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# Experimental Study of Baffle Angle Effect on the Removal Efficiency of Sedimentation Basin

[1]*Mohammad mehdi Heydari,* [2]*Mahmood Shafai-Bajestan,*
[1]*Heydar Ali Kashkuli and* [3]*Hossein Sedghi*

[1]Department of Water Engineering, Sciences and Research Branch,
Islamic Azad University, Khouzestan, Iran
[2]Department of Water Science and Engineering, Shahid Chamran University, Ahwaz, Iran
[3]Department of Water Engineering, Science and Research Branch,
Islamic Azad University, Tehran, Iran

**Abstract:** Sedimentation basins are essential hydraulic structures which have to be designed and constructed at all river water intakes to remove most of suspended sediments which enters the intake by flowing water. The bigger the basin, the best the retardation of the sediments, but the expenses and dredging are higher too. Therefore, improvement of performance and increasing sediment removal efficiency of settling basins by alternative method is necessary. A common approach for increasing settling tanks performance is to use baffle. In present work, to investigate effect of baffle and its angle of attack with the flow ($\theta$) on the sediment removal efficiency, a series of experiments on a straight canal with 8m length, 0.3m width and 0.5m height and 3m length of basin using three different sediment concentrations under three Froude numbers were carried using glass baffles in different angles. Effects of baffle height and position were not considered. The results indicate that, the baffle installed at the bottom of the basin increased sediment removal efficiency about 6-7 percent and the best of baffle angle is obtained 60°.

**Key words:** Sedimentation basins・Baffle・Angle・Removal efficiency・Suspended Sediment

## INTRODUCTION

Sedimentation by gravity is the most common and extensively applied treatment process for the removal of solids from water and wastewater and it has been used for over one hundred years. Sedimentation tanks are one of the major parts of a treatment plant especially in purification of turbid flows. Sedimentation tanks can be rectangular with horizontal flow or circular where an upflow pattern results. In these tanks, the low speed turbid water will flow through the length of the tank and suspended particle have enough time to settle. Finding new and useful methods to increase hydraulic efficiency is the objective of many theoretical, experimental and numerical studies. In rectangular tanks, influent enters the basin at the inlet. Energy dissipation is the main objective in designing a primary clarifier inlet. Energy of influent must be dissipating at the inlet zone by selecting the best position and configuration of inlet or using the baffles in the inlet zone [1]. The two main types of sedimentation (clarifier) tanks are primary and secondary (or final) settling tanks. Influent concentration in a primary sedimentation tank is low and hence, the concentration field has minor influence on the flow field. Therefore, in the primary sedimentation tank, the buoyancy effects can be neglected. But in the secondary (or final) sedimentation tank, however, the concentration of particles in influent is high [2]. In the present study, focus is made on the sedimentation basin in irrigation network. One of the problems in irrigation structures is sedimentation control at the main entrance to the irrigation networks [3]. Every large network of irrigation canals requires at least a proper sedimentation basin. Sedimentation basins are essential hydraulic structures which have to be designed and constructed at all river water intakes to remove most of suspended sediments which enters the intake by flowing water. Also, A sedimentation basin consists of an oversized section of a canal, built downstream from the canal headworks, an its design is based on increasing the canal surface area

**Corresponding Author:** Mohammad mehdi Heydari, Department of water engineering, Sciences and research branch, Islamic Azad University, Khouzestan, Iran.

to reduce the flow velocity low enough to permit much of the fine suspended particles that might otherwise be transported through the canal and be deposited [4-6]. The settled sediments can be removed by mechanical means or flushing. The bigger the basin, the best the retardation of the sediments, but the expenses and dredging are higher too. Therefore, improvement of performance and increasing sediment removal efficiency of sedimentation basins by alternative method is necessary. The sedimentation performance depends on the characteristics of the suspended solid and flow field in the basin.

A common approach for increasing sedimentation basins performance is to use baffles [7]. Baffles can interrupt short-circuiting, giving rise to a modified flow field and, potentially, improved the basin performance. Energy of influent must be dissipating at the inlet zone by selecting the best position and configuration of inlet or using the baffles in the inlet zone [8]. Also, baffles are usually placed in the front of inlet opening or those are built at the bottom of the tank to increase their sedimentation performance [7]. A uniform flow field is essential to the efficient performance sedimentation basin. Baffle enables particles to settle at a constant velocity and in a short period of time and the circulation zones between the inlet and outlet of the basin decrease and enhance sedimentation performance. Baffle positioning is essential in dissipating the kinetic energy of incoming flow and reducing chances for occurrence of short circuits [8]. The baffles act as barriers, effectively suppressing the horizontal velocities of the flow and forcing the particles to the bottom of the basin [9]. It must be noted that the use of baffles without enough concern would result in basins with the worse performance than the basin without a baffle. A baffle's cost is also high.

Most previous studies have been conducted in primary and secondary tanks (settling tank). There are a number of comprehensive studies on baffled tanks that investigate their hydraulic efficiency [7, 10-11].

Wills and Davis [12] have studied the effects of transverse and longitudinal baffles ($\theta$=90°) on the performance of the sedimentation tanks and showed that the transverse baffles decreased short circuiting. Crosby [13] observed that a mid-radius vertical baffle extending from the floor up to mid-depth decreased the effluent suspended sediments concentration of the clarifier by 37.5%. Krebs *et al* [1, 14-15] investigated the effect of the inlet and intermediate vertical baffles on the flow field in final clarifiers. Their research was based on experiments, numerical modeling and analytical relations. Energy dissipation is the main objective in designing a primary clarifier inlet. Energy of influent must be dissipating at the inlet zone by selecting the best position and configuration of inlet or using the baffles in the inlet zone [15].

Bretscher *et al*. [16] showed that installation of the intermediate vertical baffle was effective on the velocity and concentration fields for a rectangular settling tank.

Ahmed *et al*. [17] studied the effects of the position and height of the baffle ($\theta$=90°) in a secondary sedimentation tank by the bottom inlet by placing the baffle at three different positions and various heights, qualitatively. The best result was for the case in which an inlet baffle of the height of 67% of the total depth was placed in the first 5% of the channel.

After testing many potential raceway design modifications, Huggins *et al*. [18] noticed that adding a vertical bottom baffle the overall percentage of solids removal efficiency increased from 81.8% to 91.1%, resulting in a reduction of approximately 51% of the effluent solids.

Tamayol *et al*. [19] showed that best position for the inlet is near the bottom and existence of a reflection entrance baffle near the free surface of settling tanks can increase the performance of primary settling tanks.

Goula *et al*. [20] used numerical modeling to study particle settling in a sedimentation tank equipped with a vertical baffle installed at the inlet zone (bottom inlet). They showed that the baffle increased particle settling efficiency from 90.4% for a standard tank without a baffle to 98.6% for a tank with an installed bottom baffle.

Razmi *et al*. [21] found that best location of the vertical baffle is obtained when the volume of the circulation zone is minimized or the dead zone is divided into smaller parts and they showed that this baffle can reduce the size of the dead zones and turbulent kinetic energy in comparison with the no-baffle condition.

Shahrohki *et al*. [22, 23], numerical simulation was performed to investigate the effects of vertical baffle location on the flow field in rectangular primary sedimentation tanks. The results of this computational model prove that the baffle (using a baffle height-to-depth ratio of b/H=0.18) should be placed between 0.125 and 0.20 (inlet-to-tank length ratio) based on the smallest volume of the circulation zone and kinetic energy, the maximum concentration of the suspended sediments in the settling zone and the highest value of removal efficiency [23].

Razmi *et al*. [24] investigated on the effects of the baffle position on the performance of a primary settling tank experimentally and numerically. Their results showed that the best position of the bottom baffle (θ=90°) is relatively close to the entrance jet 10-20 % tank length, while the best baffle height is around 25 - 30% of the water depth.

The effect of baffle angles and position were examined using a 2D model (Flow-3D, 2003) applied to a small-scale, 2-m long laboratory setup [25-26, 9]. Right-angled (to the tank base) baffles were most favorable for sedimentation. In addition, it was concluded that, to get high settling performance, the baffle should be somewhere close to the inlet. However the effects of baffle height and optimal baffle configuration were not considered.

The above literature review indicates that most of numerical and experimental studies have been conducted for settling tanks and various inlets. Moreover, less attention is paid to effects angle of baffle on the efficiency of sedimentation basin.

The main objective of the present work is to investigate the effect of the bottom baffle and its angle on the performance of irrigation sedimentation basin in laboratory. So, in this study is to determine the best angle of baffles in a sedimentation basin. Also, the effects of Froude number and sediment concentration on the sediment removal efficiency of the sedimentation basin with a baffle were investigated in this study.

## MATERIALS AND METHODS

Experiments were carried out at the Mechanic Laboratory of Islamic Azad University Kashan. The experiments were conducted in a tilting flume having a length of 8 m, a width of 0.30 m and a depth of 0.50 m with and without baffles.

A rectangular sedimentation basin 3.0 m in length and 0.3 m in width was provided at the end of the channel. Figure 1 shows a view of applied experimental flume in this study.

A sluice gate was provided at the end of flume for control of the depth of flow (H) within the flume. Water was supplied from a ground pool and total flow rate was measured by a calibrated 60° V notched weir at the beginning of the channel. At the upstream of flume a stilling box has been installed to reduce the kinetic energy of the entrance flow. A pump outputting between 1 and 10 L/s replenishes the flume.

Figure 2 shows sedimentation basin with a length (L) of 3m, width (W) of 0.3 m and depth of flow (H) of 0.20 m.

The height of the baffle was fixed to almost 40% of the total water depth, b=0.08 m with different angles (θ) and it was located in the middle of the basin (s/L= 0.50).

Sediment particles were imported in the sedimentation basin to measure the efficiency of the basin. Natural sand of a relative density of 2.70 was used as the sediment. Uniform sand with median size of $D_{50}$=0.130 mm was used (Figure 3). The rate of injection of sand as the suspended sediment for all of the runs was kept equal to the capacity of the flume and basin to transport sediment.

In this study, 63 experiments were carried out under clear-water conditions at three Froude numbers (Fr) of 0.026, 0.063 and 0.116 and six angles for baffle (θ) 30°, 45°, 60°, 90°, 120° and 150° and no baffle and three inlet concentration (c) 1, 3 and 5 gr/lit in order to investigate the effect of angle baffle on efficiency of the basin.

In this study, Effects of baffle height and position were not considered.

The measurement of efficiency was taken after reaching to the equilibrium time. The equilibrium time is when the outlet sediment concentration reaches a constant value. So, an experiment was conducted for 90 min, with Froude number of 0.026 and inlet sediment

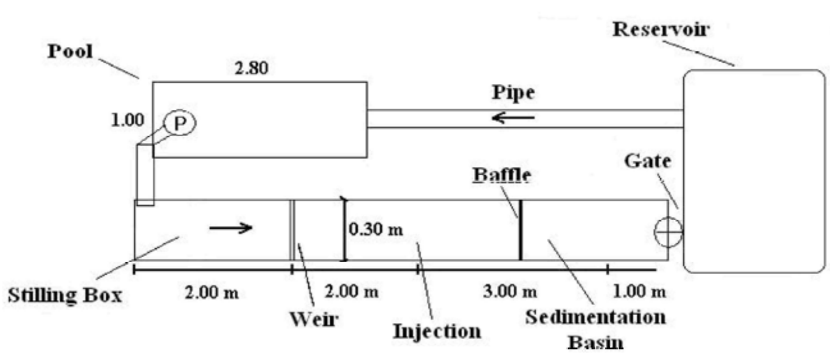


Fig. 1: A view of applied experimental flume in this study

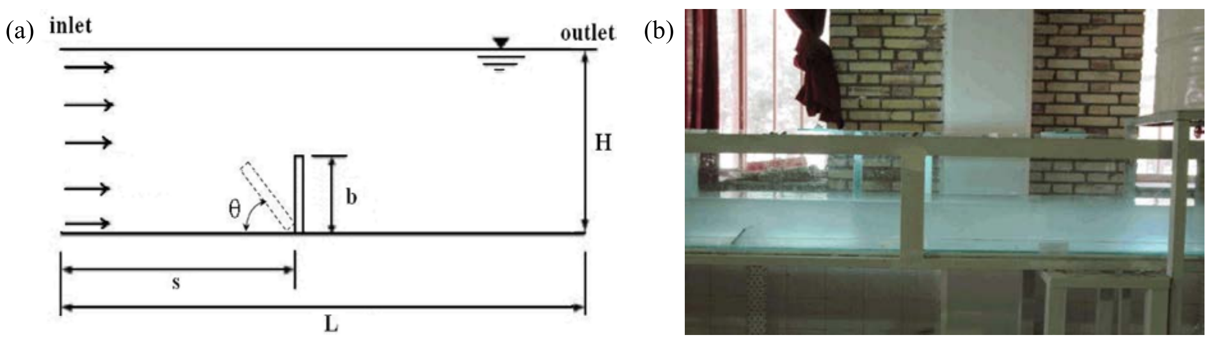


Fig. 2: (a) Schematic diagram of the basin; (b) a photo of baffle with θ=60° in the basin

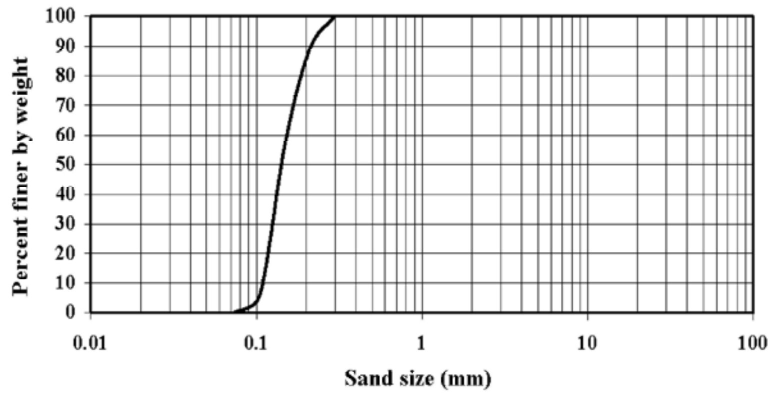


Fig. 3: Grain sizing curve of sand

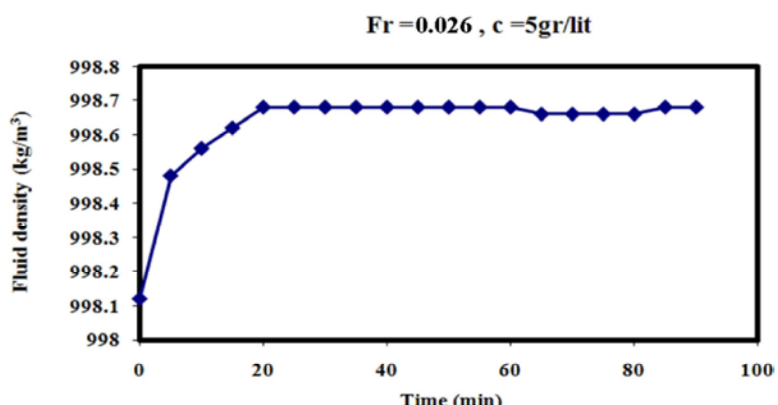


Fig. 4: Equilibrium time for a basin without baffle

concentration 5 gr/lit in basin without baffle to reach at an equilibrium time. The output fluid density was measured at 5 min intervals for the all time. Figure 4 shows the output fluid density versus time. Therefore, the duration of 30 min as equilibrium time, for all experimental tsts was selected.

Uniform flow in the channel and sedimentation basin was established by operation of the sluice gate. The sediment was injected into the flow at the upstream and the entire width basin at a constant rate. The sediment load downstream of the basin was collected in reservoir. At end of test time, the sediment that is deposited in the sedimentation basin was dried and weighed to determine the efficiency. The removal efficiency of the basin was computed as follows:

$$RE = \frac{W_d}{W_i} \times 100 \quad (1)$$

Where RE = basin efficiency; and $W_i$ and $W_d$ = Dry weight of sediment entering and depositing in the basin per unit time.

The experiments were repeated for different angles, discharges and sediment concentration.

## RESULTS AND DISCUSSION

The results are presented in four main parts; the first part effects of the vertical baffle installed in bottom of basin, the second part investigates the angle of baffle and two last parts effects of Froude number and inlet sediment concentration on sediment removal efficiency were studied.

**Effect of Bottom Baffle (Θ=90°):** Figure 5 shows the values of efficiency (%) at basin with and without baffle for different Froude number and sediment concentration. Results showed that by installing the vertical baffle at the bottom and middle of the sedimentation basin, sediment removal efficiency increases and for all experiments are between 0.30 and 3.90% compared to the basin without a baffle. It is seen also that the maximum value of removal efficiency was 3.90% for c=3gr/lit and Fr=0.116. Furthermore, it can be seen that with increasing Froude number and concentration, affect of baffle on the removal efficiency increases.

A comparison between the removal efficiency for the basin with baffle and no baffle for the same Froude number and inlet sediment concentration illustrates that installing the baffle can reduces the velocity near the bed and consequently improves the sedimentation process.

**Effect of Baffle Angle:** Table 1 shows the values of the removal efficiency at six angles for baffle (θ) 30°, 45°, 60°, 90°, 120° and 150°. The table indicates that the baffle angle θ = 60° exhibits the best performance.

The results show that difference between the values of efficiency (%) at sedimentation basin with baffle angle θ = 60° increased from 1.1% to 6.2% compared to the basin without a baffle. This finding is in agreement with the results of [27]. The maximum value of removal efficiency was 6.20% for c=5gr/lit and Fr=0.116.

Streamlines of flow around the baffle near the bed for θ = 60° with the flow are shown in Figure 6. It can be seen for this case, two recirculation zones exist. A small vortex in zone upstream and a large vortex in zone downstream were formed. Vortex zones reduce the effective volume of the basins and the effective volume for sedimentation process will be decreased and the suspended particles will not have sufficient space for deposition. Therefore, the increasing of the removal efficiency at basin with baffle angle θ = 60° indicate that these zones in this case is minimum. This means that decreasing the baffle installation angle from 90° to 60° leads to decrease of the height and extent of the vortex zones after the baffle position.

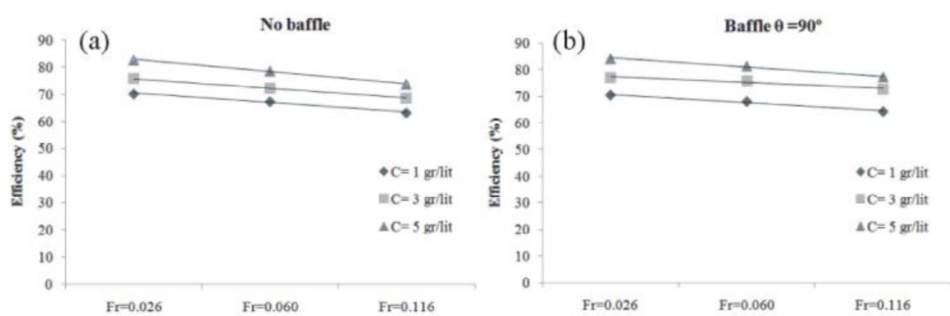


Fig. 5: The removal efficiency (%) of the basin (a) No baffle; (b) a vertical baffle

Table 1: The removal efficiency (%) of the basin for various cases

| | Fr=0.026 | | | Fr=0.060 | | | Fr=0.116 | | |
|---|---|---|---|---|---|---|---|---|---|
| Basin | c=1g/l | c=3g/l | c=5g/l | c=1g/l | c=3g/l | c=5g/l | c=1g/l | c=3g/l | c=5g/l |
| No baffle | 70.20 | 75.80 | 82.60 | 67.40 | 72.20 | 78.50 | 63.30 | 68.70 | 73.60 |
| Baffle (θ=30°) | 70.40 | 76.50 | 82.90 | 66.80 | 72.30 | 78.60 | 63.10 | 69.10 | 74.80 |
| Baffle (θ=45°) | 70.90 | 77.30 | 83.50 | 67.50 | 74.30 | 79.80 | 63.40 | 70.80 | 75.50 |
| Baffle (θ=60°) | 71.10 | 78.20 | 85.30 | 69.10 | 76.80 | 83.70 | 65.60 | 74.00 | 79.80 |
| Baffle (θ=90°) | 70.50 | 77.10 | 84.20 | 68.10 | 75.70 | 81.40 | 64.40 | 72.60 | 77.30 |
| Baffle (θ=120°) | 70.10 | 76.50 | 82.80 | 67.20 | 73.90 | 79.30 | 62.10 | 69.70 | 74.80 |
| Baffle (θ=150°) | 69.60 | 74.90 | 79.30 | 61.80 | 68.50 | 73.80 | 59.20 | 62.80 | 67.00 |

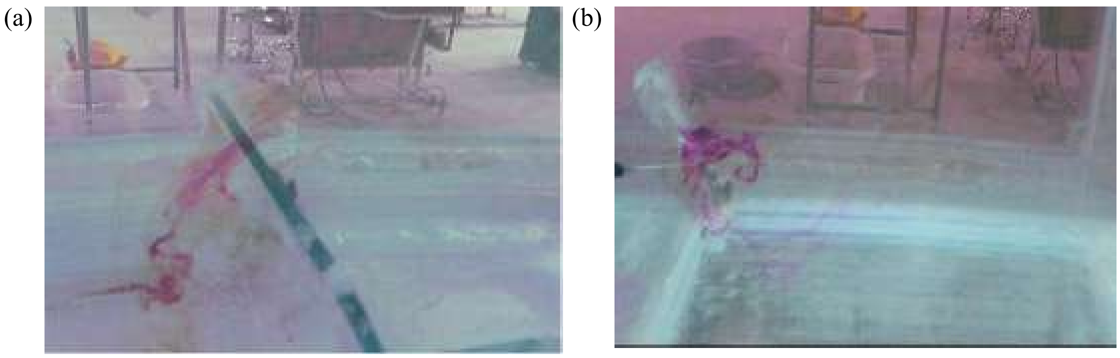


Fig. 6: Streamlines in the basin (a) Upstream of baffle; (b) Downstream of baffle

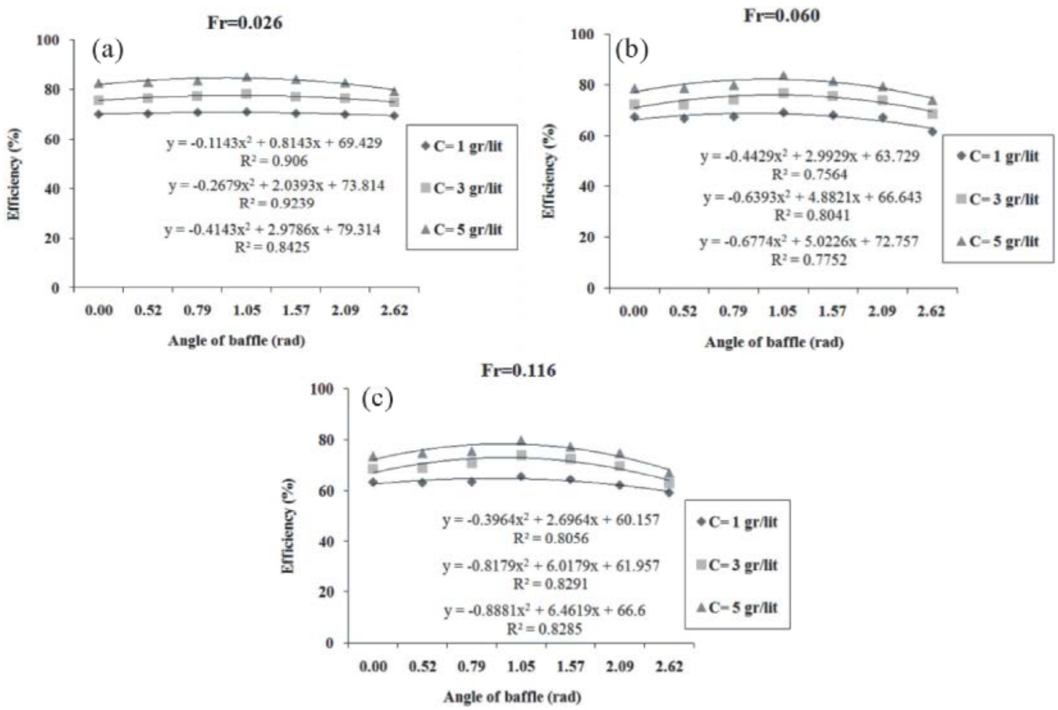


Fig. 7: Variation of efficiency with different angles of baffle for different concentration (a) Fr=0.026; (b) Fr=0.060 and (c) Fr=0.116

The results also indicate that in most experiments compared to the basin without a baffle, increasing and decreasing the removal efficiency occur for baffle with angles less and more than 90 degrees, respectively.

It was found that increasing the baffle angle from 60 to 90° for c=5gr/lit and Fr=0.116, there will be decrease in the removal efficiency form 79.8 to 77.3 (2.50%), respectively. Results further showed that by an increase in the baffle angle from 60 to 120°, there will be decrease in the removal efficiency form 79.8 to 73.8 (5.0%), respectively.

Also, from the results obtained in this paper a second order polynomial has been fitted between the removal efficiency (RE (%)) and different angles of baffle (θ) by high correlation ($R^2$) as follows (angles are in radian):

$$RE = A(\theta)^2 + B(\theta) + C \tag{2}$$

Variations of constants A, B, C and $R^2$ are shown in Figure 7.

**Effect of Froude Number:** Four different Froude numbers 0.026, 0.060, 0.067 and 0.116 were applied in order to investigate the effect of flow conditions on the efficiency. Figure 8 shows effect of Froude number on the values of efficiency (%) at basin with and without baffle for angle baffle (θ = 60°) and high inlet sediment concentration (c=5gr/lit).

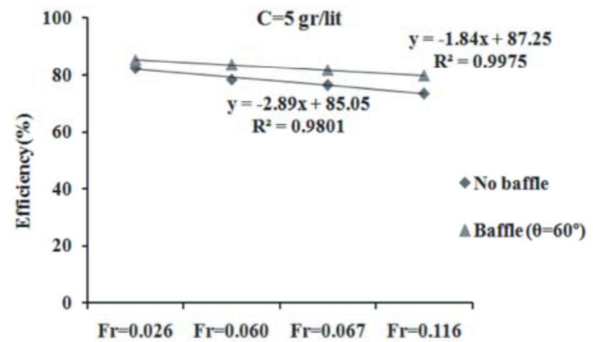


Fig. 8: Removal efficiency of basin without and with baffle (θ=60°) for different Froude numbers

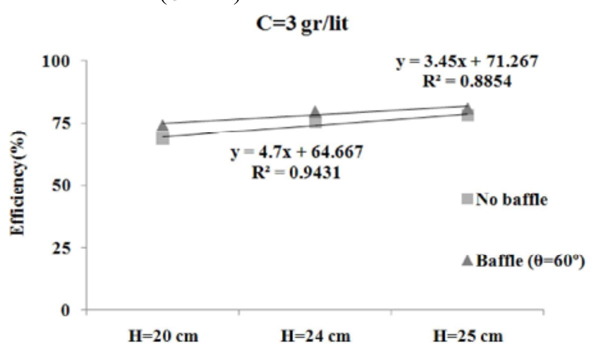


Fig. 9: Removal efficiency of basin without and with baffle (θ=60°) for different flow depth

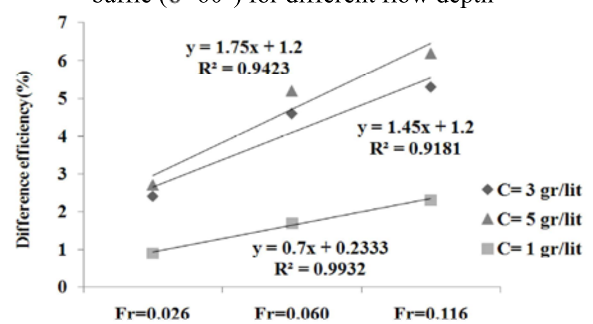


Fig. 10: Difference between efficiency of basin without and with baffle (θ=60°) for different sediment concentration and Froude numbers

Increasing Froude number is associated by increase in flow velocity, as a result the removal efficiency decreases. The main reason of such finding is that with increases in Froude number, occurs increases in vortex.

It also can be observed in Figure 8 that with increasing Fr, the removal efficiency decreases with and without baffle. The rate of decrease of RE with increase of Fr in basin with the baffle angle 60° is lower than basin without baffle due to slope equations in Figure 8. With decreasing Fr, effect of baffle on removal efficiency decreases and it is in agreement with the results of Tamayol *et al*. [7].

It is noted that with fixed inlet sediment concentration with increasing Fr from 0.026 to 0.116 at basin with the baffle angle 60°, the removal efficiency decreases from 85.30 to 79.80 % about 5.5 %, while this value is between 82.60 and 73.60 % about 9 % at basin without baffle.

Also, with increasing Froude number, sediment concentration at the outlet of basin increased during running time and it is about 20%.

**Effect of Flow Depth:** The flow depth (H) was constant for all experiments with a value of 0.20 m. In order to evaluation of effect flow depth on the removal efficiency sedimentation basin without and with baffle (θ = 60°), three depth flow 0.20, 0.24 and 0.25 m with inlet sediment concentration 3gr/lit and Fr=0.116 were used. The results of measurements of suspended sediment removal efficiency are shown in Figure 9.

It can be observed in Figure 9 that with increasing H, the removal efficiency increases with and without baffle. The main reason is that with increases H, occurs increases due to the increasing H and cross section area, the velocity decreases and its effect is observed at removal efficiency.

The rate of increase of RE with increase of H in basin with the baffle angle 60° is lower than basin without baffle due to slope equations in Figure 9.

With increasing H from 0.20 to 0.25 m at basin without baffle, the RE increases from 68.70 to 78.10 %, while this value is between 74.0 and 80.90 % at basin with the baffle angle 60°. These results show that, with increasing H, baffle has low effect on RE and it indicate that the baffle height is also an important and effective parameter.

**Effect of Inlet Sediment Concentration:** Figure 10 shows difference between the values of efficiency (%) at sedimentation basin without and with baffle for angle baffle (θ = 60°) and different concentrations and Froude numbers. Results showed that efficiency increases with an increase in inlet sediment concentration.

Also, for all of Froude numbers, increasing the inlet concentration from 1 to 5 gr/lit in basin with the baffle angle 60°, the removal efficiency increases about 14.2 %, while this value is about 11.1% at basin without baffle (Table 1). Moreover, for the sedimentation basins with the vertical baffle this value is about 13.3%.

In a low inlet suspended sediment concentration, the influence of the baffle on the efficiency is low, whereas it has a significant effect at high concentration.

## CONCLUSION

Sedimentation basins are used in irrigation networks for removal of the sediments. Installation of baffles can improve the efficiency of the basin in terms of settling. In this work, the experimental tests were performed to investigate the effects the baffle and its angle on the sediment removal efficiency of the sedimentation basin. The results show that the installation of a vertical baffle at bottom and middle of the basin improves efficiency about 4 %, while the baffle height was 40% of the water depth. It is found that baffle angle $\theta = 60°$, the overall percentage of removal efficiency increased about 7.0% and it was best performance. The measured data indicated that by increasing the Froude number and decreasing depth flow, removal efficiency of basin with and without baffle was decreased. Also, it is obtained that with increasing inlet suspended sediment concentration about 5 times, removal efficiency of basin with baffle ($\theta = 60°$) increases about 14.2%.

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