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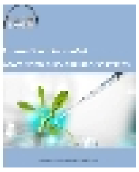

Gradation effect on sediment trapping efficiency in structures of vortex tube

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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Unfamiliarity with sediment problems in the watershed has outdated a number of projects during their work, brought up heavy costs .Usually it is tried to prevent entering the sediment that moves as bed load in the rivers to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 desalting 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 vortex tube in vitro and controlled discharge with four ratio of tube slit width to diameter (t/d), 0.15, 0.20, 0.25 and 3.0 and using three gradation include: D_1 (particles passing the sieve 8 and remaining on the sieve 10), D_2 (particles passing the sieve 16 and remaining on the sieve 20) and D_3 (particles passing the sieve 20 and remaining on the sieve 30) at an angle of 45 degrees with different discharges. The results showed that if the amount of water loss is not limiting criterion and a region is not facing with water shortage and water supply problems and prevention of the entry of sediment to the system is preferred to water supply, the more favorable option is t/d = 0.3, but if the water supply in a region is very important and there is essentially water shortage, a better option is t/d = 0.25.

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 flowis discharged into a desilting basin, river or drainage. Fig.1 shows a view of the vortex desilter.

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

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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.

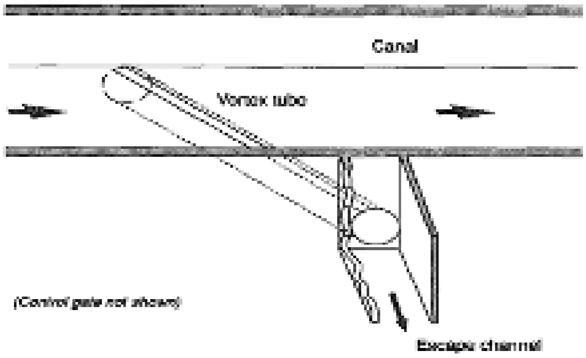

Fig. 1: View of vortex tube

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 ($\frac{v}{\sqrt{gh}}$)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.

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 vortex tube in vitro and controlled discharge with four ratio of tube slit width to diameter (t/d), 0.15, 0.20, 0.25 and 3.0 and using three gradation include: D_1 (particles passing the sieve 8 and remaining on the sieve 10), D_2 (particles passing the sieve 16 and remaining on the sieve 20) and D_3 (particles passing the sieve 20 and remaining on the sieve 30) at an angle of 45 degrees with different discharges.

2. Materials and methods

The experiments of this research was planned in the laboratory of Islamic Azad University of Ahvaz, located in Chanibeh to check the effect of orifice of vortex tube on sediment trap efficiency of different gradation in four t/d and four different discharges, in the flume with a length of 13 m, width of 50 cm, and depth of 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 deration 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, to evaluate the effect of orifice of the vortex tube with a tube diameter (t/d) in the sediment trap efficiency, 4 input discharges, 10, 13, 15 and 20 liters per second and with the ratio t/d equal to0.15, 0.2, 0.25 and 0.3, were planned and the amounts of diversion discharge and water depth was 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 the tests performed, the diversion, output and total discharge in liters per second and also diversion sediment (trapped), the sediments input to the system and remained sediments were measured in kilograms which results are given in Table 1 to 4.

Table 1: Results of discharge and sediment for (t/d) equal to 0.15

Row	Froude number (Fr)	Sieve	Qi Diversion discharge (L/S)	Qo Final discharge (L/S)	Qt Total discharge (L/S)	Qsi Diversion sediment weight (Kg)	Qso Final sediment weight (Kg)	Qst Total sediments (Kg)	Te% Percent of diversion sediments	we% Water loss percent
1	0.43	D1	0.93	9.06	10	0.72	0.45	1.18	61.68	9.34
2		D2	0.93	9.06	10	2 62	1.03	3.66	71.75	9.34
3		D3	0.98	9.01	10	4.23	1.53	5.77	73.37	9.81
4	0.56	D1	1.03	11.97	13	2. 32	1.23	3.55	65.34	7.92
5		D2	1.02	11.97	13	4 53	1.52	6. 06	74.79	7.83
6		D3	1.08	11.92	13	5.92	1. 77	7.69	76.98	8.3
7	0.65	D1	1.08	13.92	15	5.28	2.63	7.92	66.75	7.2
8		D2	1.08	13.92	15	8.63	2.73	11:36	75.98	7.2
9		D3	1.13	13.86	15	9.79	2.73	12:52	78.19	7.54
10	0.87	D1	1.18	18 81	20	5.02	3.25	8.32	60.71	5.92
11		D2	1.23	18.76	20	7.65	3.35	1 1:01	69.52	6.19
12		D3	1.29	18.7	20	10.7	4.52	15:23	70.29	6.48
Average									70.44	7.75

Table 2: Results of discharge and sediment for (t/d) equal to 0.20

Row	Froude number (Fr)	Sieve	Qi Diversion discharge (L/S)	Qo Final discharge (L/S)	Qt Total discharge (L/S)	Qsi Diversion sediment weight (Kg)	Qso Final sediment weight (Kg)	Qst Total sediments (Kg)	Te% Percent of diversion sediments	we% Water loss percent
1	0.43	D1	1.15	8.84	10	1.26	0.45	1.71	73.64	11.75
2		D2	1.29	8.70	10	4.80	0.69	5.49	87.53	12.96
3		D3	1.41	8.58	10	7.52	0.85	8.37	89.78	14.12
4	0.56	D1	1.47	11.52	13	4.80	1.25	6.06	79.28	11.33

5		D2	1.41	11.58	13	9.25	0.85	10.11	91.50	10.86
6		D3	1.53	11.46	13	10.19	0.69	10.89	93.63	11.80
7	0.65	D1	1.53	13.46	15	8.65	2.12	10.78	80.25	10.23
8		D2	1.47	13.52	15	12.97	1.01	13.99	92.75	9.82
9		D3	1.53	13.46	15	17.75	1.13	18.88	94.05	10.23
10	0.87	D1	1.54	18.45	20	10.65	4.79	15.44	68.97	7.78
11		D2	1.59	18.40	20	12.49	2.53	15.03	83.12	7.99
12		D3	1.66	18.33	20	16.10	2.14	18.24	88.24	8.32
Average									85.22	10.60

Table 3: Results of discharge and sediment for (t/d) equal to 0.25

Row	Froude number (Fr)	Sieve	Qi Diversion discharge (L/S)	Qo Final discharge (L/S)	Qt Total discharge (L/S)	Qsi Diversion sediment weight (Kg)	Qso Final sediment weight (Kg)	Qst Total sediments (Kg)	Te% Percent of diversion sediments	we% Water loss percent
1	0.43	D1	1.29	8.70	10	2.66	0.54	3.21	82.98	12.96
2		D2	1.35	8.64	10	4.17	0.33	4.50	92.65	13.53
3		D3	1.47	8.52	10	5.41	0.29	5.70	94.89	14.73
4	0.56	D1	1.41	11.58	13	7.50	1.53	9.03	83.05	10.86
5		D2	1.47	11.52	13	10.37	0.61	10.98	94.39	11.33
6		D3	1.53	11.46	13	12.10	0.50	12.60	96.01	11.80
7	0.65	D1	1.47	13.52	15	10.97	1.93	12.91	84.97	9.820
8		D2	1.47	13.52	15	14.97	0.78	15.76	95.02	9.820
9		D3	1.59	13.40	15	18.87	0.49	19.37	97.42	10.66
10	0.87	D1	1.60	18.39	20	16.32	3.97	20.29	80.42	7.99
11		D2	1.42	18.57	20	21.09	2.05	23.14	91.14	7.22
12		D3	1.73	18.26	20	21.51	1.56	23.07	93.23	8.65
Average									90.51	10.76

Table 4: Results of discharge and sediment for (t/d) equal to 0.3

Row	Froude number (Fr)	Sieve	Qi Diversion discharge (L/S)	Qo Final discharge (L/S)	Qt Total discharge (L/S)	Qsi Diversion sediment weight (Kg)	Qso Final sediment weight (Kg)	Qst Total sediments (Kg)	Te% Percent of diversion sediments	we% Water loss percent
1	0.43	D1	1.66	8.33	10	2.90	0.50	3.41	85.18	16.64
2		D2	1.59	8.40	10	4.81	0.38	5.19	92.58	15.99
3		D3	1.79	8.20	10	7.13	0.48	7.61	93.65	17.99
4	0.56	D1	1.66	11.33	13	7.33	1.03	8.36	87.67	12.80
5		D2	1.59	11.40	13	9.73	0.45	10.18	95.52	12.30
6		D3	1.76	11.23	13	13.47	0.37	13.84	97.31	13.53
7	0.65	D1	1.79	13.20	15	12.12	1.49	13.61	89.02	11.99
8		D2	1.73	13.26	15	13.95	0.60	14.55	95.86	11.54
9		D3	1.79	13.20	15	16.59	0.38	16.91	98.10	11.99
10	0.87	D1	1.94	18.05	20	17.84	3.84	21.68	82.28	9.70
11		D2	1.94	18.05	20	21.58	1.82	23.40	92.21	9.70
12		D3	2.01	17.98	20	21.87	1.28	23.16	94.45	10.07
Average									91.98	12.85

Reviewing the results presented in the table above, with the comparison of the amount of trapped sediment indifferent orifice ratios to the tube diameter, it can be said that t/d = 0.3, with an average rate of trapping 91.98% and t/d = 0.25 with an average trapping of 90.51%has the maximum efficiency. The minimum efficiency was for t/d=0.15 with the average value of trapping 70.44%. The highest efficiency in this index was related to t/d=0.3 and gradation $D_3$with 98.10% and the lowest efficiency related to t/d=0.15 and gradation D_1 with60.71%.Also the results of the Fig. 4 indicates that the trapping efficiency increases by increasing t/d, and in the all orifice to tube diameter ratios, in gradation D_3 is more than D_2 and trapped sediments related to D_2 is more than D_1.

In other words, the smaller the gradation, the trapping efficiency increases. It seems that this result will be true as long as sediments move as bed load and it is predicted in the higher discharges that by suspending particles, the trapping ratio of smaller particles decreases than larger particles.

The results presented in Fig.2 to 5 shows that in all orifices to the tube diameter ratios, trap efficiency first increases by increasing the Froude number and then decreases. The highest trapping efficiency occurred in the Froude number 0.65. The results also show that in Froude numbers, trapping ratio is greatly reduced more than 0.8. Since an amount of discharge is naturally required in vortex tube for diversion and sediment output, according to the table above, the test results show that regardless of gradation, the least water loss is related to t/d = 0.15 as 7.75 per cent and the highest water loss was for t/d = 0.3 as 12.85%.

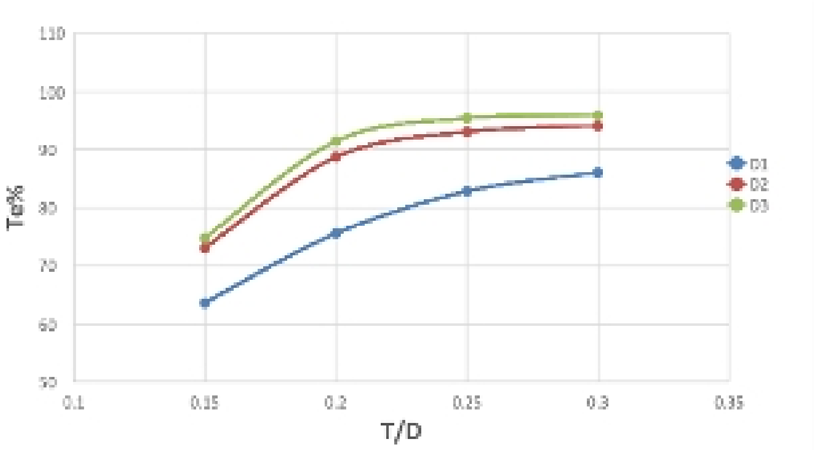

Fig. 4: Impact of (t/d) on the percentage of diversion sediment (Te%)

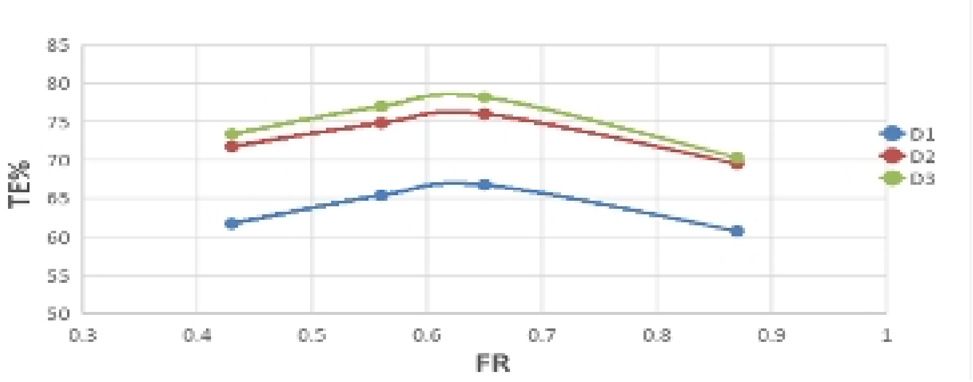

Fig. 5: The effect of Froude number on vortex tube trapping efficiency in three gradation in t/d= 0.15

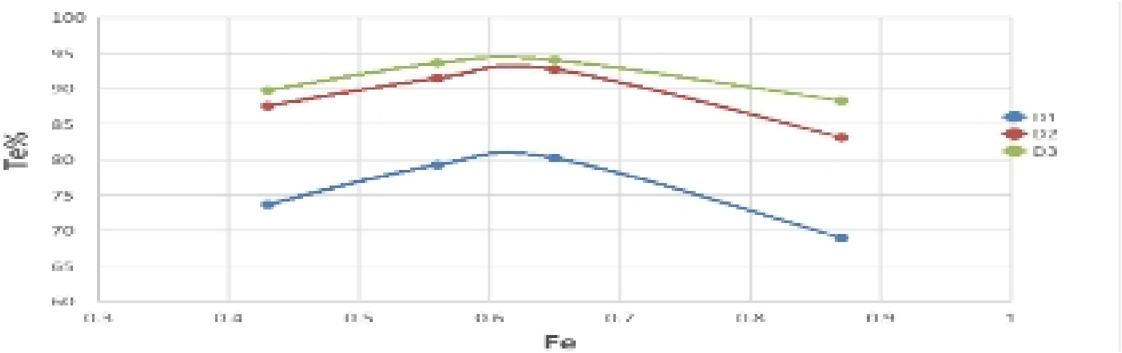

Fig. 6: The effect of Froude number on vortex tube trapping efficiency in three gradation in t/d= 0.20

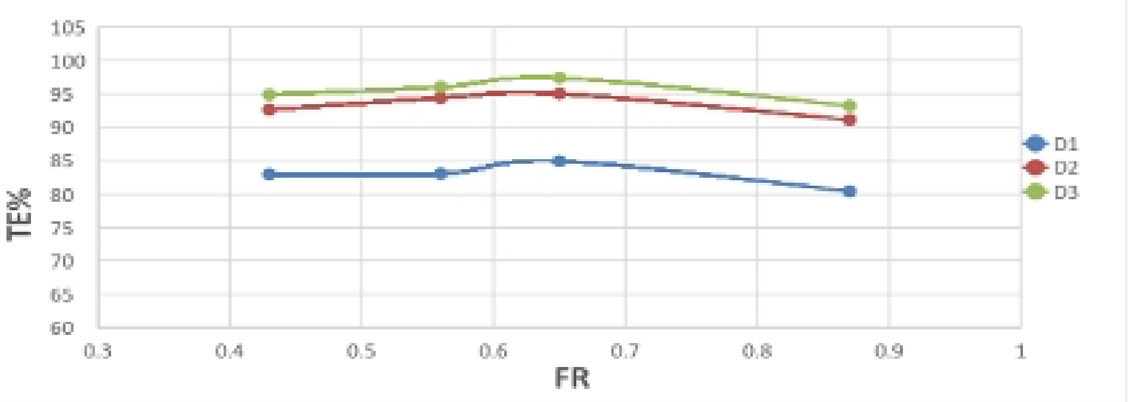

Fig. 7: The effect of Froude number on vortex tube trapping efficiency in three gradation in t/d= 0.25

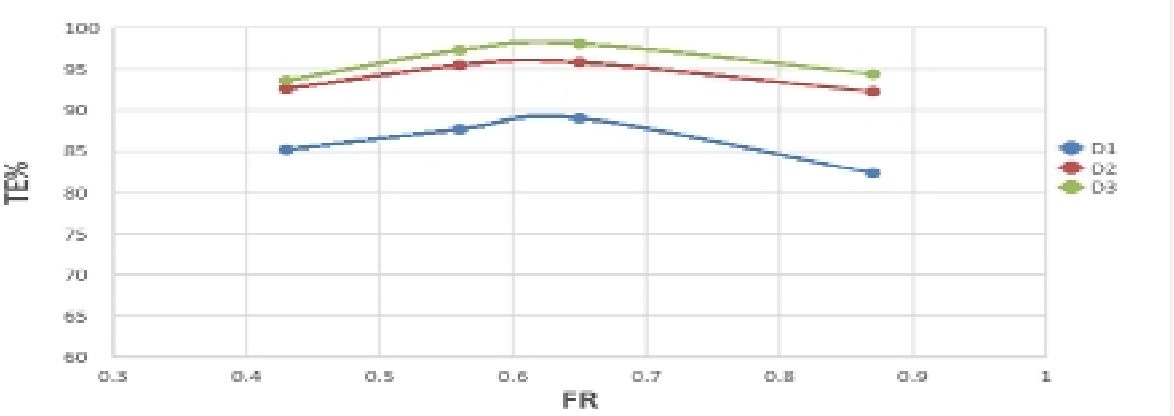

Fig. 8: The effect of Froude number on vortex tube trapping efficiency in three gradation in t/d= 0.30

4. Conclusion

According to the results of experiment, with increasing t/d, the percentage of sediment trapping has an increasing trend. If the amount of water loss is not a limiting criterion and in other words a region is not faced with water shortage and water supply problems and prevention of the entry of sediment into the system is preferred to water supply, the desirable option is t/d = 0.3, and if in a region, the water supply is very important and water shortage is basically existed, a better option is t/d = 0.25.

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