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LABORATORY INVESTIGATION OF THE EFFECT OF THE SIZE OF ORIFICE ON THE PERFORMANCE OF CURVATURE SUBMERGE VANES FOR SEDIMENT LEACHING OF THE VORTEX SETTLING BASIN'S FLOOR

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Abstract

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In this paper, considering the accumulation of the sediments on the fl oor of the vortex settling basin during sediment extracting, curvature submerge vanes were used on the fl oor of the vortex basin and the eff ect of the size of the orifi ce was studied on the performance of the curvature submerge vanes for sediment leaching of the fl oor of the basin. Experiments were performed on a physical model with a height of 90 cm and a diameter of 206 cm and a fl oor slope of 10% and also three orifices were used with diameters of 59, 46 and 36 mm. The submerge vanes were placed in different arrangements and diff erent radial sections. The results of the experiments indicated that the performance of the vanes in sediment extracting on the fl oor is primarily infl uenced by the orifi ce and secondly by the arrangements and radial sections of the vanes' placements.

Keywords: Curvature submerge vanes, efficiency, orifice, sediment, vortex settling basin

INTRODUCTION

The issue of controlling the sediments present in the flows is an issue which has always been considered in the application of the river flows. Because the natural flows always transfer some sediment with them according to the conditions affecting the flow and the characteristics of the waterway bed, due to flowing to the non-rigid soil bed.

Lack of control over the sedimentation entrance to the intakes leads to their transmission into the irrigation canals and installations, and causes a lot of difficulties as the result of carrying the sediments or their deposition in various parts. In case the flow rate is high, the tiny particles suspended in the water cause a lot of damage to the facilities, especially in the cases where the mechanical devices such as pumps and turbines are used. Among the problems related to lack of control of the sediments in the intakes, the following cases can be noted:

a) Reduction of the transfer capacity of the canals in case of sediment deposition.
b) Erosion and devastation of the canal walls in case of presence of the coarse material.
c) Disruption of water supply to farms due to water cut off for dredging the canals.
d) High costs of canal dredging.

Therefore we need to solve the issue of the presence of sediments for application of the water from natural streams. There are various methods for solving the issue of the presence of sediments in the intakes. Vortex settling basins are also one of the structures used to control the sediments in water networks by the use of this quality of the vortex flow.

Vortex settling basins is used for removing the sediments from the intakes, especially the small grain and suspended particles. The demand for this type of sediment extractor is increasing, because this method is more economical and in smaller sizes than the traditional methods such as settling basins. It also helps save water.

This type of sediment extractor uses the vortex flow to remove the sediments from the water flow. The flow of water enters the cylindrical basin which has a central orifice in its floor, tangentially and with high speed. The tangential and high speed flow into the cylinder creates a vortex. This field of vortex flows created in these basins is usually of the Rankin vortex type (Athar, 2002).

Formation of Rankin vortex, causes increase sediment concentration to outward. On the other hand, centrifugal force of vortex, conduct the sediment movement to vortexes walls. After that the secondary flow inside the vortex (because of flow orifice suction), motivates this movement to the central orifice in the basin bottom (Ghafari, 2000).

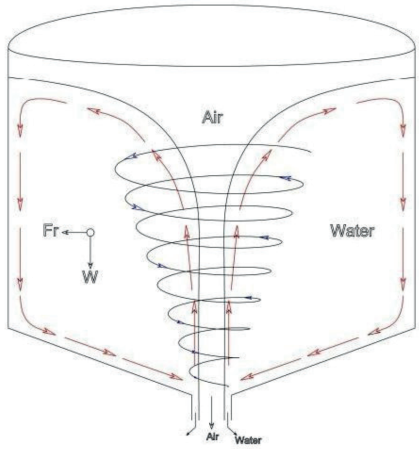
In general, the secondary flows in such systems are created as the result of the following factors:

a) Reduction of the marginal speed of the fluid due to the friction between the floor of the basin and the fluid.
b) The flow perpendicular to the vortex flow toward the center of the basin.
c) The eruptive inlet flow and the side overflows and the centrifugal force of the basin's vortex.

For the maximum length of the rotation, the basin should be constructed tangent to the input channel. The secondary flows lead those layers of the flow which are close to the floor, toward the central orifice. Thus, the sediment particles that are heavier than the fluid move toward the orifice by travelling through a spiral path and enter the discharge tube. The discharge tube is connected to the discharge canal and that is connected to the river and by this means the sediments are extracted from the water (Fig. 1).

A core of air is formed in the center of the orifice, the dimensions of this core depend on the size of the orifice, also this core of air reduces the output discharge from the central orifice and increases the hydraulic efficiency of the basin.

Many researchers have worked on these basins to increase its efficiency. For instance Ogihara and Sakaguchi (1984) used the tulip spillway for transferring the clear water in their investigation instead of lateral spillway. Mashauri (1986) conducted his experiments on three models with different scales. Paul (1991) introduced a design that a horseshoe-formed vane (deflector) was used which was installed in the input channel at a distance of a third of the depth of the flow. Athar *et al.* (2002) presented two other models of vortex settling basin.



1: *The spiral path and the secondary flow formed in the basin*

Deposition of a percentage of the sediments on the floor of the basin and no withdrawal from the flushing orifice are one of the major problems of these types of basins. This problem that may be due to some reasons such as lack of an appropriate designation or any other factor will cause dysfunction of the basin over time. This issue has caused a necessity for conducting the essential studies and research to provide a method for withdrawal or reduction of these sediments.

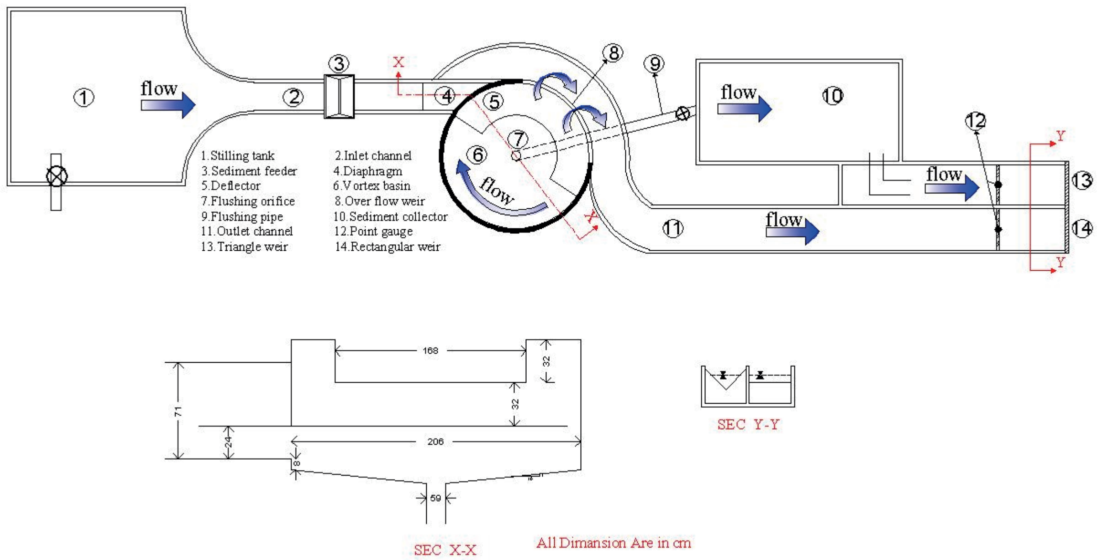
Different researchers have investigated different approaches to resolving the problem of deposition of the sediments on the floor of these basins. Researchers at Istanbul Technical University (IUT) such as Cecen and Akmandor (1973), Curiet *et al.* (1979) and Cecen and Bayazit (1975) concluded in their studies that making a dip in the basin's floor helps to drain the sediments from the floor of the basin. Paul *et al.* (1991) and Ziaei (2000) presented a model with two inputs for the basin and changing the flow from clockwise to counter clockwise and vice versa for sediment leaching of the basin's floor.

In the present study the effect of the size of the orifice was investigated in the laboratory on the performance of curved submerge vanes during sediment leaching of the basin's floor. In this project, by planting the curvature submerge vanes on the floor of the basin, the secondary flows formed by these vanes are reinforced, and also the vortex flow within the basin is modified and thus it leads to easy movement of the floor sediments toward the flushing orifice. Now in this study, the effect of changes in the orifice size was investigated on the performance rate of curvature submerge vanes.

EXPERIMENTAL EQUIPMENTS

Experimental Model

Laboratory experiments on the physical model of vortex settling basin were conducted in the Soil Conservation and Watershed Management Research Institute. In Fig. 2 the plan of the laboratory model is



2: *The plan of the experimental model of vortex settling basin*

I: *The characteristics of vortex settling basin*

Basin Height (cm)	Basin Diameter (cm)	Flushing Orifice Diameter (mm)	Sloping floor (%)	Basin Overflow Length (cm)	Basin Overflow Height (cm)	Height below the diaphragm (cm)
96	206	59	10	168	32	24

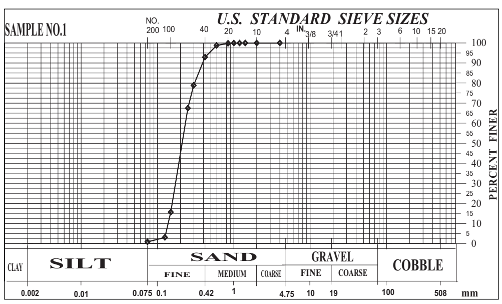
indicated and the components are mentioned and in Tab. I the model specifications are shown.

Also in this basin, a deflector is embedded horizontally and flat below the spillway and a diaphragm is embedded in the inlet. The deflector structure is embedded to prevent the exit of sediment particles on arrival to the basin under the influence of the outflow jet of the spillway, which increases the residence time of the sediment containing flow in the basin, and ultimately the sediments will spin more.

According the previous studies by researchers such as Cecen and Bayazit (1975) and Mashauri (1986), optimum floor slope is considered 10%. It is content that increasing the slop, would Reduction of the sediments in the floor basin but in return increased the output discharge from the central orifice and reduces the efficiency of the basin.

Sediment Injection

In this study, materials with a uniform grain size were used for better distribution, therefore in these experiments sand with d_{50} = 0.22 mm were used, according to the grading curve in Fig. 3. The specific gravity of the sediments used is 2.65 grams per cubic centimeters. The sands used were washed and free of clay and silt small grains. Sediment injections were performed dry and uniform with a specified volume of sediments (22 g/s) and at specified times, by an injection device (Fig. 4) which was placed at a distance of 1.5 meters from the canal, upstream the vortex settling basin. Considering the previous studies by researchers such as Athar *et al.* (2002), Keshavarzi and Gheisi (2006) and Niknia *et al.* (2011) in this regard, and studying their methods in injection of the sediments, the method of Keshavarzi and Gheisi (2006) was selected for injection of sediments to the canal upstream the basin.



3: *Gradation curve of the injected sediments to the vortex settling basin with d_{50} = 0.22 mm*

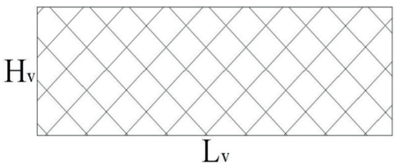
4: *Sediment injection machine*

II: *Calculation of the dimensions of curved submerge vanes*

Parameter	Height of submerge vane H_v	Length of submerge vane L_v
Recommended by Odgaard and Kennedy (1983)	$0.2 < \frac{H_v}{d} < 0.5$	$3H_v < L_v < 4H_v$
Applied value	$0.5 = \frac{H_v}{d}$	$3H_v = L_v$

Curvature Submerge Vanes

So far no research has been conducted and no theory has been provided in the usage of submerge vanes in the floor of vortex basins, dimensions and optimal arrangement of these vanes in these basins. However, extensive studies have been conducted on the application of the vanes in front of the intake openings and control of erosion of the river coasts. Therefore, the suggestions presented in the mentioned fields (Odgaard and Kennedy, 1983) were used in the present study as the idea for the initial designation of these vanes in the floor of the vortex basin. The vanes are galvanized and with a thickness of 2 mm and a basic shape of rectangular (Fig. 5). Dimensions of the vanes are given in Tab. II.



5: *The basic shape of curvature submerge vanes*

6: *The vanes with six types of curvatures*

In the above table, *d* is Vertical distance from input channel edge to bottom of basin which has shown in Fig. 2 ($d = 8$ cm).

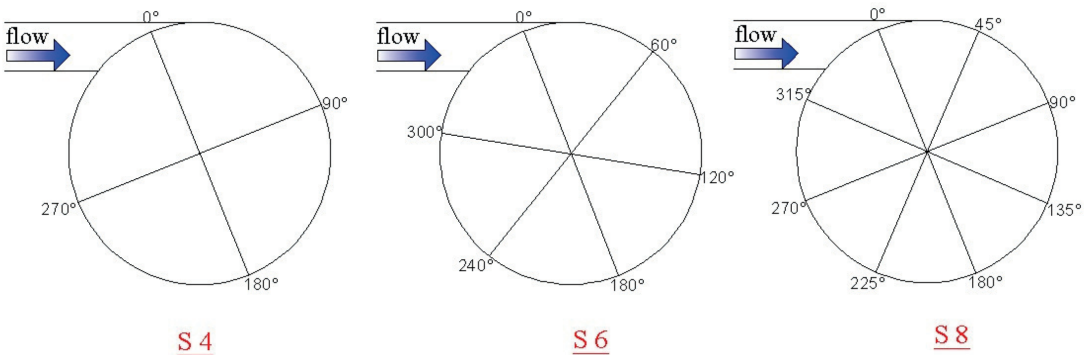
The vanes in the floor of the basin have curvatures proportional to the circle located over them. Therefore, according to the transverse distance between the vanes, there are 6 types of vanes with different curvatures (Fig. 6).

The floor was divided into radial sections with equal angles in order to evaluate the effect of the longitudinal distance between the vanes on the efficiency of the vortex basin. The longitudinal distance was examined in three modes of 4, 6 and 8 radial sections, with equal angles of 90, 60 and 45 degrees, respectively called S4, S6 and S8 as shown in Fig. 7.

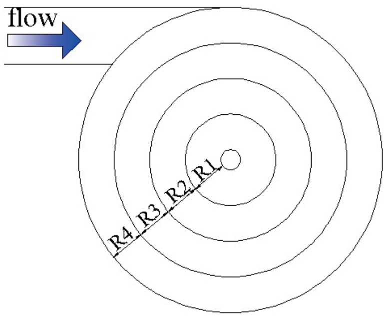
The floor of the basin was divided into 4 concentric circles with equal distances in order to evaluate the radial distance of the vanes from the flushing orifice. Circles are shown in Fig. 8 with their considered labels.

Another vane was placed between the vanes for further influence of the vanes on the vortex flow. The transverse distance of the vanes from each other was considered a fixed value of $\delta_n = 3H_v$ (Odgaard and Kennedy, 1983) (Fig. 9).

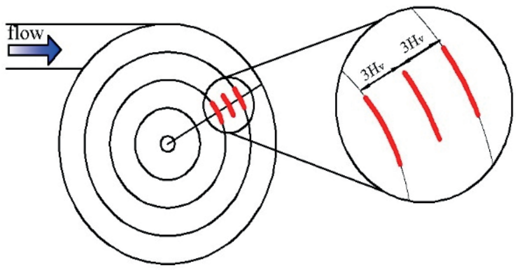
Preliminary experiments of sediment injection in the mode without the vanes indicate that in the R1 zone no sediment will stay on the floor of the basin, while in the R2, R3 and R4 zones there are sedimentations. Thus the R1 zone was ignored for insertion of the vanes. The submerge vanes were planted in 6 different modes. First the vanes were placed in the desired radial sections in a circle with triplet sets separately in the R2, R3 and R4 zones. Then the vanes of R 2 3, R 3 4 and R 2 3 4 circles were combined to investigate the further expansion of



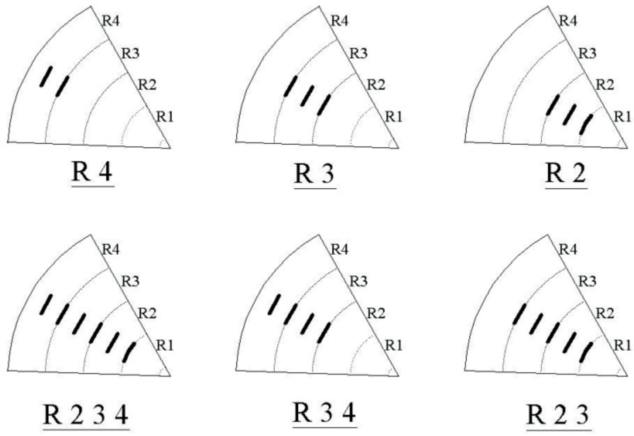
7: *Radial sections of placements of the vanes*



8: *Radial distance of the vanes' positions from the orifice*



9: *Transverse distance between the vanes*



10: *Different arrangements of curvature submerge vanes*

the influenced area. The arrangements used are shown in Fig. 10.

An Experimental Program

With the entry of the water to the basin with a discharge of 45 liters per second and the flow being stabilized, sediments were injected upstream the basin, sediments were injected with a fixed discharge and at specified times (20 minutes). With the completion of sediment injection the pump was turned off and the discharge valve of the orifice was shot simultaneously, and the sediments remaining within the basin after draining the water inside and the sediments injected from the orifice were collected separately and weighed after drying. This process of the experiment was performed for different arrangements of the vanes and three modes of radial sections placements and three orifices in 36, 46 and 59 mm (Fig. 11).

11: *Orifices used*

EXPERIMENTAL RESULTS AND DISCUSSION

The η_T, η_O and η_B parameters were used to calculate the efficiency of the vortex settling basin. These parameters are defined as follows:

$$\eta_T = \eta_O + \eta_B, \quad (1)$$

$$\eta_O = \frac{W_O}{W_T}, \quad (2)$$

$$\eta_B = \frac{W_B}{W_T}. \quad (3)$$

In the above equations, η_T is the total sediment extracting efficiency, η_O the sediment extracting efficiency of the flushing orifice, η_B the sediment extracting efficiency of the basin's floor, *the WT weight* of the total sediments entering the basin, *the* W_O *weight* of the sediments entering the flushing orifice, *the WB weight* of the sediments of the basin's floor. Also the G' parameter is used to show the sediment extracting rate of the floor:

$$G' = \frac{(\eta_B - \eta'_B)}{\eta_B}. \quad (4)$$

In equation 4, G' is the efficiency of sediment leaching from the floor, η_B the efficiency of sediment extracting of the basin's floor without curvature submerge vanes and η'_B the efficiency of sediment extracting of the basin's floor with curvature submerge vanes.

Also Q_0/Q_t is used to show the rate of basin's discharge loss in different modes where Q_0 is the output discharge of the flushing orifice and Q_t the total discharge entering the basin.

For a simpler evaluation of the effects of each of the variables, initially in the first stage appropriate arrangements were selected for one size of the flushing orifice and a constant discharge entering the basin and in the second stage the effect of the orifice was studied on the performance of the curvature submerge vanes in the vortex settling basin.

The First Stage

At this stage of the experiments, the effect of the vanes on the defined parameters was assessed with the placement of the vanes in three radial section modes of (S4, S6 and S8) and six arrangements of (R2, R3, R4, R2 3, R3 4 and R2 3 4). To get started, an orifice with a diameter of 59 mm and a maximum input discharge of 45 l/s was used.

The Simple Effect of Radial Distance (R)

The results of the analysis of the simple effects of the variance of the radial distance of the vanes placements from the orifice R, on the sediment parameters of η_T, η_O and η_B and the hydraulic parameter of Q_0/Q_t are presented in Fig. 12. It is noteworthy that R0 represents a condition that no vanes have been planted in the floor of the basin.

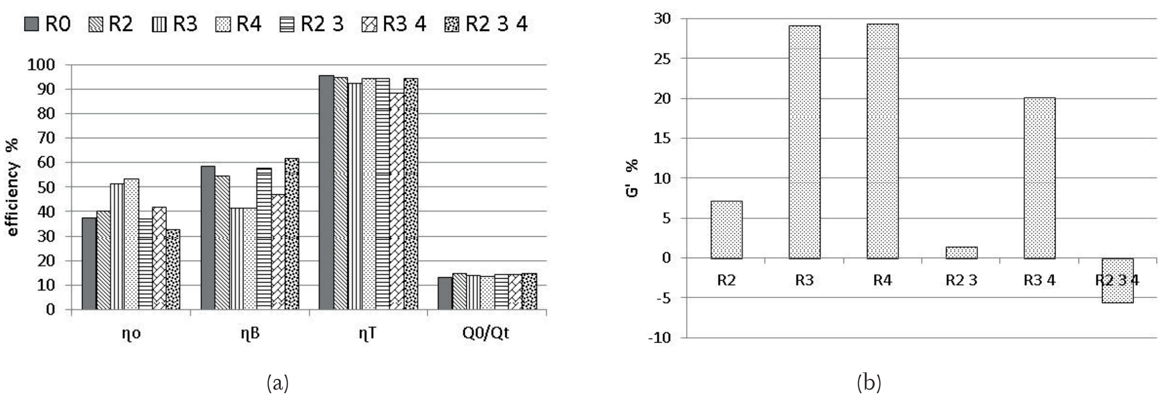
As observed in Fig. 12(a), the use of vanes has a small effect on total efficiency and wasted discharge while these vanes have considerably changed the value of η_O and η_B, in a way that whenever the orifice efficiency is reduced, the floor efficiency goes up in any R position.

Fig. 12(b) shows the G' parameter in R3, R4 and R3 4 positions which indicates more sediment washing from the floor of basin. Positive values explain the successful performance of vanes n sediment flushing from the floor. On the other hand, the value of G' parameter hasn't changed much in simple and compound positions of R2 and sediment flushing from the floor of basin is low as well, i.e. the performance of vanes is not successful in flushing the sediments from the floor of basin. Fig. 12(b) also shows that not only the sediment flushing is not performed in R2 3 4 position, but also the sediments are increased at the floor of the basin.

Therefore, considering the suitable and optimum performance of R3, R4 and R3 4 in sediment flushing from the floor of the basin, these positions are used in order to present the rest of the results and R2, R2 3 and R 2 3 4 arrangements would be omitted because of their low efficiency and sediment flushing from the floor of the basin.

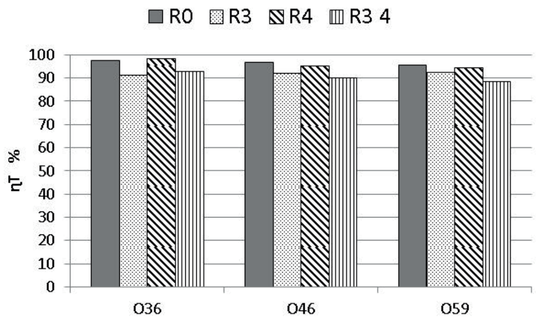
The achieved results about the effect of orifice on sedimentary parameter η_T and hydraulic parameters such as Q_O/Q_t and G' are illustrated on Figs. 13(a), 13(b) and 13(c). A 45 L/S discharge was applied in order to show this effect. It should be mentioned that R0 explains a position in which no vane is placed at the floor of the basin.

It is observed in Fig. 13(a) that the changes of orifice have no considerable effect on η_T and it hasn't changed a lot compared to the position with no vanes. Fig. 13(b) shows that the wasted discharge goes up when the orifice diameter is increased. It also shows that the effect of these changes on wasted discharge is more compared to the changes in radial distance (R). As shown by Fig. 13(c), the sediment flushing from the floor of the basin goes up when the orifice diameter is increased. It also shows that the compared to the variations of radial distance (R),

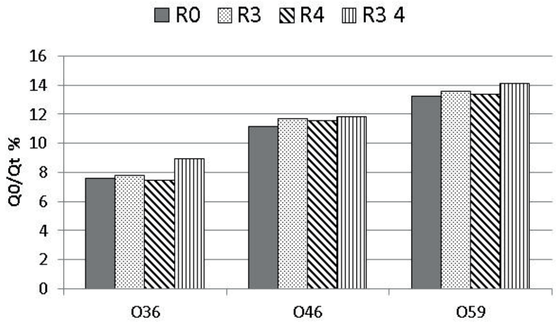


(a) (b)

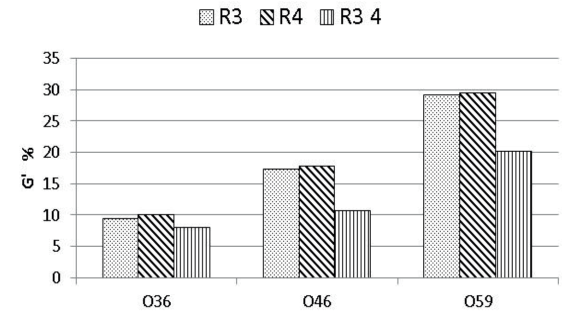
12: *(a) The effect of the radial distance of the (R) vain positions on sedimentary and hydraulic parameters; (b) The effect of the radial distance of the (R) vain positions on percentage of sediment flushing at the floor of the basin (G')*



(a)

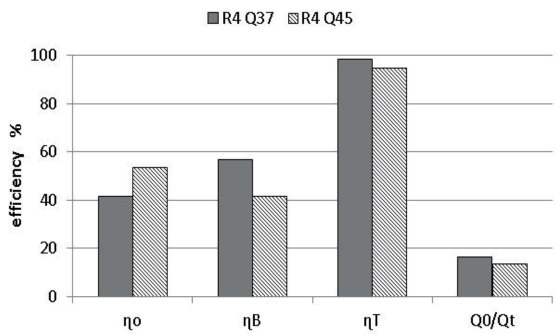


(b)

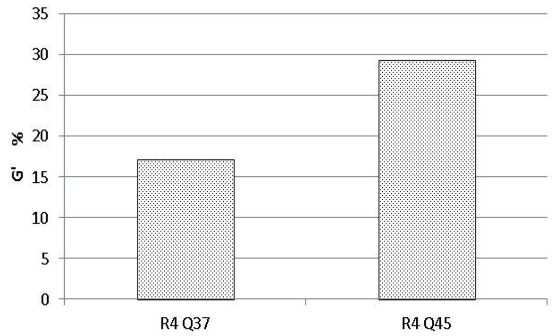


(c)

13: *(a) Mutual effect of Orifice diameter (O) and radial distance (R) on average percentage of total sediment flushing (η_T); (b) Mutual effect of Orifice diameter (O) and radial distance (R) on average percent of wasted discharge (Q_O/Q_t); (c) Mutual effect of Orifice diameter (O) and radial distance (R) on average percent of sediment flushing from the floor of the basin*



(a)



(b)

14: *(a) The effect of the entered discharge on (Q) on percentages of sedimentary and hydraulic parameters of the basin without the vanes; (b) The effect of the entered discharge on (Q) on percentage of sediment flushing from the floor of the basin*

the changes in orifice diameter have a stronger effect on sediment flushing from the floor of basin.

Therefore, considering Figs. 13(b) and 13(c), we would have more sediment flushing from the floor of basin through choosing an orifice with 59 mm diameter and accepting more wasted discharge.

The R4 radial distance and an orifice with a 59 mm diameter were used in order to show the effect of discharge on sedimentary and hydraulic parameters.

The results achieved about the effect of discharge on sedimentary parameters such as η_T, η_O and η_B, and hydraulic parameters such as Q_O/Q_t and G' are illustrated on Figs. 14(a) and 14(b).

As observed in Fig. 14(a), η_T doesn't change that much when the discharge goes up while the wasted discharge (Q_O/Q_t) would be reduced. This hydraulic performance improvement can be caused by the increase in the power of vortex which is proportional with the increase in entered discharge. It also shows that through increasing discharge, η_O parameter is increased as well while η_B is reduced. The rate of sediment flushing from the floor of the basin for each discharge is illustrated in Fig. 14(b). It is completely clear that if discharge increases, the sediment flushing from the floor would be increased as well.

CONCLUSION

Experimental models enable us to investigate the performance of a plan technically and economically. Considering the achieved results, the total efficiency doesn't change that much in different positions of vanes, while a considerable effect on orifice efficiency and the efficiency or the floor of basin is evident compared to the condition with no vanes. Thus, R3, R4 and R3 4 arrangements are chosen as the optimum positions for sediment flushing from the floor of the basin. This result shows that it is more efficient to place the vanes in more radial distances from the orifice.

Results also indicated that when there are vanes in vortex settling basin, wasted discharge and sediment flushing from the floor goes up as the orifice diameter increases.

Besides, an increase in discharge increases the wasted discharge and sediment flushing from the floor of the basin as well.

By and large, the efficiency of the sediment flushing from the floor of vortex settling basin with vanes is respectively affected by orifice, discharge and radial distance of the vanes.

List of Symbols

d_{50} .... Median diameter of sediment grains.
d .... Vertical distance from input channel edge to bottom of basin.
H_v .... Height submerged vanes.
L_v .... Length submerged vanes.
R............ The areas in which vanes are placed.
S .... Number of radial section in which vanes are placed.
η_T .... Total settling efficiency.
η_o .... Orifice settling efficiency.
η_B .... Floor settling efficiency.
W_T .... The total weight of sediments entered to the basin.
W_o .... The weight of sediments entered to the flushing orifice.
W_B .... The weight of sediments at the floor of basin.
W'_T .... The total weight of injected sediments in the upstream channel.
W''_T .... The weight of settled sediments under the sediment injection machine.
G' .... The efficiency of the sediment flushing at the floor.
η'_B .... The settling efficiency at the floor of the basin without curvature submerged vanes.
Q_O .... The outgoing discharge from flushing orifice.
Q_t .... The total entered discharge to the basin.
Q_O/Q_t ..... The value of the wasted discharge in the basin.

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