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Effects of curvature submerge vane in efficiency of vortex settling basin

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ABSTRACT

In this century due to population growth, the use of river water has become more complicated. Since most rivers pass across loose and erodible areas, they always act as the most important factor of transferring eroded materials from the solid crust of the earth. Vortex basins are among the solutions known for the high-speed separation of solids from liquids (filtration). One of the problems of such basins is the settling of sediments in their floor which necessitates the performance of required investigations and researches in order to present a method to exclude or reduce such sediments. The present research presents and investigates a plan to resolve this problem. This paper proceeds to perform an experimental study on the effect of a group of curvature submerged vanes in different positions at the floor of a vortex settling basin with a 90° radial section on the efficiency of the basin. The experiments were performed on a physical model with 96 cm height, 206 cm diameter, 10% floor slope, tow discharges of 45 and 37 L/S, and three orifices with 59, 46 and 36 mm diameters. Uniform aggregate (d_{50}=0.22 mm) was applied in experiments. The efficiency of the basin was determined in six different positions of curvature submerged vanes and the values were investigated compared to each other. The results of experiments showed that the efficiency is higher when the vanes are placed more distant from the orifices while changes in orifice diameter and discharge considerably effect on the efficiency.

1. Introduction

Taking water from river has long been common for agriculture and drinking and later for industrial uses and financing energy. One of the main issues encountered by engineers while designing hydraulic structures including irrigation and hydroelectric intakes and other cases is the condition of sediments entered to the transmission system which should be controlled. Because of the harmful effects derived by the entrance of these sediments into hydraulic structures, different tools are applied in order to control a part of them. Of course, it is impossible and sometimes undesirable to eliminate all sediments. Small grained silt works as a sealant in transmission systems, modifies the soil texture and fertilizes agricultural lands as a result.

Application of settling basins, vortex tube extractors, submerged vanes, tunnel sediment extractors in the entrance of channels and vortex settling basins are among the methods of controlling sediments. In order to omit the undesirable characteristics of settling basins (such as high economical cost) and other settling methods for sedimentation of suspended solids, a cylindrical settling basin can be applied. Vortex settling basins are among the structures which control the entered sediments to water channels through vortex flows. These basins perform the separation of sediment grains in a high speed. Low water waste, being economical compared to other methods, being permanent unlike other settling systems, being needless to perform short-term dredging, and finally, smaller size compared to classic basins are all among the advantages of this sediment controlling method.

A wide range of researches have been performed on different kinds of this settling structure throughout the world. For instance, scholars such as Cecen and Akmandor (1973), Curi et al. (1979), and Cecen & Bayazit (1975) in Istanbul Technical University (ITU) have investigated the use of vortex in sediment filtration systems as one of the possible solutions for high-speed separation of solids from liquids.

In his researches, Salakhov (1975) showed that vortex settling basins are completely efficient in controlling underneath layers of sediments (near to the basin bed) during intake operation. Ogihara & Sakaguchi (1984) have presented a model which is different in the position of the outgoing flow from spillway. In order to transmit clear water, a bell-mouth spillway was applied in this basin. Mashauri (1986) has presented a model which separates the entrance and outlet of the flows with a horizontal vane. The model presented by Paul (1991) has used a horseshoe-shaped vane (deflector) installed in the entrance channel in a distance equal to one-third of the flow depth. Ziaei (2000) has suggested that the settled sediments in the floor of settling basin can be washed through devising tow flow entrances and changing the flow direction from clockwise to anticlockwise and vice versa. Athar et al. (2002) have presented two other models of vortex settling basins. In their experiments, Niknia & Keshavarzi (2011) investigated the flow structure under deflector and compared it with the flow structure in the absence of deflector for the anticlockwise flows entered to the vortex basin.

One of the problems of vortex settling basins is the settling of sediments in their floor which necessitates the performance of required investigations and researches in order to present a method to exclude or reduce such sediments. The present research presents and investigates a model to resolve this problem. This model includes the application of a group of curvature submerge vanes in different positions placed at the floor of vortex settling basin in different positions.

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2. Experimental equipments

2.1. Experimental model

The experiments were performed on the vortex settling basin physical model of Soil Conservation and Watershed Management Research Institute, Tehran, Iran. Figure 1 illustrates the plan of the physical model of vortex settling basin. The characteristics of the model are mentioned in Table 1.

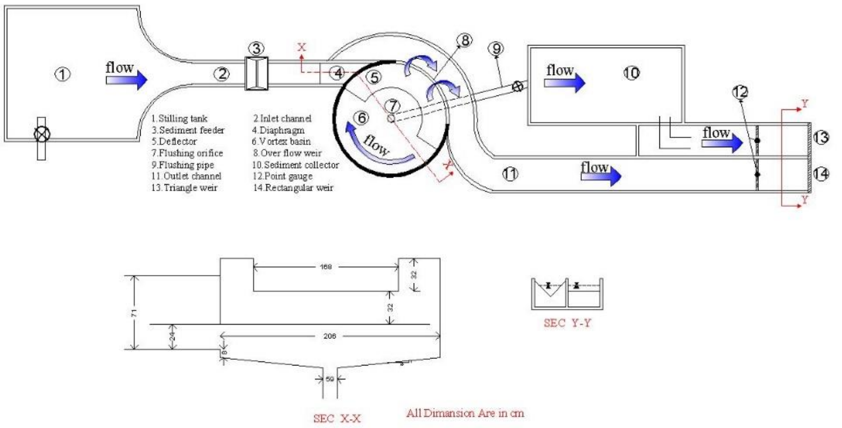


Fig. 1. The plan of the experimental model of vortex settling basin.

Table 1. 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

Tow outlet channels for the transmission of water excluded from the basin spillway and the flushing orifice are devised in this system. These depth and width of these channels are both 60 cm. There is also a deflector devised horizontally and flatly at the bottom of spillway, and a diaphragm on its entrance. Structure of the deflector is devised in order to prevent the sediment grains from being excluded just as they enter to the basin affected by outgoing jet flow from the spillway, which increases the duration of the settling of the sediment containing flow in the basin and finally, swirls the sediments more.
This system includes a water reservoir with a content of 12.5 m^3 and a centrifugal pump with a maximum discharge of 45 L/S.

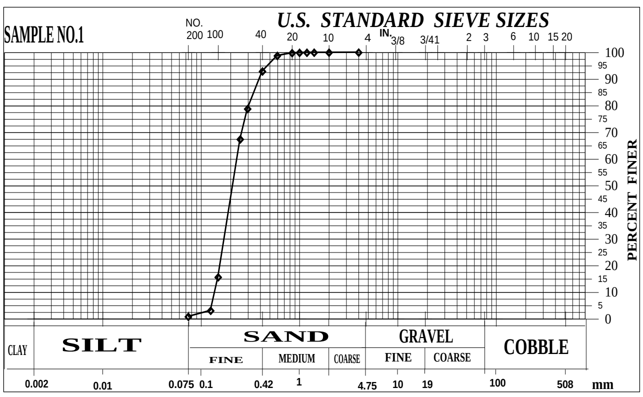
2.2. Sediment injection

In this method, sediments should be injected well-distributed in the entering flow to the basin. Sediments should also be infused in a suitable area so that they have enough time for a normal distribution in flow profile and have suspended flow in the model. Scholars have used different gradations in their studies, some of which are observed in Table 2. Through investigation of different settling materials and considering issues such as providing, gradation, injection, sampling, collecting, drying, specific weight and uniform distribution, the sand with specific weight of 2.65 g/cm^3 was applied in this research, The gradation extents of the applied sand are observed in figure 2(a). d50 for this sand is equal to 0.22 mm.

The sediment injection is performed applying an infusion machine (Fig. 2(b)) placed 1.5 m far from the upstream channel of the vortex settling basin, in a dry and uniform form with a specific volume (22 g/s) and within a specific time.

Table 2. Range of sediment size used in previous studies.

Authors	Range of sediment size (mm)
Curi et al. (1977)	2.12
Mashauri M-I (1986)	0.375-1.80
Mashauri M-II (1986)	0.1875-0.75
Esen (1989)	0.320-2.7
Mashauri M-III (1986)	0.063-0.25
IPRI (1989)	0.09-0.30
Paul et al. M-I (1991)	0.175
Paul et al. M-II (1991)	0.05-1.00
Paul et al. M-III (1991)	7.64
Athar et al. (2002)	0.055-0.931
Keshavarzi et al. (2006)	0.074-0.3
Niknia et al. (2011)	0.08-2.00



(a)

(b)

Fig. 2. (a) Gradation curve of the injected sediments to the vortex settling basin with d50=0.22mm; (b) Sediment injection machine.

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2.3. Curvature submerge vanes

Considering the wide application of submerged vanes in rivers and intakes to improve efficiency of these structures, they are not that much used in vortex settling basin. Therefore, according to the suggestion of Odgaard and Kennedy (1983), the size of these vanes is illustrated in Table 3 (Fig. 3(a)).

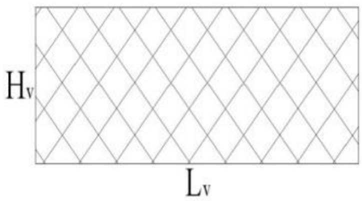
Table 3. The Dimension of submerged vanes.

Vane Height $H_v\ (cm)$	Vane length $L_v = 3H_v (cm)$
4	12

These vanes are placed at the floor of the basin in a curvaceous form on concentric circles. The curve of each vane depends on the circle perimeter on which it is placed. Thus, considering the radial distance of vanes from each other, they have six different curves with 27.95, 40.45, 52.95, 65.45, 77.95 and 90.45 cm radiuses. Six types of vanes with different curves are observed in Fig. 3(b).

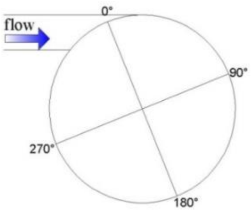
Vanes in 90° radial section (Fig. 4(a)) are placed in areas 2, 3 and 4 (Fig. 4(b)) at the floor of the basin. The vanes in 2, 3 and 4 are placed in six different positions each named considering the area in which they are devised.

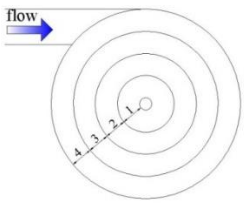
These six types of arrangements (different positions) are: R2, R3, R4, R2 3, R3 4 and R2 3 4. You can see these six types in figure 5. These vanes aren't placed in area 1 because according to the experiments, without placing vanes in this area, they have no effect on the sediment flushing of basin floor.



(a) (b)

Fig. 3. (a) Characteristics submerge vane; (b) Six types of curvature submerged vanes.





(a) (b)

Fig. 4. (a) The radial section in which vanes are devised at the floor of basin; (b) The areas in which vanes are devised at the floor of basin.

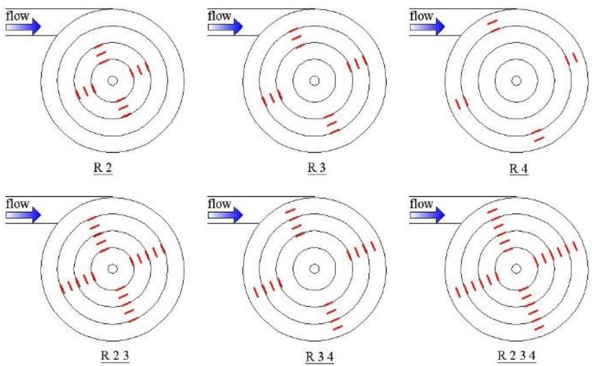


Fig. 5. Six types of arrangements for devising vanes at the floor of basin.

In order to perform a better coverage, some vanes are placed between the circles (figure 6). The traverse distance of vanes from each other is considered as a constant value of δ=3Hv (Odgaard & Kennedy, 1983).

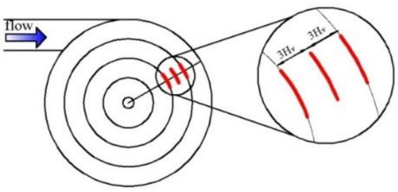


Fig. 6 The traverse distance between the curvature submerge vane.

2.4. Experimental program

Water is entered to the system through pumping and interned to the basin through the entrance of the basin and from beneath of the diaphragm. It creates a vortex flow it the basin a part of which out goes from the flushing orifice and the other part is excluded from the top of the spillway. The excluded water from the orifice goes to a channel with triangular spillway while the excluded water from the spillway goes to one with rectangular spillway. When the flow gets steady in the system, the system discharge can be calculated through

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reading the gauges fixed on two outlet channels and considering the type of spillways. The applied discharges are 37 and 45 L/S. Sediment nourishment gets started after stabilization of flow and adjustment of discharge. This act is performed with a specific discharge and within a specific time (20 min) in upstream channel. Afterward, as sediments are finished, the pump gets off simultaneously with closing the evacuation valve of the orifice. After settling of remained sediments in the basin, the water contained by the basin would be evacuated (figure 7) and the sediments inside the basin and those excluded from the orifice would be gathered, dried and finally weighted separately. Three flushing orifice with diameters of 36, 46 and 59 mm were used in order to determine the effect of flushing orifice on the efficiency of basin. This experimental process was first performed without and then with vanes.

Fig. 7. Floor of the basin after the end of the experiment.

3. Results and discussion

The sediments entered to the vortex settling basin are divided into several parts. The first part of these sediments is entered to the flushing orifice, the second part settles at the floor of the basin and the third part passes from the top of the spillway. Now, we use the following relations in order to indicate the obtained efficiency:

$$\eta_T = \eta_o + \eta_B \quad (1)$$

$$\eta_o = \frac{W_o}{W_T} \quad (2)$$

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

$$W_T = W_T^{'} - W_T^{''} \quad (4)$$

In the relations above, ηT represents the total settling efficiency, ηOrefers to the settling efficiency of the flushing orifice, ηB is the settling efficiency at the floor of the basin, WT represents the total weight of sediments entered to the basin, WO refers to the weight of sediments entered to the flushing orifice, WB represents the weight of sediments at the floor of basin, W'T is the total weight of injected sediments in the upstream channel and W"T refers to the weight of settled sediments under the sediment injection machine.

During the injection, a part of sediments settle under the sediment injection machine before entering to the basin. Therefore, these sediments are collected, dried after the experiment is done, then their weight would be subtracted from the weight of injected sediments.

Besides, G' parameter is used in order to indicate the rate of sediment flushing at the floor.

$$G' = \frac{(\eta_B^{'} - \eta_B)}{\eta_B^{'}} \quad (5)$$

In relation five, G' is the efficiency of the sediment flushing at the floor, η'B represents the settling efficiency at the floor of the basin without curvature submerged vanes and ηB refers to the settling efficiency at the floor of the basin with curvature submerged vanes.

In order to show the value of the wasted discharge in the basin in different positions, ηO/ηt was used in which ηO is the outgoing discharge from flushing orifice and ηt refers to the total entered discharge to the basin.

The results achieved about the effect of radial distance of the position of vanes (R2, R3, R4, R2 3, R3 4 & R2 3 4) at the floor on sedimentary parameters such as ηT, ηO and ηB, and hydraulic parameters such as ηO/ηt and G', are illustrated in figure 8. A 45 L/S discharge and a 59 mm orifice were applied in order to show this effect. R0 indicates a position in which no vane is placed at the floor of the basin.

As observed in Fig. 8 (a), the use of vanes has a small effect on total efficiency and wasted discharge while these vanes have considerably changed the value of ηO and ηB, in a way that whenever the orifice efficiency is reduced, the floor efficiency goes up in any R position.

Fig. 8 (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. 8 (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.

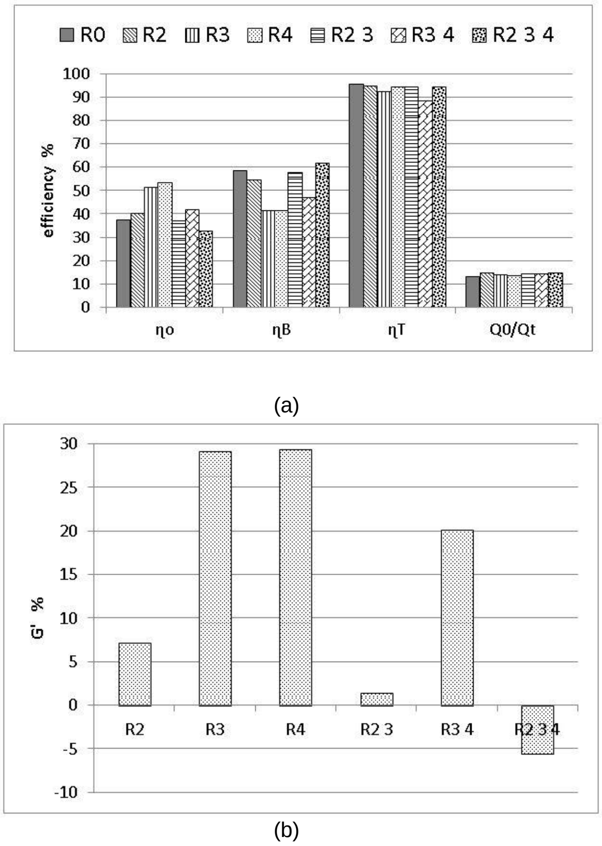

Fig. 8. (a) The effect of the radial distance of the (R) vain positions on sedimentary and hydraulic parameters; (b) The effect of the radial distance of the (R) vain positions on percentage of sediment flushing at the floor of the basin (G').

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 ηT and hydraulic parameters such as QO/Qt and G' are illustrated on Figs. 9(a), 9(b) and 9(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.

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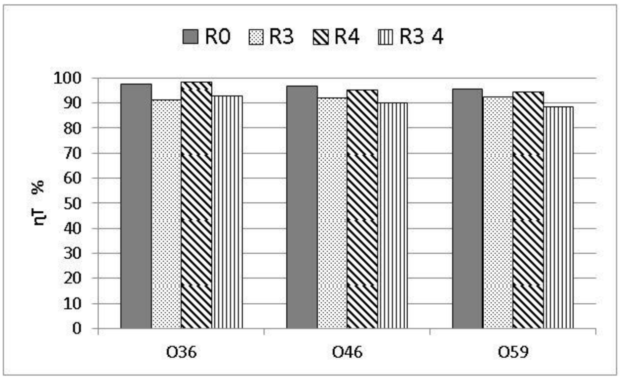
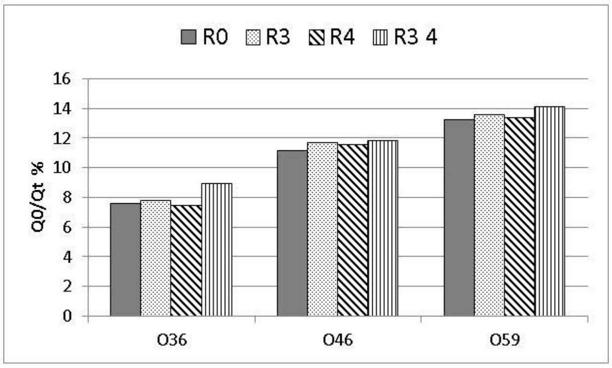
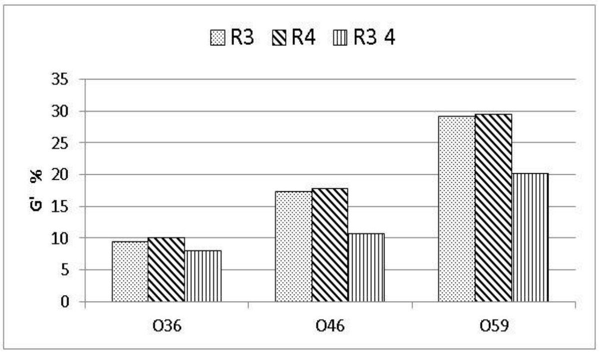


(a)



(b)



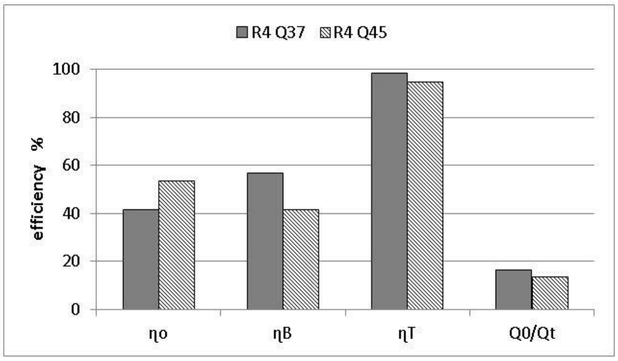
(c)

Fig. 9. (a) Mutual effect of Orifice diameter (O) and radial distance (R) on average percentage of total sediment flushing (ηT); (b) Mutual effect of Orifice diameter (O) and radial distance (R) on average percent of wasted discharge (ϘO/Ϙt); (c) Mutual effect of Orifice diameter (O) and radial distance (R) on average percent of sediment flushing from the floor of the basin.

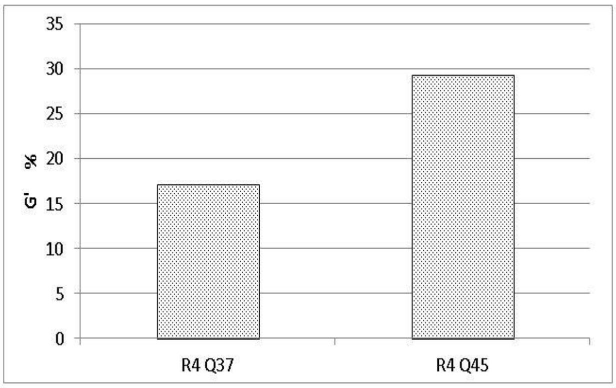
It is observed in Fig. 9(a) that the changes of orifice have no considerable effect on ηT and it hasn't changed a lot compared to the position with no vanes. Fig. 9(b) shows that the wasted discharge goes up when the orifice diameter is increased. It also shows that the effect of these changes on wasted discharge is more compared to the changes in radial distance (R). As shown by Fig. 9(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), the changes in orifice diameter have a stronger effect on sediment flushing from the floor of basin.

Therefore, considering Figs. 9(b) and 9(c), we would have more sediment flushing from the floor of basin through choosing an orifice with 59mm 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 ηT, ηO and ηB, and hydraulic parameters such as ϘO/Ϙt and G' are illustrated on Figs. 10(a) and 10(b).

As observed in figure 10(a), ηT doesn't change that much when the discharge goes up while the wasted discharge (ϘO/Ϙt) 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, ηO parameter is increased as well while ηB is reduced. The rate of sediment flushing from the floor of the basin for each discharge is illustrated in figure 10(b). It is completely clear that if discharge increases, the sediment flushing from the floor would be increased as well.



(a)



(b)

Fig. 10. (a) The effect of the entered discharge on (Ϙ) on percentages of sedimentary and hydraulic parameters of the basin without the vanes; (b) The effect of the entered discharge on (Ϙ) on percentage of sediment flushing from the floor of the basin.

4. Conclusions

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.

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