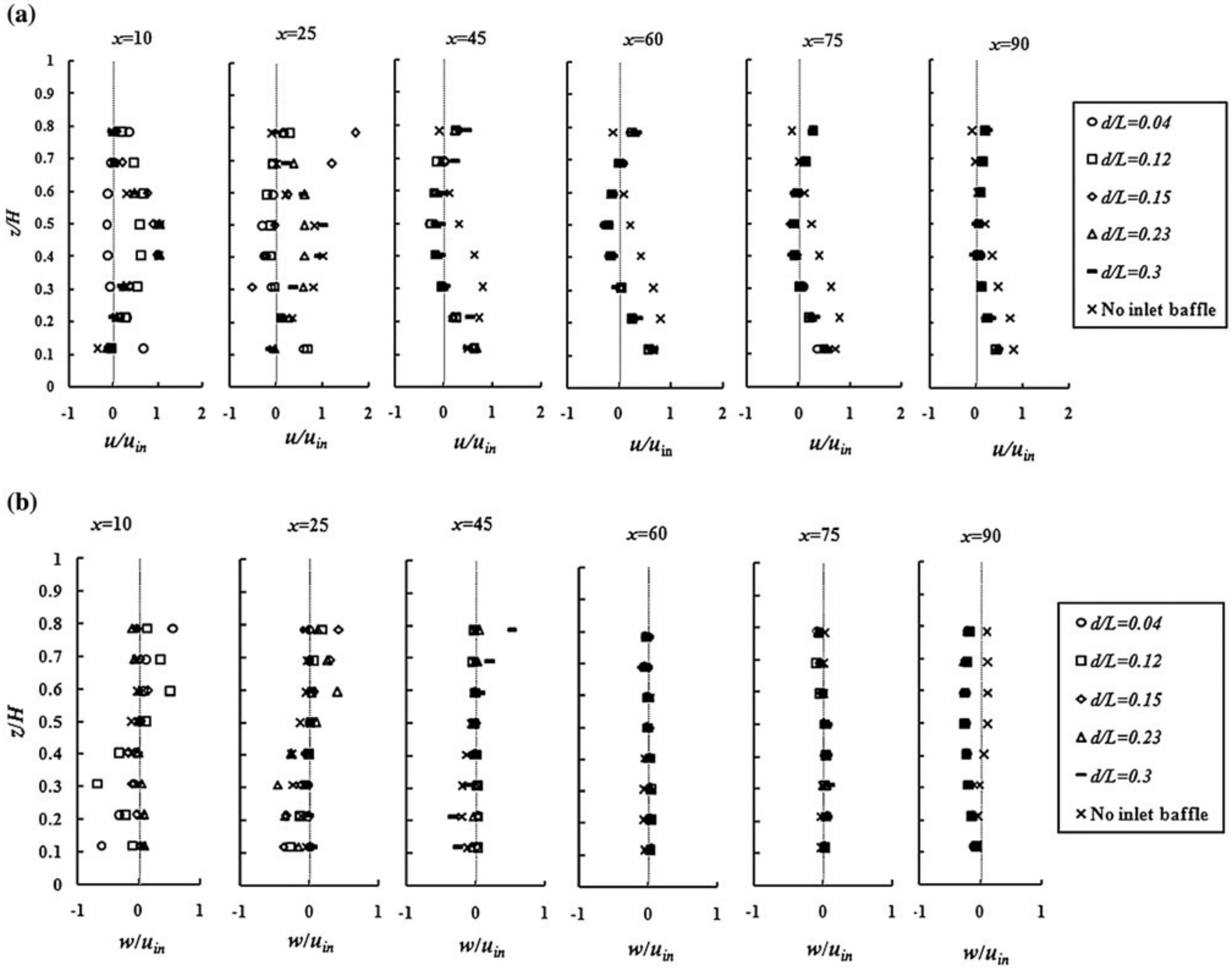

Fig. 2. Experimental velocity component of different inlet baffle location d/L for (a) x-direction and (b) z-direction.

hand, constructing the inlet baffle far away from inlet has a negative effect on the flow pattern and that leads to reduce the performance of oil droplet floatation.

An installed flat platform in front of the internal flow at several locations was described and it is demonstrated that the inlet liquid flow of oil and water in a separator tank has a significant effect on separation performance.

Fig. 2(b) shows the *z*-direction velocity profile inside the oil and water separator tank. After section $x = 45$ cm (when there is no baffle constructed), all *z*-velocity components were the same and the uniformity of flow field was achieved. In the top part of the tank, most velocity magnitude near zero and this situation allows oil droplets to coalesce with other droplets and allows it to be separated from the water then to rise toward the water surface, thus increasing the efficiency of the tank separator. Meanwhile, in section 90 cm, the *z*-velocity carries negative values because this section is near to the end part of the baffle.

What is important in the separator tank is the flow pattern between inlet baffle and end baffles, so in Fig. 2(a) and (b), it can be seen that baffles constructed at the location with *d*/*L* ratio 0.12 had the lowest amount of *x* and *z* direction velocities and established more uniformity flow field in comparison with those from other cases.

Fig. 3 shows the velocity distribution of streamline inside the oil/water separator tank for different inlet baffle structure locations.

The standard deviation is another indicator that can be used to verify the best location of baffle inside the oil and water separator tank [20]. For each baffle location case, the axial velocity is retrieved at eight equally spaced points along four vertical positions in the separator tank, and then, the SD is calculated.

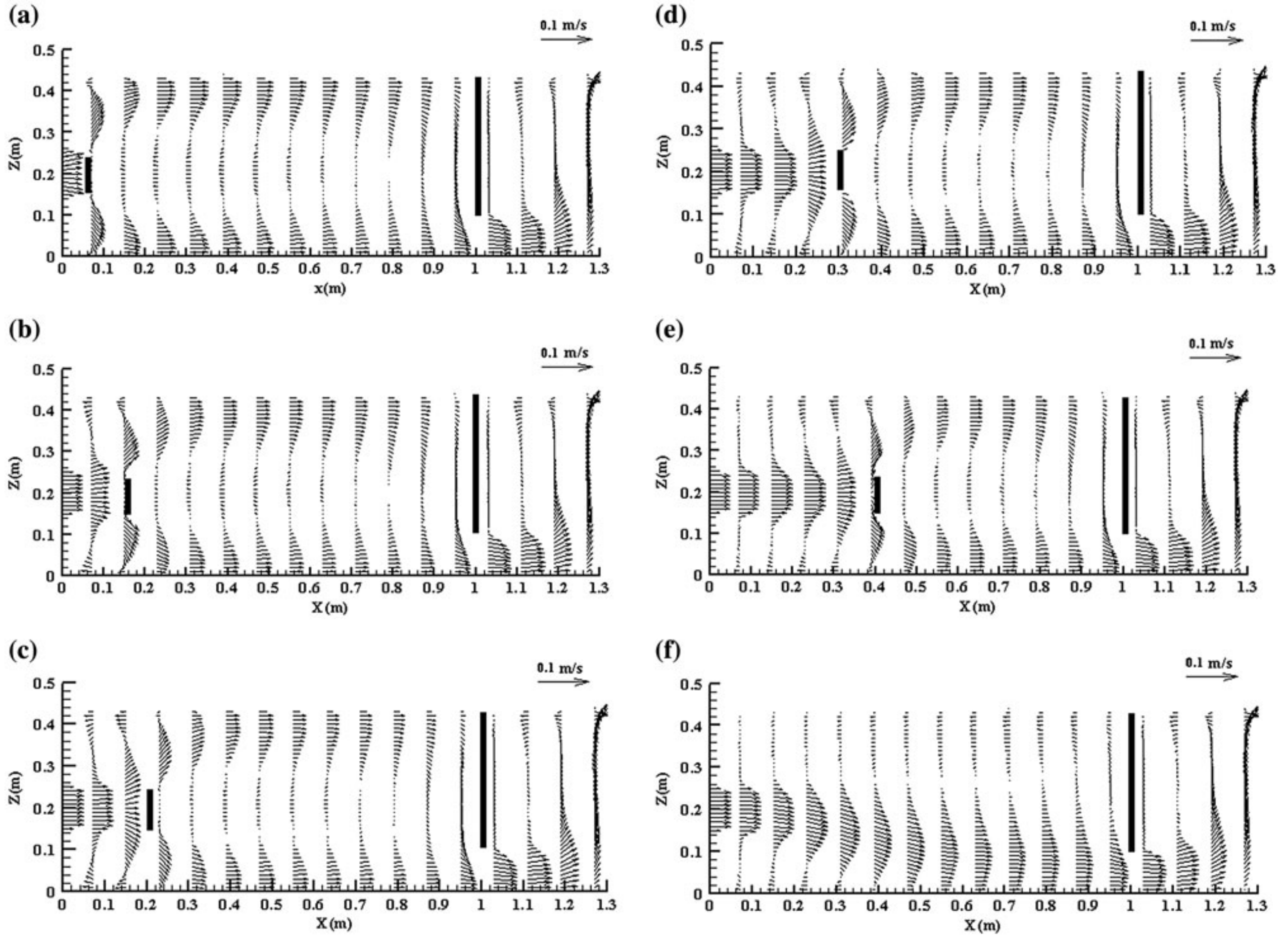

Fig. 3. Computed streamlines in *x*-direction for inlet baffle cases (a) $d/L = 0.04$, (b) $d/L = 0.12$, (c) $d/L = 0.15$, (d) $d/L = 0.23$, (e) $d/L = 0.30$, and (f) no inlet baffle.

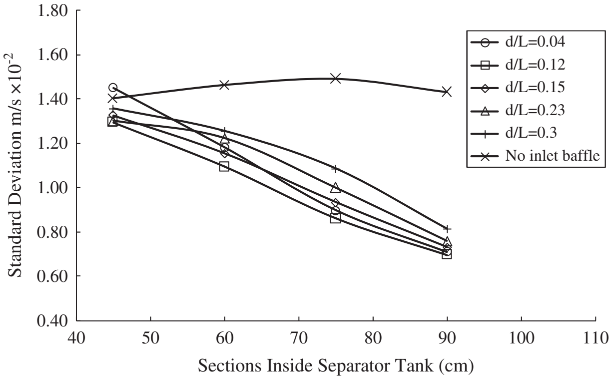

Fig. 4. Standard deviation of x-direction velocity across the separator tanks with different baffle locations d/L.

Table 1
Standard deviation of the longitudinal velocity in separator tank

	Standard deviation of x-velocity (m/s)(×10^{-2}) Sections x (cm)			
Inlet Baffle Location (d/L)	45	60	75	90
0.04	1.452	1.182	0.898	0.712
0.12	**1.296**	**1.094**	**0.862**	**0.698**
0.15	1.326	1.156	0.933	0.733
0.23	1.302	1.224	1.000	0.760
0.30	1.357	1.255	1.085	0.816
No inlet baffle	1.404	1.461	1.491	1.431

Notes: The bold values show the minimum values of standard deviation.

The minimum standard deviation SD of the x-direction velocity across the sections in Fig. 3 has achieved the best uniformity of the flow pattern. Fig. 4 and Table 1 show the SD of x-velocity across the separator tank sections 45, 60, 75, and 90 cm with all cases of the inlet baffle position (d/L) and in the case with no inlet baffle. It can be seen that the baffle location at $d/L = 0.12$ has the minimum magnitude (SD) along the separator tank, and thus, it exhibits the best performance.

4.2. Concentration and efficiency laboratory measurement

The oil removal efficiency at different inlet baffle locations in the oil and water separator tank was examined and shown in Table 2. This table describes the number of samples measured from both the inlet and outlet in milligram per liter, then the oil removal efficiency performance was calculated by taking the average of three samples in the tank inlet and outlet. The highest oil removal performance efficiency (79.5%) had occurred with the inlet baffle location $d/L = 0.12$. It is clear that the difference in the removal efficiency between the constructed inlet baffle and without the inlet baffle separator tank was 19%. In addition, the removal efficiency in the inlet baffle location at $d/L = 0.04$, 0.12, and 0.15 gave results 78.1, 79.5, and 78.4%, respectively, and these values were very close together, while placing the inlet baffle at $d/L = 0.23$ and 0.30 had yielded the removal efficiency of 75.8 and 71.7%, respectively. Consequently, whenever the inlet baffle was placed far from the inlet, it would achieve low removal efficiency performance. The case without the inlet baffle construction inside the oil and water separator tank indicates a minimum removal performance of 60.5%.

5. Conclusion

Attaining the best flow uniformity in the oil and water separator tank would prove the improvement of the maximum removal efficiency of oil droplets from water. Studying the effect of the inlet baffle position in a separator tank is a method that improves flow uniformity. The optimum inlet baffle position must be created to mitigate the inlet horizontal velocity as

Table 2
Inlet and outlet experimental results of oil concentration and removal efficiency

Inlet baffle location (d/L)	Inlet (mg/L)			Outlet (mg/L)			Average removal (%)
	Sample 1	Sample 2	Sample 3	Sample 1	Sample 2	Sample 3	
0.04	302	269	213	67	49	55	78.1
0.12	258	281	221	45	52	58	79.5
0.15	261	279	263	35	67	70	78.4
0.23	270	274	NA[a]	71	52	75	75.8
0.30	296	266	222	NA[a]	79	69	71.7
No inlet baffle	311	232	253	90	103	119	60.5

[a] NA = Not Available.

much as possible and to enable more uniformity to be achieved. This situation permits oil droplets to coalesce with other droplets and to rise at a fast pace toward the separator surface. Nevertheless, studies have yet to look into two directions of the velocity profile, uniformity flow, the distribution of oil concentration, and removal efficiency to ascertain the optimum inlet baffle position in the oil and water separator tank. Despite the fact that no comprehensive standard for creating a suitable inlet baffle configuration exists, the results of this study have a role to play in the design of highly efficient baffles for the separator tanks.

In this current work, experimental tests had been performed in three stages, to study the effects of different inlet baffle positions on the flow pattern. Firstly, the x and z velocity of the flow was measured using the ADV. Secondly, the uniformity was compared using the standard deviation (SD) of x-velocity across the cross section. Thirdly, the inlet and outlet oil concentration were also measured. Lastly, the removal efficiency of the oil and water separator tank was computed. The results have established that the installation of inlet baffle at optimum position can well improve the tank removal efficiency. Comparing this to the case without the inlet baffle, a tank with inlet baffle reduces the kinetic energy, or rather the velocity magnitude. To add, the results of this four-part experiment have confirmed that the inlet baffle should be placed at the location $d/L = 0.12$ leaning on the best uniformity flow minimum SD, minimum outlet oil concentration, and the highest value of the removal efficiency. We cannot dismiss too, the fact that the removal efficiency ratio is considered as good removal if we compare this to the ongoing high discharge in the oil and water gravity separator tanks.

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References

[1] J. Mattsson, A. Hedström, M. Viklander, G.-T. Blecken, Fat, oil, and grease accumulation in sewer systems: Comprehensive survey of experiences of scandinavian municipalities, J. Environ. Eng. 140 (2014) 04014003.

[2] R. Southerland, Sewer fitness: Cutting the fat, Am. City and Country 117 (2002) 27–31.

[3] K.M. Keener, J.J. Ducoste, L.M. Holt, Properties influencing fat, oil, and grease deposit formation, Water Environ. Res. 80 (2008) 2241–2246.

[4] A. Abass, A.T. Jameel, S.A. Muyubi, M.I. Abdul Karim, Removal of oil and grease as emerging pollutants of concern (EPC) in wastewater stream, IIUM Eng. J. 12 (2011) 161–169.

[5] T. Morrow, F. Dodget, Fluid flow modelling of gravity separators, Multi-phase Prod. (1991) 364.

[6] W. Chu, F.-L. Ng, Upgrading the conventional grease trap using a tube settler, Environ. Int. 26 (2000) 17–22.

[7] T.N. Aziz, L.M. Holt, K.M. Keener, J.W. Groninger, J.J. Ducoste, Performance of grease abatement devices for removal of fat, oil, and grease, J. Environ. Eng. 137 (2011) 84–92.

[8] M. Abdulkadir, V. Hernandez-Perez, The effect of mixture velocity and droplet diameter on oil-water separator using computational fluid dynamics (cfd), World Acad. Sci. Eng. Technol. 61 (2010) 35–43.

[9] Metcalf & Eddy Inc., G. Tchobanoglous, H.D. Stensel, R. Tsuchihashi, F. Burton, Wastewater Engineering: Treatment and Resource Recovery, McGraw-Hill Education, New York, NY, 2013.

[10] NPCA, Design Consideration and Discussion of Precast Concrete Gravity Grease Interceptor, National Precast Concrete Association, (2011).

[11] H.A. Hussein, R. Abdullah, S. Harun, M. Abdulkhaleq, Numerical model of baffle location effect on flow pattern in oil and water gravity separator tanks, World Appl. Sci. J. 26 (2013) 1351–1356.

[12] J.J. Ducoste, K.M. Keener, J.W. Groninger, L.M. Holt, Assessment of Grease Interceptor Performance, Water Environment Research Foundation, Alexandria, VA, Technical Report, 2008.

[13] A. Lohrmann, R. Cabrera, N. Kraus, Acoustic-doppler velocimeter (ADV) for laboratory use, Fundamentals and advancements in hydraulic measurements and experimentation. Proc. Hydraul. Div./ASCE viii (1994) 351–365.

[14] C.M. García, M.I. Cantero, Y. Niño, M.H. García, Turbulence measurements with acoustic doppler velocimeters, J. Hydraul. Eng. 131 (2005) 1062–1073.

[15] S.J. McLelland, A.P. Nicholas, A new method for evaluating errors in high-frequency ADV measurements, Hydrol. Processes 14 (2000) 351–366.

[16] G. Voulgaris, J.H. Trowbridge, Evaluation of the acoustic Doppler velocimeter (ADV) for turbulence measurements, J. Atmos. Oceanic Technol. 15 (1998) 272.

[17] Nortek, Nortek Vectorino Velocimeter-User Guide, 2004.

[18] K. Lee, J.M. Neff, Produced Water: Environmental Risks and Advances in Mitigation Technologies, Springer, 2011.

[19] APHA, Standard Methods for the Examination of Water and Wastewater, twenty-first ed., APHA, Washington, DC, USA, 2005.

[20] D. Wilkinson, B. Waldie, M.I. Mohamad Nor, H. Yen Lee, Baffle plate configurations to enhance separation in horizontal primary separators, Chem. Eng. J. 77 (2000) 221–226.