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Study of the rate of sediment trapping and water loss in the vortex tube structure at different placement angles

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Abstract: Unfamiliarity with sediment problems in the watershed has outdated a number of projects during their work, brought up heavy costs .Usually it is tried to prevent entering the sediment that moves as bed load in the rivers to the basin that methods such as increasing the basin bed level, mounting floor wall or submerged plates for removing sediment from the inlet, and desilting basin, using vortex tube include such methods. Since lots of variables are effective in sediment trapping and loss of vortex tube water, the aim of this study was to evaluate the performance of the vortex tube in vitro and in controlled discharge at four angles of 30, 45, 60 and 90 degrees in the flow path and using three gradation include: D_1 (particles passed the sieve 8 and remaining on the sieve 10), D_2 (particles passed the sieve 16 and remaining on the sieve 20) and D_3 (particles passed the sieve 20 and remaining on the sieve 30) and the ratio t:t/d the crack width on tube and d: tube diameter0.25. The results showed that the maximum sediment trap efficiency is related to the angle 45 and then60, but since the rate of water loss is higher at an angle of 45, it is recommended to use the angle 60. With increasing angle, water loss has initially increased and then decreased, so that the maximum water loss was obtained at an angle of 45 and the minimum at 90°.

Key words: Vortex tube; Trapping; Percent of orifice; Sedimentation; The Froude number

1. Introduction

It is usually tried to avoid the entry of sediment to basin which moves as bed load in the rivers, that some of the methods are as following: increasing the basin level balance, mounting bed walls or, submerged plates for removing sediment from the basin span, desilting basin and using vortex tube. Even by designing these structures and due to the constant number of the structures and variability of hydraulic conditions, particularly in times of flood that has a large amount of sedimentation, the possibility of entering sediment in times of flood to basin is certain. So it is essential to design simple and economical structures that can remove the bed sediment and return it to the river. Inattention to sedimentation entering basins resulted in transferring them into the facilities and creates lots of problems as a result of loading sedimentation or accumulating them in different parts. Transferable sedimentations largely depend on the amount of sediment in the catchment and river characteristics. While, in the parts of the transmission system, particularly in systems where the water is passed gravitationally, flow rate is low, so that the water is unable to hold material transferred in a suspended state, additional sediments are deposited in channels. It starts from the basin and spread gradually throughout the system. As a result of sedimentation channels are encountered and by rising channel bottom elevation, the free board is decreased and the water delivery capacity is reduced. That's why the sediment control in the inlet is very important. One of the new desilting methods of river flows is using vortex tube that is more economical due to the small size compared with conventional rectangular desilting basins, and can be continuously utilized. The sediment control method is created based on using vortex force and sediment gravity force. The desilteris used when the bed capacity concentration is high for continuous flushing of sediments and its main part is formed by the tube or horizontal channel which is embedded within and under the bottom of the channel and transfer the sediments near the bed outside. Then the flow is discharged into a desilting basin, river or drainage. Fig.1 shows a view of the vortex desilter.

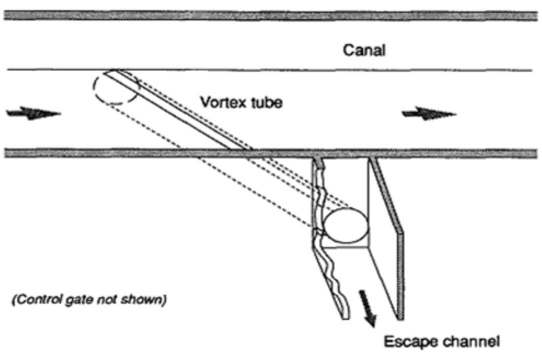

Fig. 1: View of vortex tube

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Vertex tube can be placed close to catchment facilities or far enough from the downstream of facilities where sediment distribution is reached an equilibrium state. The idea of using vortex tube under appropriate circumstances has some advantages compared with various sediment control methods and is more efficient, since all work is done in a totally controlled level. In this structure, the water enters a vertex tube under an angle and creates a strong vortex and eddy current will be created. Flow in tube is controlled by a valve in the downstream, and is discharged from there into a channel. Vortex desilter shows a high efficiency when the suspended load is low and bed load is considerable. However, good efficiency is recorded for this even when the suspended load is high and dominant .Parshal (1951) can be seen as the innovator of this plan .Blench (1952) stated that vortex desilting is used for large channels with flow loading capacity m^3/s280 1000 ft^3/s. Robinson (1962) and Ahmad (1962) offered a Froude number $\left(\frac{v}{\sqrt{gh}}\right)$0.8 in the channel. Parshal (1952) observed that the lowest efficiency occurs when the Froude number is 1. Atkinson (1994) by researches on the angle of tube position (θ) and ration of tube gap width with a diameter of ($\frac{t}{d}$), showed that the tangential velocity in the tube is maximum when the tube has a 90 degree angle to the flow path or near it and when the ratio of ($\frac{t}{d}$) is low (About 0.3 or less).

NikMehr et al. (2010) examined the factors influencing the trapping of vortex tube such as tangential velocity, approaching speed and energy loss, with controlled and uncontrolled (free) discharge in irrigation canals. Their research was done with 4 relative width of the entrance slit of sediments in diameter (t/d) 0.15, 0.2, 0.25 and 0.3 and influenced by4 controlled discharge flow rate 2.5%, 5%, 7.5 % and 10%. The results showed that when the ratio of the entrance slit of sediments to tube diameter is0.15, parameters effective in sediment trapping are in controlled and uncontrolled states and in optimal conditions. Muazzen et al. (2006), by building the experimental model attempted to examine the effect of variables such as tube diameter and angle of the tube placement under different hydraulic conditions. The results showed that the trapping efficiency depends on the Froude number, so that increasing Froude number, the trapping efficiency is firstly increased and then decreased. The maximum trapping efficiency was in the Froude number 0.6. The rate of water loss is decreased by increasing Froude number so that the maximum loss was8.5% for the Froude number 2.0 and the lowest rate was 4% for the Froude number 1.09. Water loss amount was maximum 7% for Froude number 0.6 to 0.8.

Due to the fact that many variables are effective in the sediment trapping and water loss in vortex tubes, this study aimed to evaluate the performance of vortex tubes in vitro and controlled discharge in four angles of 30, 45, 60 and 90 using three different gradations with the ratio t/d 0.25(t: gap width on the tube and d: tube diameter).

2. Materials and methods

This research tests were conducted in laboratory of Ahwaz Islamic Azad University, located in Chonibeh to evaluate the effect of gradation on trap efficiency in the vortex tube structures with different angles. The practical steps of this test were planned by installation of vortex tube with a 2 inches diameter and orifice to diameter ratio (t/d) 0.25 at the bottom of the flume with four different angles (30, 45, 60 and 90) and under four different discharges and three different gradations D_1, D_2 and D_3 in a flume with a length of 13 m, width 50 cm, depth 60 cm. For hydraulic experiments, first the flow path was completely clean to make the flow of water in the flume visible and clear, and then using a water tankers, ground reservoir was dewatered. After the main flume pump was turned on after dearation and after a while ensured that the flow overflowed from the air reservoir, the water inlet valve has been opened to flume to let water into the main canal. Inlet valve was opened so to provide the average desired discharge. After a while, the discharge through the 13-meter flume at the downstream entered the basin, and its amount was measured by triangle spillway with a 60° angle .The output flow from the slotted pipe that was transferred to a ground reservoir through a 3.5-meter flume was measured by a triangular spillway with the apex angle of 90°. Fig.2 shows a view of the 90 degrees spillway.

Fig. 2: 90 degrees spillway of measuring output discharge from vortex tube

The sum of two discharges is the discharge entering the flume that if it is different from the desired discharge, inlet valve is a little open or closed to make the discharge equal to the desired one. To ensure the constant flow, discharge was again measured in the downstream of the flume and the passed discharge from the basin. In the same conditions, flow depth at the upstream, beginning, end, and downstream of the vortex tube was realized by rulers installed in the body of the flume as well as depth gauge.

Due to the limitations of the laboratory and the discharge of pump, experiments were done with maximum discharge 20 Lit/S and at least 10 Lit/S. In this study, 4 input discharges 10, 13, 15 and 20 liters per second with the ratio 0.25 t/d was planned, and diversion discharge and water depth values were measured at the points mentioned earlier. To slow down the flow of pump into the flume, a lattice pump was used to amortize the energy. Sediments used in this experiment consist of three gradation include: D_1 (particles passed through sieve 8 and remaining on the sieve 10), D_2 (particles passed through sieve 16 and remaining on the sieve 20) and D_3(particles passed through sieve20 and remaining on the sieve 30), that was used in a layer with a thickness of 3 cm for experiments. To measure the diversion sediments, at the end of each test, a lattice plate was used with a diameter less than the diameter of particles. (Fig.3) Then dry sediments and were weighted by digital balance in laboratory conditions.

To measure the past sediment (which was not trapped), the deposited sediments on the bed of the main channel and the sediments entered the system were collected at the end of each test and then dry sediments were weighted by digital balance in laboratory conditions.

Fig. 3: Discharge output tube and diversion sediment and collecting sediment

3. Discussion and conclusion

Generally, in performed tests, the deviation discharge, the output and total discharge were weighted in liters per second and sediment diversion (trapped), the sediments entering the system and remaining sediments were measured in kilograms which results are given in Table 1 to 4.

Table 1: Results of diversion discharge and sediment for30 degrees angle

Water losses percentage R %	Sedimentation rate of diversion (Te%)	Sediment transport Weight Qst (kg)	Sediment Terminal Weight Qso (kg)	Weight sediment diversion Qsi (kg)	total discharge Qt (lit/s)	Terminal discharge Qo (lit/s)	diversion discharge Qi (lit/s)	Sieve	Froude number(Fr)	ROW
13.53	75.36	2.6	0.64	1.96	10	8.65	1.35	10		1
12.96	91.17	4.52	0.40	4.13	10	8.70	1.30	20	0.43	2
14.12	94.67	6.49	0.35	6.15	10	8.59	1.41	30		3
11.33	78.93	5.28	1.11	4.17	13	11.53	1.47	10		4
10.86	93.87	9.31	0.57	8.74	13	11.59	1.41	20	0.56	5
11.81	96.68	12.33	0.41	11.93	13	11.47	1.53	30		6
10.23	74.69	9.40	2.38	7.02	15	13.47	1.53	10		7
9.82	89.56	13.08	1.36	11.71	15	13.53	1.48	20	0.65	8
10.23	91.55	16.28	1.37	14.90	15	13.47	1.54	30		9
8.32	72.96	13.13	3.55	9.58	20	18.34	1.66	10		10
7.96	87.55	19.11	2.38	16.74	20	18.40	1.60	20	0.87	11
8.32	89.32	19.40	2.07	17.32	20	18.34	1.66	30		12
10.55	86.36	Average								

Table 2: Results of diversion discharge and sediment for45 degrees angle

Water losses percentage (R %)	Sedimentation rate of diversion (Te%)	Sediment transport Weight Qst (kg)	Sediment Terminal Weight Qso (kg)	Weight sediment diversion Qsi (kg)	total discharge Qt (lit/s)	Terminal discharge Qo (lit/s)	diversion discharge Qi (lit/s)	Sieve	Froude number (Fr)	ROW
16.64	83.05	3.21	0.54	2.67	10	4.34	1.64	10	0.43	1
15.60	96.28	6.41	0.24	6.17	10	8.40	1.60	20		2
18.00	97.47	8.30	0.21	8.08	10	8.20	1.80	30		3
12.80	85.64	8.77	1.26	7.50	13	11.34	1.66	10	0.56	4
12.30	97.91	12.26	0.26	12	13	11.40	1.60	20		5
14.38	98.86	12.25	0.14	12.11	13	11.13	1.87	30		6
12.00	81.74	11.72	2.14	9.58	15	13.20	1.80	10	0.65	7
11.54	95.69	12.80	0.55	12.25	15	13.27	1.73	20		8
11.99	96.60	17.67	0.60	17.08	15	13.20	1.80	30		9
9.70	80.42	20.30	3.97	16.32	20	18.06	1.94	10		10

9.70	94.39	22.35	1.25	21.10	20	18.06	1.94	20	0.87	11
10.07	96.23	22.35	0.84	21.52	20	18.00	2.01	30		12
12.93	92.01	Average								

Table 3: Results of diversion discharge and sediment for60 degrees angle

Water losses percentage (R %)	Sediment ation rate of diversion (Te%)	Sediment transport Weight Qst (kg)	Sediment Terminal Weight Qso (kg)	Weight sediment diversion Qsi (kg)	total discharge Qt (lit/s)	Terminal discharge Qo (lit/s)	diversion discharge Qi (lit/s)	Sieve	Froude number (Fr)	ROW
12.96	81.51	2.83	0.52	2.31	10	8.70	1.30	10	0.43	1
13.53	94.48	6.82	0.38	6.44	10	8.65	1.35	20		2
14.73	96.65	7.95	0.83	7.82	10	8.53	1.47	30		3
10.86	84.92	8.70	1.31	7.39	13	11.59	1.41	10	0.56	4
11.33	97.58	12.88	0.58	12.30	13	11.53	1.47	20		5
11.81	98.35	7.95	0.26	15.63	13	11.47	1.54	30		6
9.82	80.82	12.03	2.30	9.72	15	13.53	1.47	10	0.65	7
9.82	95.41	13.15	0.60	12.55	15	13.53	1.47	20		8
10.66	95.43	17.39	0.79	12.60	15	13.40	1.60	30		9
8.00	80.12	20.22	4.01	16.20	20	18.40	1.60	10	0.87	10
8.32	94.24	21.62	1.24	20.37	20	18.34	1.66	20		11
8.65	95.21	22.08	1.06	21.15	20	18.27	1.73	30		12
10.87	91.23	Average								

Table 4: Results of diversion discharge and sediment for60 degrees angle

Water losses percentage (R %)	Sediment ation rate of diversion (Te%)	Sediment transport Weight Qst (kg)	Sedimen t Terminal Weight Qso (kg)	Weight sediment diversion Qsi (kg)	total discharge Qt (lit/s)	Terminal discharge Qo (lit/s)	diversion discharge Qi (lit/s)	Sieve	Froude number (Fr)	ROW
9.34	76.15	1.50	0.36	1.14	10	9.07	0.93	10	0.43	1
9.34	89.65	3.90	0.40	3.50	10	9.07	0.93	20		2
9.81	93.84	4.95	0.31	4.78	10	9.02	0.98	30		3
7.92	79.99	5.59	1.11	4.47	13	11.97	1.03	10	0.56	4
7.55	94.64	6.33	0.34	5.99	13	12.02	0.98	20		5
8.31	96.44	9.33	0.32	8.99	13	11.92	1.08	30		6
7.20	74.10	7.87	2.04	5.83	15	13.92	1.08	10	0.65	7
7.20	85.65	12.22	1.75	10.47	15	13.92	1.08	20		8
7.54	90.64	14.36	1.34	13.01	15	13.87	1.13	30		9
5.93	70.16	14.52	4.33	10.18	20	18.82	1.18	10	0.87	10
6.20	82.88	18.20	3.11	15.09	20	18.76	1.24	20		11
6.48	88.61	17.89	2.04	15.85	20	18.70	1.30	30		12
7.73	85.22	Average								

Examining the results presented in the table above, by comparing the amount of trapped sediment at different angles, it can be said that 45°angle with an average rate of trapping 92.01% and 60°with an average trapping of91.23% have the highest efficiency. The lowest efficiency is related to the angle of 90° with an average amount of trapping 85.22%. The maximum efficiency in this index is related to the angle 45° and gradation D_3 with 98.86% and the minimum efficiency is70.16% which is related to the angle 90 and gradation D_1. The results of these tests indicate that regardless of gradation (mean of different gradations), the lowest water loss is related to the angle 90° with a rate of 7.73% and the maximum water loss is related to the 45 degree angle with a rate of 12.93%. Also according to Fig.1, the results show that increasing the angle, water loss has initially increased and then decreased, so that in gradation D_3 and the angle 45°, the maximum water loss was 13.6%and the minimum water loss was at 90°and the rate of 7.57%.The results of the graphs(2) to (5) also show that increasing the flow Froude number, water loss in the vortex tube decreases which is due to the reduced water depth by increasing the Froude number on the vortex tube. The result is consistent with the results of Muazeniand Shafaei (2003), DashtBozorg and Morteza (2013).

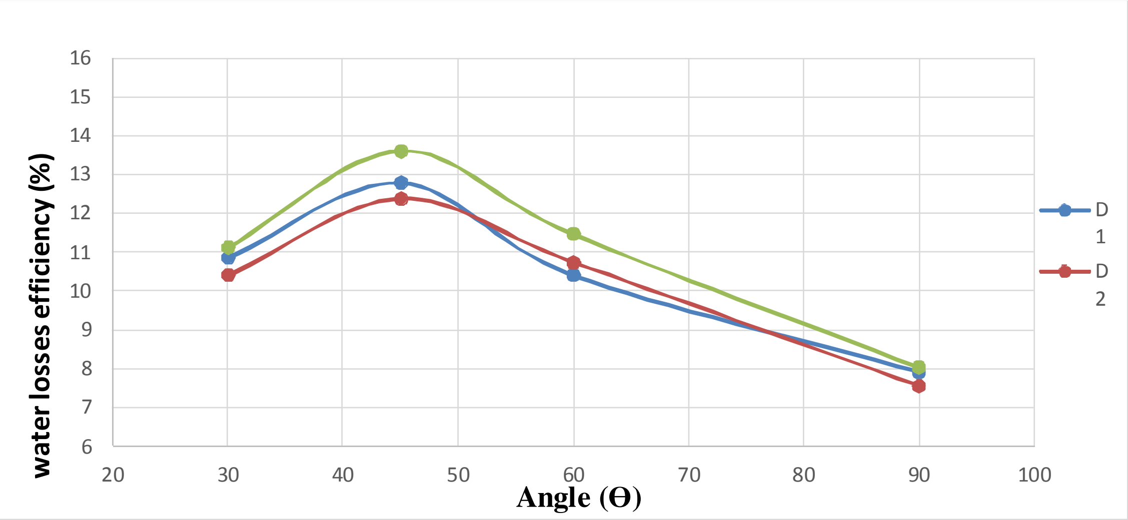

Fig. 1: Impact of angle on the water loss

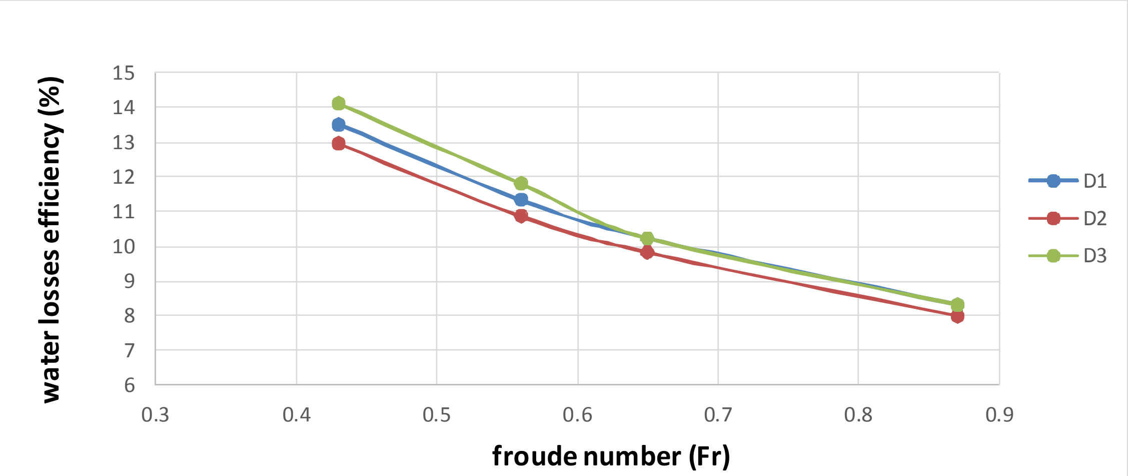

Fig. 2: Impact of Froude number on vortex tube water loss in three gradations and in conditions d = 2in and Θ=30

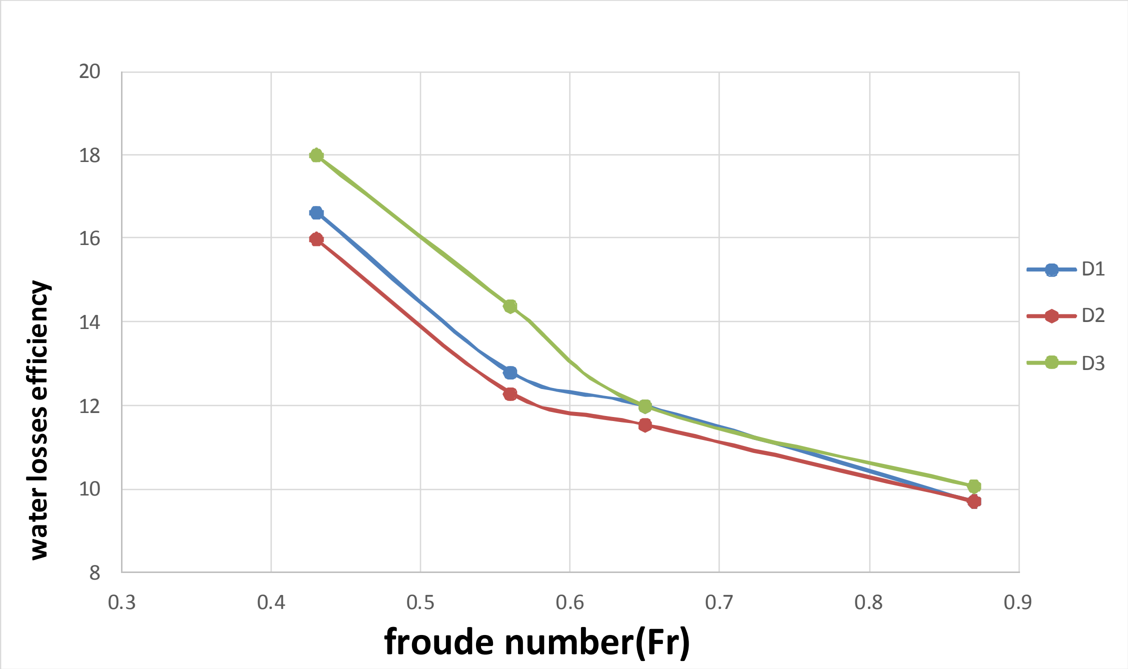

Fig. 3: Impact of Froude number on vortex tube water loss in three gradations and in conditions d = 2in and Θ=45

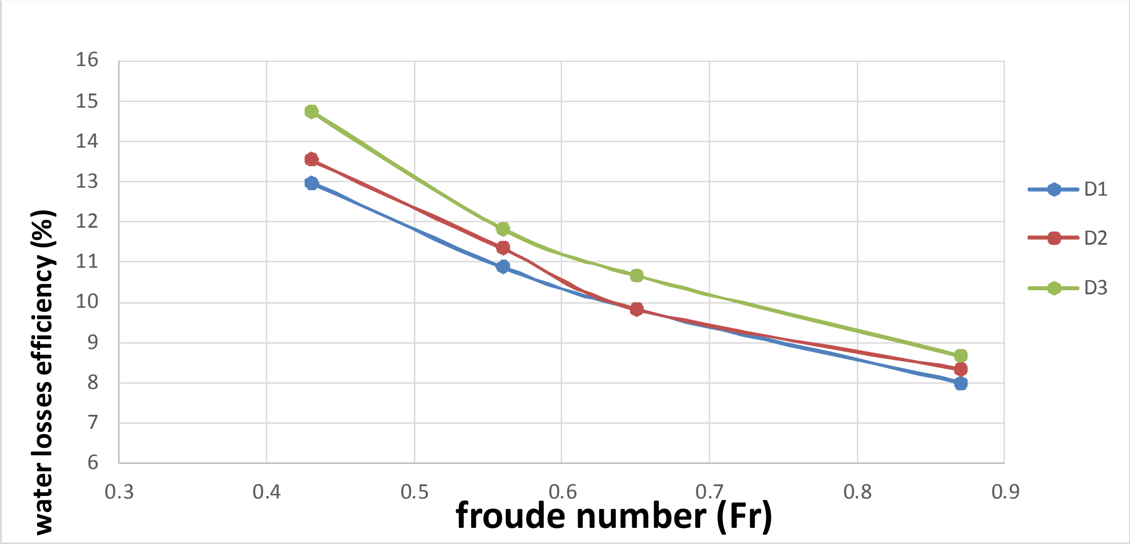

Fig. 4: Impact of Froude number on vortex tube water loss in three gradations and in conditions d = 2in and Θ=60

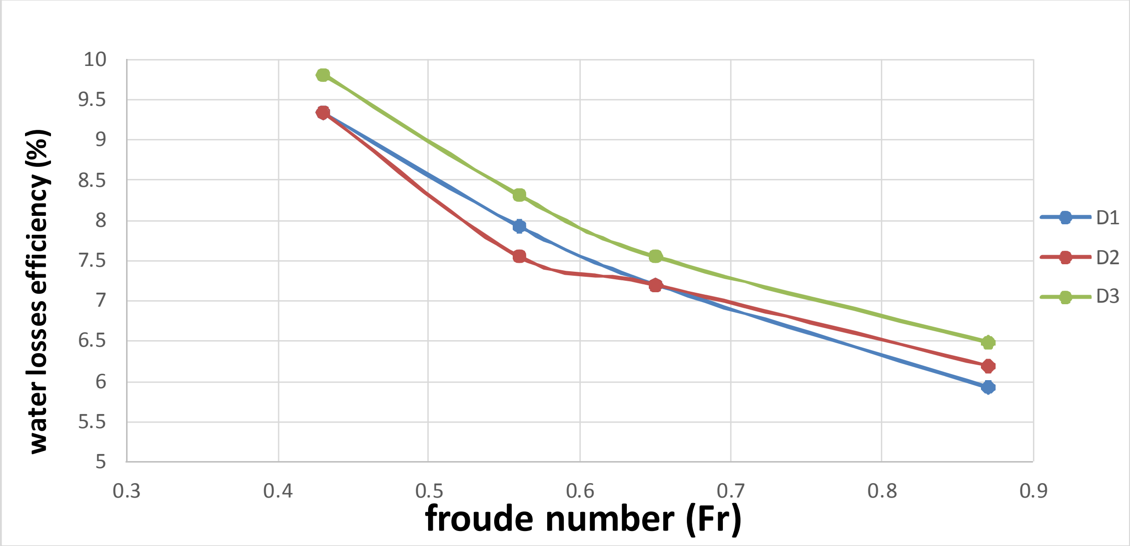

Fig. 5: Impact of Froude number on vortex tube water loss in three gradations and in conditions d = 2in and Θ=90

4. Conclusion

The results showed that the maximum sediment trap efficiency is related to the angle 45 and then60, but since the rate of water loss is higher at an angle of 45, it is recommended to use the angle 60. With increasing angle, water loss has initially increased and then decreased, so that the maximum water loss was obtained at an angle of 45 and the minimum at 90°.

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