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Analysis of the Split Width Ratio and Vortex Tube Deployment Angle Effect on Trap Efficiency and Flow Losses in Meandered Rivers

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Abstract: *Providing a condition that supplies maximum impoundment along with minimum sediment is one of the significant issues in designing basins to prevent the blockage of the basin, which occurs due to sediment accumulation. Vortex tube is one of the bed sediments substrate separator which is constructed at the beginning of the transmission channels. This sediment can be used permanently and is economical due to small dimensions and easy installation. The optimal design of the vortex tube requires finding dimensions that can increase the trap efficiency. The 180-degrees experimental model with a torsional radius (R / B = 3) of 3 and a vortex tube deployment angle of 115 degrees with a 45-degree of impoundment angle to evaluate the effect of split width ratio and the vortex tube deployment angle on the sediment trap efficiency and flow losses. The findings of the current research indicate that the maximum efficiency of sediment trap is different depending on the angle of the vortex tube deployment angle and occurs in different Froude numbers, however, the angle of 60 degrees generally has the highest sediment trap efficiency between the test angles (60, 70, 80 and 90 degrees). Water losses also decrease with the increase in Froude numbers so that the maximum water loss is about 30% in the Froude number of 0.5 and the lowest is about 5.4% in the Froude number of 1.2.*

Keywords: *Vortex Tube, Sediment, Froude Ratio, Basin, Trap Efficiency, Flood Losses*

INTRODUCTION

There is a greater depth of water in the outer arc and the riverbed has become stable. Another reason for this is the movement of riverbed at the river curvature towards the inner arc that reduces the sediments concentration in the outer arc. Generally, the sediment transmission of the river to the basin and the transmission channel has many problems, for instance, their seizure in the channel reduces capacity and increase maintenance costs of the facilities (Mahtabi et al. 2015; Bigelow et al. 2016). Attempts are usually made to prevent the arrival of inlet sediment to the basin which moves in the riverbed, and among these methods, raising the level of basin floor, installing the walls of the floor, or submerged plates to remove sediment from the basin can be mentioned. Even by designing these structures and due to the fixed number of these structures, especially in the event of a large sediment flow, the possibility of the arrival of bed sediment into basins during flood times is definite. In the current study, the effect of split width and vortex tube deployment angle on the sediment trap efficiency, as well as the rate of flow losses, has been investigated by using the laboratory method. The impoundment angle is 45 degrees, and in this position and the impoundment angle, using sediment injection method on rigid substrate, the effect of different parameters of vortex tube design on the control and exit of the inlet sediment to the lateral basin in a 180-degree arc and mechanisms resulting from change of the tube parameters on the exit of the sediments by the tube from the basin, was studied. The flame used in this study has a 180-degree arc and a R / B ratio of 3 (central radius to channel width), it also has a width and height of 60 cm, a length of 8 m input channel and a length of 6 m output channel and an internal radius of 1.5 m and the external radius of 2.1 m. At 115 ° arc. The impoundment channel is 45 ° (impoundment angle to the main channel) and 20 cm width. Subsequently, the issues such as the ratio of the vortex tube width to the trap efficiency, the deployment angle, and the flow loss rate by the tube, are examined. These include:In addition to Ahmed's study, the diameter of the vortex tube is approximately equal to the depth of flow (flow depth in the number of Froude is 0.8). Also, the two edges of the tube should be the same and the opening split tube is better to have the diameter of one sixth of the tube environment. Connsman and Alberston, in examining the shape of the vortex tube at the exit of channel sediments, found that in the design of vortex sediment, the efficiency will be higher if the two edges of the tube are on the same level. They also came to the conclusion that in a specific condition and due to the blocking of the tubes, the efficiency decreases sharply if the concentration of the sediment increases to a greater extent. The flow angle of the sediment is selected for flow rates of 45 to 65 degrees and it is believed that the yield for sediments is greater than 0.65 mm to 90%, and approximately 10% of the flow is used to drain sediment.

Research Method

Flume Design and manufacture

The Karun River is a river that most of which is in the plain and necessarily has many meanders along its length. This flume was made according to the arches of the Karun River and also in the conditions that the flow conditions and sediment control in arched spikes, can be checked. The present laboratory flume was designed, implemented and built in the sediment laboratory of Khuzestan Water and Power Organization which is made up of several components with the specifications given in Table 1. A view of the laboratory flume and related equipment is also shown in Fig. 1.

Table 1: Laboratory Flume Specifications

Arc Angle (0)	Channel Height (m)	Radius Curvature of Arc Width Ratio	Channel Width (m)	Arc Length (m)		Curvature Radius	Output Channel Length (m)	Input Channel Length (m)
				External	Internal			
180	0.6	3	0.6	6.6	4.7	1.8	4	6

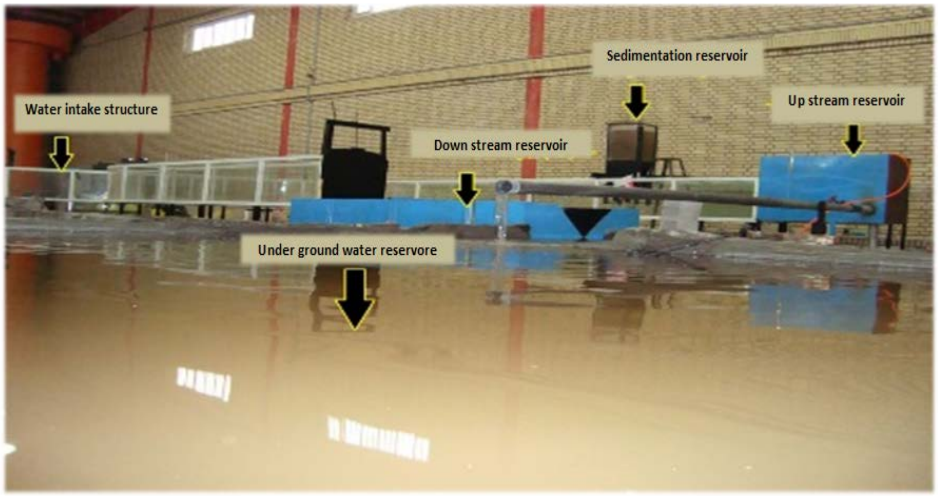

Figure 1 - A View of the Laboratory Flume and Related Equipment

Different design stages of flume and laboratory equipment

Flume Installation

The floor plan of the laboratory was accurately taken at this stage with all the points of entry and exit of water and control valves using the New Plane Camera. Afterwards, the foundation of the laboratory floor was designed with an arctic flame by considering the position of the flume on the bed.

- **Flume body**

Flume dimensions are selected based on the depth, length and height of the test, as well as the available space (Van Gent 2015). Laboratory flume is a rectangular channel with dimensions of 18 m length, 0.6 m width and 0.6 m height. The maximum flow into the channel is about 18 liters per second. The flume body is located at a height of 0.6 meters from the ground. For fabrication of metal frame, 50 mm cans and 30 × 30 mm angle in order to maintain resistance to water volume. Specific materials were used in the construction of the body of the model to achieve the accuracy of the experiments' results. The flame is made of 6 mm transparent glass to reduce the wall roughening effect and the hydraulic phenomena can be visible in the enclosure. The flume is also made of 3 mm foil, as shown Fig. 2.

Figure 2 - Laboratory Flume Body

In order to calm the flow of water, the length of the entrance channel was 6 meters (more than 10-12 times the channel width). Moreover, a relaxant at the beginning of the channel has also been used up to ensure calm flow.

- **Impoundment Channel**

The impoundment channel was made of a transparent glass 6 mm thickness. The lower edge of the side nozzle with a θ = 45 θ angle was carefully cut, and an external arc was installed at ˚115 = φ. The length of the channel was 2 meters and the split of the floor was zero. The width of the basin was also selected according to the previous researchers' advice. The width of the basin was 0.3 times the width of the main channel, Rezvan (1989). Furthermore, the results of the research of Inldkoper et al. (1975), have also indicated that if the ratio of the basin width to the main channel width is between 0.12 and 0.5, the change of this ratio is not effective in the ratio of high deviation rates. Therefore, the value of 0.34 for the ratio of the channel width to the main channel was used in this research, and hence, the width of the channel was 20 cm.

- **Gate Design**

A gate in the outlet side is needed in order to adjust the height of water required in the channel as well as the channel flow. Therefore, the metal gate was designed using a sheet and a controller bolt that easily adjusted the height in the model.

- **Stilling Basin**

To measure the flow at the channel entrance, a 90-degree triangular spillway was used that will be discussed in more detail on how spillway design method will proceed. To facilitate the flow of water through the spillway and to decontaminate excess water, the baffle was designed and built, and it was placed at the beginning of the flume on the tank floor and on the inlet tube to the reservoir. The tank has a length of 1m, a width of 1.5 m, and a height of 1 m, which is carried by a submerged pump to the reservoir in the water supply tank, supplied by the tubes, fittings and valves, and in this way, the reservoir recharges the flume first, Moreover, a relaxing network and a compressed-straw slab were used to calm down the flow of water before entering the input channel.

- **Ground Water Reservoir**

The 4 x 4.5 m meter square cube reservoir was designed and built to meet the required capacity of 14000 liters in order to supply water, and in order to establish a water supply cycle, a rectangular canal with a size of 10 × 1 × 0.6 meters and a capacity of 6000 liters was constructed. that in addition to providing water, the task was to transmit water from the intake to the pumping station. At the beginning of this, another square reservoir with a size of 2 × 2 × 0.6 m was designed and constructed to collect the flow and sediments of the outlet from the side water jet and to measure the flow through the triangular spillway in it.

- **Design and Calibrate Triangular Spillway**

The sharp edges of the triangular spillways, known as *V* spillway, are symmetrically arranged in a plane perpendicular to the sides and bottom of the channel (Bijankhan & Ferro, 2017; Musavi-Jahromi et al. 2016). It has a higher sensitivity to low altitude in the low flow due to the relatively smaller cross-section, and therefore they are more accurate in measuring low flow compared to rectangular spillways. Therefore, in laboratory work, triangular spillways are used more.

Provide Required Sediment

Using river sediment was the best action, hence sediments were prepared for testing by preparing these sediments from the river and carrying them to the laboratory, and then leaching them to flow additional soils. It is worth mentioning that these sediments have an average diameter of 0.5 mm and a perfectly uniform density of 2.65. Sediments were continuously injected by a sediment injection device at a constant rate of 1510 cc / min (about 4 kg / min or 67 g / s) from the beginning of the arc into the stream in experiments.

Eddy Tube Preparation

PVC tubes were used to make eddy tubes. This tube has a diameter of 6 cm, on which grooves of different widths (6, 9, 12 and 15 mm) were created. To install the tube at the bottom of the channel, a space of 40 cm from the bottom of the basin was cut to a 15 cm (15 cm) free space in the basin to allow the eddy tube to be placed at any desired angle below it. Then, by attaching the tube to the bottom of the channel, two Plexiglas plate were used that were cut to the angle of the tube.

Experiments

To perform the test, first the pump was switched on and the water flowed into the input reservoir, and it entered the flume entrance channel after entering the 90° spillway. In this way, the inlet flow to the flume was measured by this spillway. It should be noted that a drain tap was installed in the inlet reservoir, which was used in order to accurately adjust the flow rate. In this case, the input of the channel was equal to 18 liters per second for all experiments, and considering the fact that five ratios of impoundment were tested, four drainage tests were performed totally. Impoundment rates were 5.4, 6.3, 7.2, 8.1, and 8.5 liters per second, and with a ratio of 30, 35, 40, 45, and 47 percent respectively.

- **Sediment Control Experiments**

Therefore, sediment injection method on rigid substrate was used. Using this technique, it is possible to detect and track the deposition of sediments in the arc, the formation of the bed topography, the mechanism of the sediments entry into the basin, and the mechanisms for changing the parameters of the vortex tube on the exit of inlet sediments to the basin. For this purpose, the bottom of the channel was stained with powder paint (white spray) in order to see the sediment movements during the test.

Construction and Design of the Sediment Injection Machine

Sediment injection method was used and, it was accompanied by sediment injection in rigid bedding as the result of the designed experiments. Therefore, it was necessary to design and construct a sediment injection system that could uniformly inject the sediments at a fixed rate across the channel. The system was tested after its design, and the result was satisfactory. Table 2 presents hydraulic flow characteristics in sediment control experiments.

Table 2 - Hydraulic Flow Characteristics in Sediment Control Experiments

The Water Height in the Arch Upstream Channel hm (m)	Stream Flow Qm (I/S)	Medium Speed in the Main Channel Vm (m/s)	Flow Diversion (Qm/Qd)-Qr	Froude number in the Upstream Channel Fr
0.08	18	0.375	0.47-0.3	0.42

The sediment injection rate was equal to the load carrying power in the straight channel upstream of the arc. Consequently, due to the constant flow rate and hence the number of flow losses in the main channel in all experiments, a sediment injection rate was used for all experiments. According to the experiments' results, the sediment injection was obtained at 1510 cubic centimeters per minute (about 4 kg / min or 67 g / s)

Data Analysis

Method

The main purpose of the construction is to study the effect of different parameters of the vortex tube design on the sediment trap efficiency in lateral basins in the 180-degree arc of the rivers on the scouring of the nose. To achieve this, several experiments were carried out on a physical model.All experiments were carried out in an 18-meter flume, 0.6 m width and 0.6 m height with a zero split in a model that was designed and implemented by the researcher and colleagues in the Hydrological Laboratory of Khuzestan Water and Resources Organization. Tubes used in this model are made of PVC. At the beginning of the input channel, which is considered to be 6 meters in length, a compressed-straw slab is used to allow a tranquil flow. Moreover, a gate is located at the bottom of the outlet channel and basin in order to control the flow depth in the flume and the basin. Also, for measuring the flow during trials, a triangular weir was used. The flow of water enters a basin with a width of 1.25 meters, a length of 2.5 meters and a height of 0.8 meters after passing through the gate and afterwards, it enters a 14,000-liters reservoir, and then the flow of water is flown by a 3-inch floating pump into the flume's primary reservoir with a length of 1.5 m, a width of 1 m, and a height 1.5 m. and then passes through a 90-degree triangular weir. The flow of water enters a flume after being measured by a piezometer which is embedded next to it, and it enters into the tested area after passing through the compressed-straw slab and tranquil flow, then it is controlled by the main channel and the basin gates, at the bottom of the flume.

Effect of Vortex Tube Split Width Ratio on Sediment Trap Efficiency

Due to the increase in tube opening, the amount of water entering the vortex tube increases in a way that it transports more sediment to the inside of the tube and increases the sediment trap efficiency. It should be noted that the percentage of increase in trap efficiency is different from that of increase in the split width at different angles and Froude.

Effect of Vortex Tube Deployment Angle on Sediment Trap Efficiency

The effect of vortex tube deployment angle on sediment trap efficiency is significant from two perspectives. First, result of the trapping efficiency and also the loss of water is higher due to the increase in the cross-sectional openness of the tube to the flow and the move from a 90-degree angle to a 60-degree angle, the. In this article, we investigated four angular position of the vortex tube with four sections of the split width to tube diameter under 5 different impoundment ratios. The results are as follows:

- **Split Width Ratio to 10% Tube Diameter**

As seen in Fig. 3, in less than 0.6 Froude numbers (Fr), the best deployment angle of the tube in which the trap efficiency is maximum, the angle is 70 degrees. After the Froude number of 0.6, the best vortex tube deployment angle is 60 degrees. Generally, the lowest efficiency is related to the angle of 90 ° and the highest efficiency is at a 60 ° angle in the ratio of 10% split width.

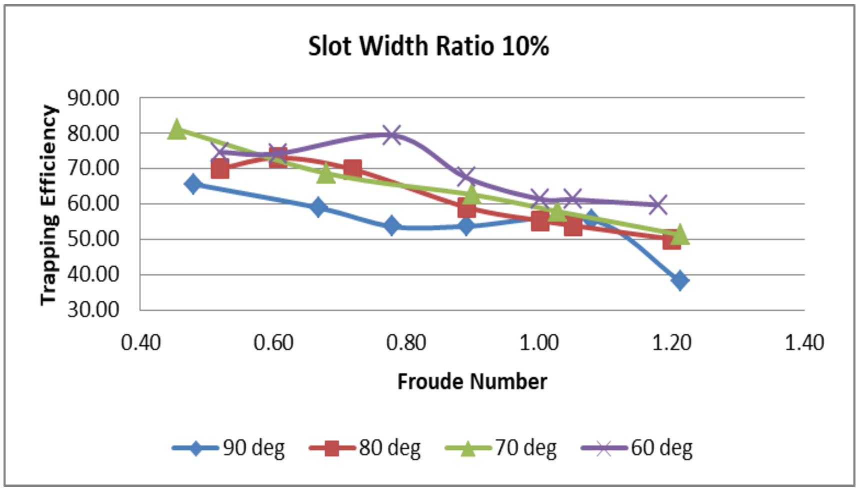

Figure 3 - The Effect of Vortex Tube Deployment Angle and the Stream flow Close to the Tube on the Sediment Trap Efficiency in the Split Width to Tube Diameter (T/D) of 10%

- **Split Width Ratio to Tube Diameter of 15%**

In this ratio, the split width is observed. In a Froude number of less than about 0.6, the best trap efficiency occurred at an angle of 70 degrees, like the split width ratio of 10%. The best deployment angle was 80 degrees in the Froude number of 0.6-0.7, and the best trap efficiency was 60 degrees in the Froude number of above 0.7.

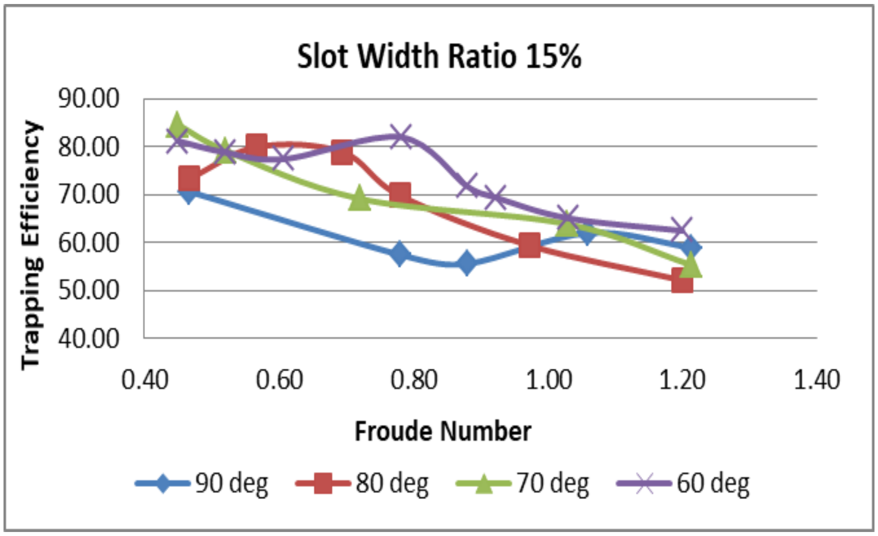

Figure 4 - The Effect of Vortex Tube Deployment Angle and the Streamflow Close to the Tube on the Sediment Trap Efficiency in the Split Width to Tube Diameter (T/D) of 15%

- **Split Width Ratio to Tube Diameter of 20%**

Like the width of previous ones in a Froude number of less than about 0.6, the best trap efficiency occurred at an angle of 70 degrees in this split width ratio. The best deployment angle was 80 degrees in the Froude number of 0.6-0.7, and the best trap efficiency was 60 degrees in the Froude number of above 0.7. It should be noted that in Froude number of greater than 1

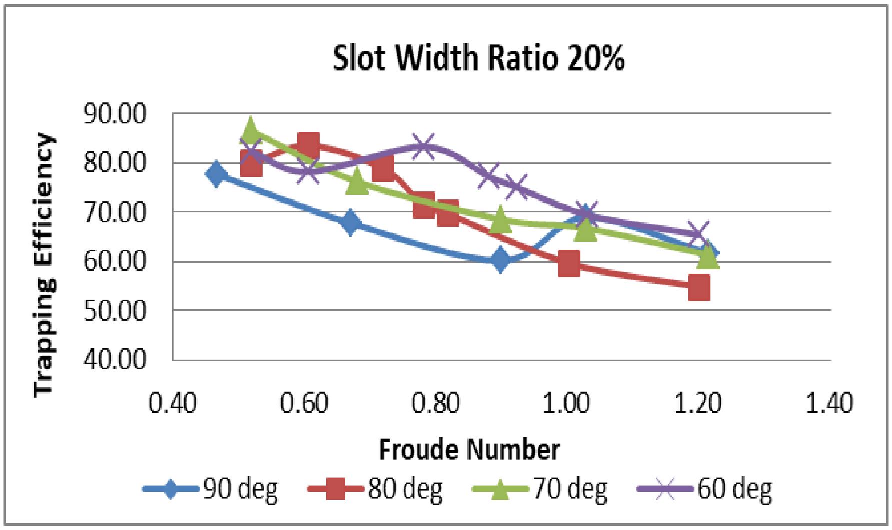

Figure 5 - The Effect of Vortex Tube Deployment Angle and the Streamflow Close to the Tube on the Sediment Trap Efficiency in the Split Width to Tube Diameter (T/D) of 20%

angle of 90 degrees, there is a better efficiency compared to the previous split widths, so that in Froude number of about 1.05, the trap efficiency is approximately equal to the trap efficiency of 60 degrees.

- **Split Width Ratio to Tube Diameter of 25%**

In this ratio, the split width has the best efficiency at less than 0.6 degrees Froude and of 70 degrees, and the vortex tube has the best efficiency at 80 degrees from 0.6-0.75 Froude numbers and in the lower rises, the best angle is 60 degrees. It should be noted that in this split width ratio, the trap efficiency of the tube with a 90-degree angle has been significant in the critical Froude.

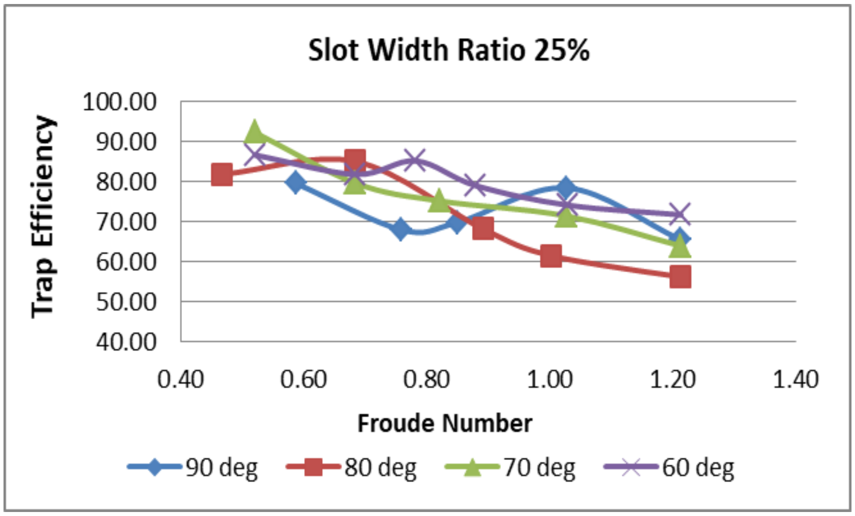

Figure 6 - The Effect of Vortex Tube Deployment Angle and the Streamflow Close to the Tube on the Sediment Trap Efficiency in the Split Width to Tube Diameter (T/D) of 25%

Flow Losses by Vortex Tube

Generally, the amount of water loss decreases with increase in the Froude number. Moreover, the water losses' percentage increases with increase in the split width. Under the same circumstances, the lowest water losses in the vortex tube are associated with a 90-degree angle and the highest losses are associated with the tube at a 60-degree angle

- **Effect of Hydraulic Flow Conditions on the Percentage of Flow Losses by Tube**

it was necessary to design experiments in order to investigate the effect of flow hydraulic conditions on trap efficiency, so that the effect of the flow hydraulic conditions on the tube trap efficiency and the percentage of flow losses by the tube can be clearly demonstrated. According to the dimensional analysis described above, the Froude number was obtained as a representative of the hydraulic conditions. As the Froude number increases, the flow that is near the outlet vortex tube decreases which can be affected by two factors, one with an increase in the flow velocity (for a constant flow that reduces depth) and the other by increasing the flow (which, due to constant velocity, increases the depth, or vice versa). In each of the above-mentioned instances, the increase in velocity causes the hydrodynamic pressure of the flow to be reduced near the tube, and also by the decrease in the depth, the static water pressure on the tube decreases which reduces the amount of water outlet from the tube. (Only 90-degrees are shown in Figure 7 due to space constraints).

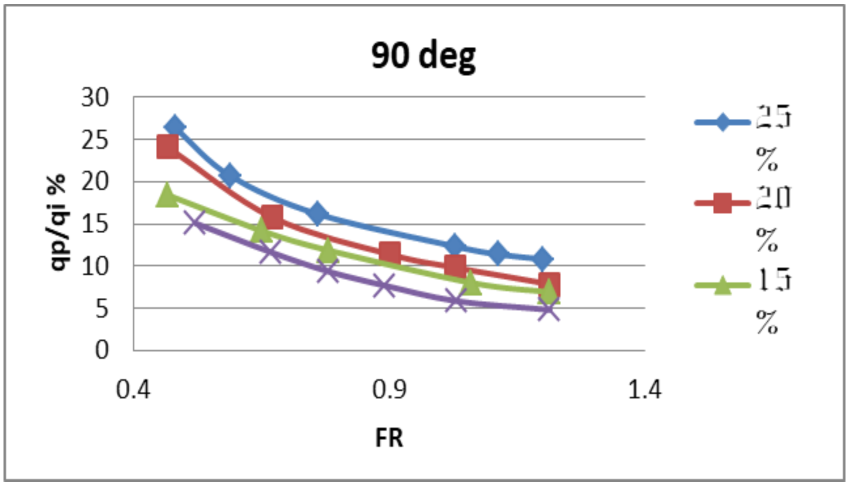

Figure 7- The Effect of the Froude Number on the Flow Loss Percentage by the Vortex Tube with a 90-degree Angle in the Ratio of Split Width to Tube Diameter

- **Investigating the Vortex Tube Split Width on the Flow Loss Percentage by Tube**

The flow rate of the outlet vortex tube increases significantly as a result of an increase in the cross-sectional area of the tube opening against the flow. The lowest flow of losses was in the ratio of 10% split width to tube diameter, and the highest losses were in the ratio of 25%. This condition increases with increase percentage of openness in all experiments. Generally, although the percentage of flow losses with the increase in the width of the openness increases in relation to the openings width, this increase varies in different angles and different Froude numbers.

- **Investigating the Effect of Vortex Tube Deploying Angle on the Flow Loss Rate**

In order to investigate the effect of vortex tube deploying angle on the flow loss rate, experiments were carried out at 4 angles of 90, 80, 70 and 60 degrees. Each tube angle was tested with 5 impoundment ratios that according to the studies, by reducing the vortex tube deployment angle (from 90 degrees to 60 degrees), the percentage of water loss significantly increases which is due to increase in the level of openness to the logical flow. (Only 25% is displayed due to space constraints). (Figure 8).

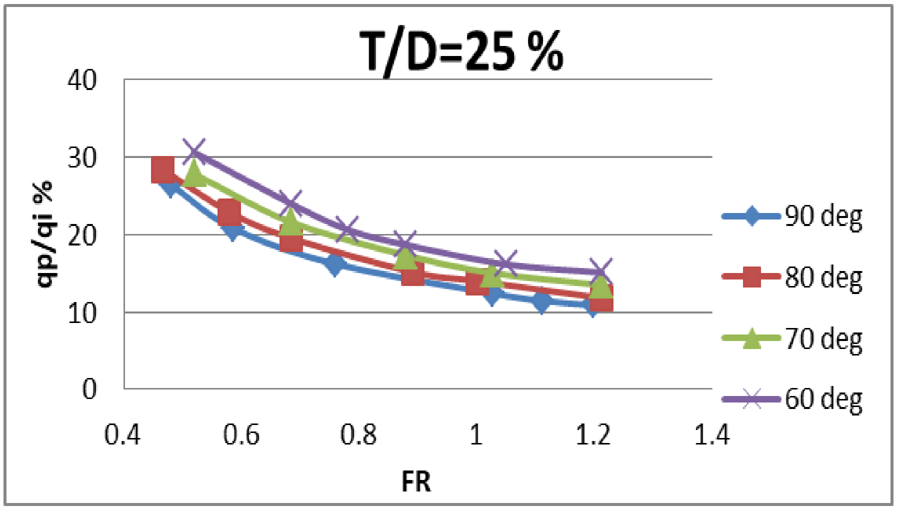

Figure 8 - The Effect of the Froude Number on the Flow Loss Percentage of the Vortex Tube in Four Tube Angles with a Split Width Ratio of 25%

Conclusion

The findings of this study can be presented as follows:

A. The Percentage of Flow Losses in the Vortex Tube

1. Increase in the number of Froude near the tube leads to significant reduction in the amount of flow from the outlet vortex tube (flow percent loss) according to the experiments,
2. Increase in tube opening ratio leads to increase in the percentage of flow losses.
3. By moving the tube installation angle of 90 degrees to the angle of 60 degrees, the percentage of flow loss increases, so that the minimum flow loss occurs in a tube with an installation angle of 90 degrees, and a maximum flow loss in the tube with an installation angle of 60 degrees.

B. Effect of impoundment ratio on the amount of inlet sediment to the basin

As the impoundment ratio increases, the amount of inlet sediment to the pond increases. However, this increase in inlet sediment occurs if the flow depth in the pond and the channel is equal in different experiments. As the constant impoundment ratio increases with the increase in the Froude of the basin to the channel Froude, the amount of inlet sediment to the basin increases and vice versa.

C. Trap efficiency

By increasing the split width ratio to tube diameter (in another term, the split width ratio to the average diameter of sediments), the sediment trap efficiency increases.

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