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Experimental Study on Flow over Triangular Labyrinth Weirs

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ABSTRACT

Recently, many research studies have focused on labyrinth weirs' hydraulic performance, especially as dependent on engineering features. In the current study, the hydraulic properties of flow over labyrinth triangular weirs models (from the upper perspective) with sharp crest have been experimentally studied and compare their efficiency with suppressed rectangular weirs (conventional weirs). Twelve fiberglass models are developed for this reason and tested in a 6m in length, 30cm in width, and 40cm height in laboratory flume, nine models were constructed for triangular labyrinth weirs and three models were constructed for suppressed rectangular weirs, Three alternative heights (p=15, 20, and 25cm) were employed in this research, for each height, the vertex angle (θ) changed three times (60°, 90°, 120°), and for each one of these weirs was used, seven different discharge were approved. The overall tests in this study were 84. The dimensionless parameters on which the discharge coefficient (Cd) is dependent were obtained using dimensional analysis. parameters were plotted. According to this experimental present study, as compared to linear weirs, labyrinth triangular weirs shown to be more hydraulically efficient. Also, the height of the weir (P) has effects on the discharge coefficient, where (Cd) increased with decreasing (P). Also, the vertex angle of triangular labyrinth weirs(θ) has a major influence on discharge coefficient and on weir performance, where the discharge coefficient raises when decreases the value of angle(θ), in another means, when the angle decreases gave an increase in the path of the flow, where it gave the triangular labyrinth weir with an angle of 60° the discharge coefficient reached its greatest value (2.55), followed by the weir with an angle of 90° and 120° respectively. In other words (a small vertex angle gives more length effective (Le) to the weir) and this leads to an increase in flow capacity or performance for the weir.

1. INTRODUCTION

Dam safety is mostly dependent on weirs. It has widely been used for the flow measurement, diversion, energy dissipation to regulate the flow depth and control in the open channel. In recent years, several types have been developed for labyrinth weirs, the common shape of labyrinth weirs rectangular, trapezoidal, half circular, arced etc.

Said et al. investigated the efficiency of a rectangular labyrinth weir, and its findings show that raising the proportion between the inlet and outflow alveolar widths raises the labyrinth's flow efficiency [1]. While Said et al. [2] investigated the efficiency of the rectangular labyrinth shape with a rounded entrance profile rather than a plane surface, which indicated an increase in rectangle labyrinth weir efficiency as comparing to trapezoidal labyrinth weir. Yousif [3] observed that the hydraulic performance of weirs with round edges rises as the weir height rises. Kumar et al. [4] researched experimentally in discharge ability of triangle labyrinth weir. They proposed a formula to estimate the flow over triangle labyrinth weirs through analyzing experimental data. Mehraein and Ghodsian [5] proposed a basic equation for predicting the discharge of triangular labyrinth weirs in free-flowing circumstances. The suggested equation predicted the discharge by 5.1 ± 8.1% error compared to the experimental study of Bilhan et al., who found that trapezoidal labyrinth weirs have a greater discharge coefficient than half-circular labyrinth weirs.

Karimi et al. [6] used a multi-layer neural network (ANN-MLP) to demonstrate the effect of dimensionless factors computed on the discharge coefficient of a triangular labyrinth side weir and found that the results of the examination show that utilizing model (MLP) along with simultaneous utilize of dimensionless parameters in order to calculate relative Froude number, weir crest length ratio to weir height (L/w), discharge coefficient, the ratio of water behind the weir to the channel width (h/b), and vertex angle showed the best results compared to other models.

Carollo et al. [7] indicated a stage-discharge relationship for a sharp-crested triangular labyrinth weir, according to this relationship and after some experiments, they found; the magnification of flow is affected by the ratio of length magnification and the head to one cycle width ratio.

Azimi and Hakim [8] conducted laboratory experiments to investigate the hydraulics of flow over rectangular labyrinth weirs in both free and submerged flow situations. They tested nine weir models with various pool lengths, widths, and discharge coefficients, finding that the discharge coefficients decreased as the approach velocity and pool aspect ratio increased. Also, at free flow, for (height of water over crest/height of weir) less than 0.4, rectangular labyrinth weirs were operationally more effective than sharp-crested weirs.

Shlash et al. [9] employed a sharp crest trapezoidal labyrinth weir with free flows situations, which resulted in a 40% decrease in flow efficiency as the width to height ratio increased to 2.5. Ghaderi et al. [10] aim to develop the hydraulic efficiency of labyrinth weirs by edging the weir wall and inclining the weir crest edge, leading to greater hydraulic performance, a higher flow factor, and higher flow rates.

Dabling and Tullis [11] investigated the effect of discharge flow characteristics with straightforward, labyrinth, and staged labyrinth weirs on outlet hydrograph performance by mathematically routing flooding outflow through a basin; peak discharge flow, the peak surface height, which show better hydraulic efficiency and dam stability for severe flood occurrences. Mohammed et al. [12] employed a two-cycle Labyrinth sharp-crested weir, which shows that the longer sidewall dimension results in a smoother water flow profile upon crest.

2. DIMENSIONAL ANALYSIS

During The dimensional parameters in calculating the coefficient of discharge can be showed as Eq. (1) through using dimensionless analysis (Buckingham Pi Theorem) (Swamee) [13] which can be put in the following formula:

$$Cd = f\left(\frac{H}{P}, Fr, Re, \theta\right) \qquad (1)$$

As Ackers [11] states, π_3 reflects the number of Reynolds (Re=$\frac{\mu}{\rho q}$), and its influence on flow can be ignored only at extremely shallow depths above the weir. After ignoring Reynold's number, the equation above seems to become Eq. (2).

$$Cd = f\left(\frac{H}{P}, Fr, \theta\right) \qquad (2)$$

where, Cd (discharge coefficient of weir), H (head over the crest of the weir), P (crest height), F=V/√(gy (Froude number), Re=$\frac{\mu}{\rho q}$ (number of Reynolds) and θ (vertex angle). See Figure 1.

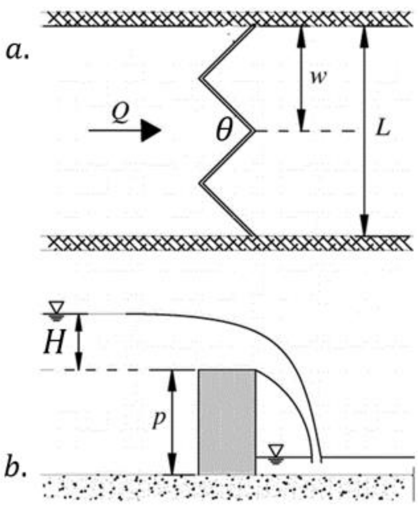

Figure 1. Flow above triangular labyrinth weirs; (a) labyrinth weir, top view and (b) side view

3. LABORATORY CHANNEL

The Experimental tests were carried out in a horizontal and rectangular laboratory channel in the field of environmental engineering, Tikrit University. The dimensions of this channel are 6m length, 30 cm width and 40cm height. This channel is equipped with water by a hydraulic pump, the maximum discharge of this pump is 22 l/s and controlled by a valve which can be changed according to the required discharge.

4. EXPERIMENTAL SETUP

The experiments run was carried by using triangular labyrinth weirs models (upper view) having sharp crest, Figures 2-4 represent before and after study sets of weirs utilized in this investigation. In this study 9 models were constructed for triangular labyrinth weirs and 3 models were constructed for suppressed rectangular weirs, three alternative heights (p=15, 20, and 25cm) were employed in this experiment, for each height, the vertex angle of triangular labyrinth weirs (θ) changed three times (60°, 90°, 120°), seven different discharge were passed. This research included a total of 84 tests. All of the models were manufactured out of 1 cm thick fiberglass, and the head over the weir models were measured with a point gauge.

Figure 2. Triangular labyrinth weir with sharp crest after test

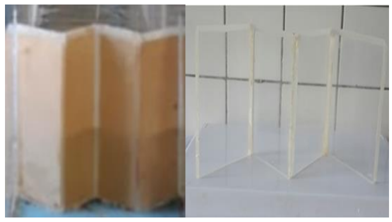

Figure 3. Triangular labyrinth weir with sharp crest before test

Figure 4. Rectangular weir with sharp crest

Figure 5. Typical triangle weir

A typical triangular weir, which was installed at the end of the channel as represented in Figure 5, was used to measure the channel's discharge (real discharge). It is a weir with a sharp triangular crest, with a vertical cut in the shape of the letter V, cut according to British Standards Institution at an angle of 45° (BS ISO 1438). A 1cm thickness plastic fiber sheet was used to construct this weir. It is calibrated using the volumetric method, where the volume of water passing through it is calculated in a specific time period and for different levels of water, then the weir equation is found that relates the amount of passing discharge and the height of the water above the weir.

5. RESULTS AND DISCUSSION

The discharge over labyrinth weir can be expressed as Eq. (3):

$$Q=\frac{2}{3}Cd\sqrt{2g}\times L\times (H)^{\frac{3}{2}} \quad (3)$$

For all samples, the real discharge of water was measured using a typical triangular weir. This weir's equation is Eq. (4):

$$Q_{tw}=0.0132(H_w)^{2.5622} \quad (4)$$

in which, Qtw is the discharge above a typical triangle weir in (L/s) and Hw is the water height over the Typical triangle weir in (cm).

The discharge coefficient Cd may be computed by using the following formula Eq. (5):

$$Cd=\frac{Q_{(real.)}}{Q_{(theo.)}} \quad (5)$$

Tables 1-4 show all of these data.

Table 1. Data for a triangular labyrinth weir with a sharp crest, both real and theoretical (θ=120°)

Test No.	H_{tw} (mm)	H (mm)	$Q_{(real.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=20 cm						
1	53.6	7.8	0.98	0.61	1.6	0.03
2	75.5	14.5	2.35	1.55	1.52	0.06
3	79.1	16.8	2.65	1.88	1.41	0.07
4	88.8	20.7	3.56	2.64	1.35	0.08
5	101	28	4.98	4.15	1.2	0.11
6	113	35	6.55	5.80	1.13	0.14
7	118	43.7	7.28	8.09	0.9	0.18
P=25 cm						
1	55.1	10.5	1.05	0.95	1.1	0.04
2	71.2	18.6	2.02	2.25	0.9	0.07
3	79.1	23.5	2.64	3.19	0.83	0.09
4	88.5	28.8	3.53	4.33	0.82	0.12
5	99.9	35.6	4.81	5.95	0.81	0.14
6	106	39.7	5.61	7.01	0.8	0.16
7	111	43.7	6.31	8.09	0.78	0.18
P=15 cm						
1	71.2	12.5	2.02	1.24	1.63	0.05
2	87.2	18.7	3.40	2.27	1.5	0.08
3	102	25	5.04	3.50	1.44	0.10
4	112	31.2	6.40	4.88	1.31	0.13
5	129	42.5	9.31	7.76	1.2	0.17
6	134	47.5	10.18	9.17	1.11	0.19
7	145	55	12.57	11.43	1.1	0.22

Table 2. Data for a triangular labyrinth weir with a sharp crest, both practical and theoretical (θ=90°)

Test No.	H_{tw} (mm)	H (mm)	$Q_{(real.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=20 cm						
1	65.1	12.5	1.61	1.24	1.3	0.05
2	78.4	17.7	2.59	2.09	1.24	0.07
3	81.7	20.1	2.88	2.52	1.14	0.08
4	85.9	22.7	3.27	3.03	1.08	0.09
5	90.9	24.7	3.78	3.44	1.1	0.10
6	90.9	26.3	3.78	3.78	1	0.11
7	102	34.2	5.04	5.60	0.9	0.14
P=25 cm						
1	53.8	7.5	0.99	0.58	1.72	0.03
2	77.1	14.5	2.47	1.55	1.6	0.06
3	81.1	16.5	2.82	1.88	1.5	0.07
4	91.3	20.7	3.82	2.64	1.45	0.08
5	104	28	5.32	4.15	1.28	0.11
6	116	34.7	7.04	5.73	1.23	0.14
7	126	40.7	8.76	7.27	1.2	0.16
P=15 cm						
1	76.4	13.2	2.42	1.34	1.8	0.05
2	92.7	19	3.97	2.32	1.71	0.08
3	104	24	5.34	3.29	1.62	0.10
4	109	28	6.06	4.15	1.46	0.11
5	120	33.2	7.66	5.36	1.43	0.13
6	131	41.2	9.71	7.41	1.31	0.17
7	147	53.7	12.82	11.02	1.16	0.22

Table 3. Data for a triangular labyrinth weir with a sharp crest, both practical and theoretical (θ=60°)

Test No.	H_{tw} (mm)	H (mm)	$Q_{(real.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=20 cm						
1	80.2	14.5	2.74	1.55	1.77	0.06
2	84	16	3.08	1.76	1.72	0.06
3	88.1	19.2	3.49	2.36	1.48	0.08
4	91.3	21.7	3.82	2.83	1.35	0.09
5	96.6	24.5	4.42	3.40	1.3	0.10
6	101	27	4.91	3.39	1.25	0.11
7	102	28.4	5.09	4.24	1.2	0.11
P=25 cm						
1	55.5	6.7	1.07	0.49	2.2	0.03
2	72.5	11.3	2.12	1.06	1.99	0.05
3	86.8	16.2	3.36	1.83	1.84	0.07
4	104	24.2	5.31	3.34	1.59	0.10
5	110	27.7	6.18	4.08	1.51	0.11
6	121	33.7	7.84	5.48	1.43	0.14
7	123	35	8.16	5.80	1.41	0.14
P=15 cm						
1	58.8	6.7	1.24	0.49	2.55	0.03
2	77.9	11.5	2.55	1.09	2.33	0.05
3	86.5	14.7	3.33	1.58	2.11	0.06
4	95.8	18.8	4.32	2.23	1.94	0.07
5	103	22.2	5.19	2.93	1.77	0.09
6	116	27.5	7.11	4.04	1.76	0.11
7	133	37.5	9.97	6.43	1.55	0.15

Table 4. Data for a conventional rectangular weir with a sharp crest, both practical and theoretical

Test No.	H_{tw} (mm)	H (mm)	$Q_{(real.)}$ (l/sec)	$Q_{(theo.)}$ (l/sec)	C_d	H/P
P=20 cm						
1	49.8	10.5	0.81	0.95	0.85	0.04
2	68.9	18.6	1.86	2.25	0.83	0.07
3	78.6	23.5	2.61	3.18	0.82	0.09
4	87.8	28.8	3.46	4.33	0.8	0.12
5	98.4	35.6	4.64	5.95	0.78	0.14
6	104	39.7	5.40	7.00	0.77	0.16
7	108	42.8	5.88	7.84	0.75	0.17
P=25 cm						
1	46	9.1	0.61	0.77	0.86	0.05
2	62.6	15.6	1.46	1.73	0.84	0.08
3	78	23	2.56	3.08	0.83	0.12
4	89.8	30.2	3.67	4.64	0.79	0.15
5	94.6	33.6	4.20	5.45	0.77	0.17
6	104	39.8	5.38	7.03	0.77	0.20
7	111	44.2	8.23	8.23	0.77	0.22
P=15 cm						
1	54	8.2	0.58	0.66	0.88	0.05
2	58.8	14	1.24	1.45	0.85	0.09
3	80	24.2	2.74	3.32	0.82	0.16
4	96.6	29.3	4.43	5.47	0.81	0.20
5	100	38.3	4.85	6.62	0.73	0.26
6	106	42.3	5.58	7.70	0.73	0.28
7	111	46.1	6.29	8.75	0.72	0.31

5.1 Coefficient discharge Cd and the dimensionless variable H/P

Eq. (5) was used to get the discharge coefficient. For all research models, the data of (Cd) is shown as a function of the ratio (H/P) as shown in Figures 6-9, in this case the angle of Vertex angle (θ) fixed and the height of weir (P) is changed. These figures show that (Cd) is equivalent to (H/P), and that (Cd) is strongly influenced by the water above the weir crest (H) in the upstream of the weir, also, the amount of the discharge coefficient (Cd) is large at low (H/P) ratios and progressively decreases as the ratio increases.

In additional weir height has great affected on (Cd), where gave the lowest height the highest values for this parameter for all study models. Also, we noticed from same figures for the same ratio (H/P), the triangular labyrinth weirs gave high performance from rectangular weirs (see Figure 9) for comparison purposes, this indicates that, in comparison to conventional rectangular weirs structures, a triangular labyrinth weir can pass a greater discharge (higher capacity) at relatively low heads.

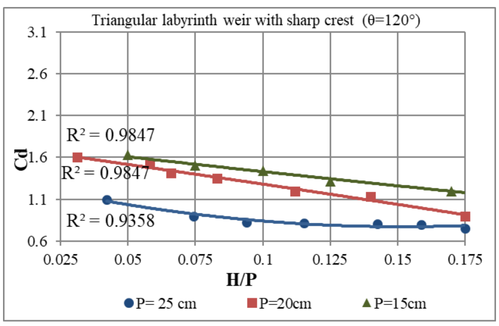

Figure 6. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (θ=120°)

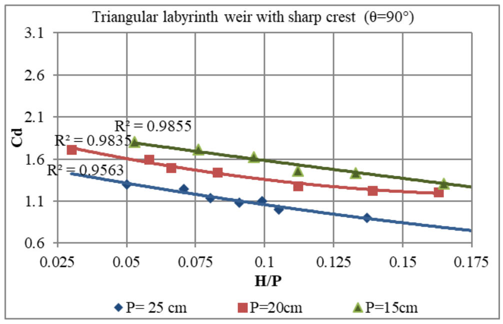

Figure 7. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (θ=90°)

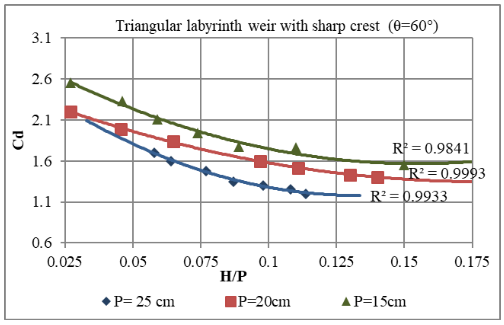

Figure 8. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (θ=60°)

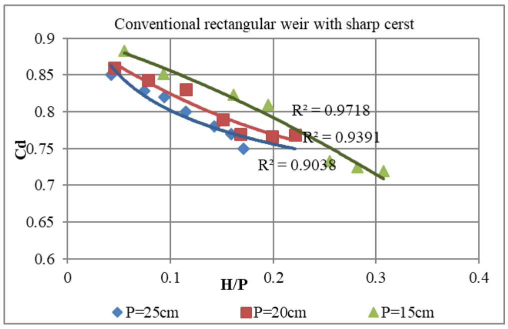

Figure 9. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (Conventional rectangular weir)

5.2 Effect of Vertex angle (θ) on discharge Coefficient (Cd)

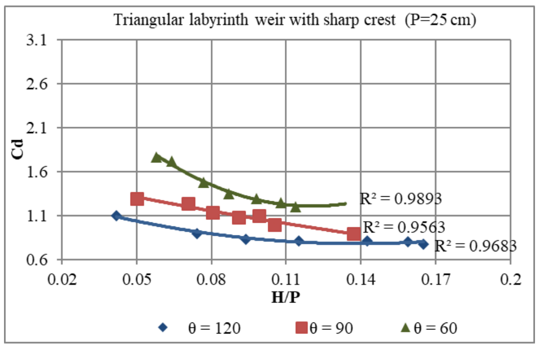

Figure 10. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (P=25 cm)

The relationship between Cd and H/P was drawn by fixing the height of weir (p) and changing the angle of the vertex of triangular labyrinth weirs (θ) as shown in Figures 10-12. It is noticed from these figures that the discharge coefficient increases as the angle of the vertex of triangular labyrinth weirs decreases due to the increase in the length of the edge of weir or the effective length of triangular labyrinth weir (Le) (longer length for flow),which leads to an increase in the path of the flow ,which gave the triangular labyrinth weir with an angle of 60° the discharge coefficient reaching its greatest value (2.55), followed by the weir with an angle of 90° and 120° respectively.

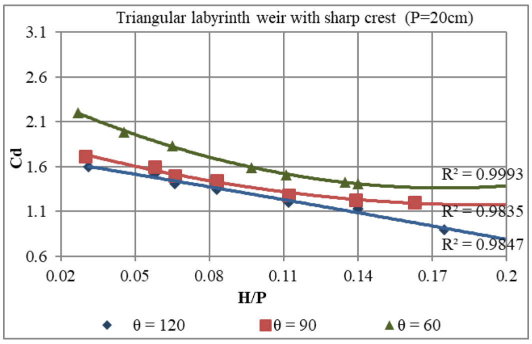

Figure 11. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (P=20cm)

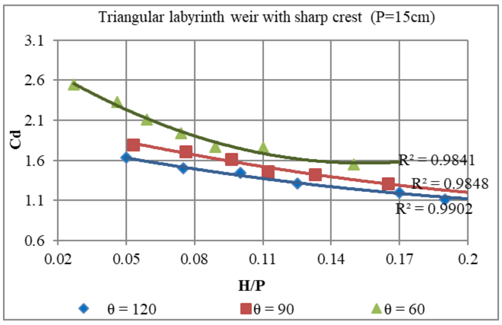

Figure 12. The discharge coefficient (Cd) and the non - dimensional variable (H/P) connection (P=15 cm)

5.3 Variations of the real discharge with respect to head of water (H)

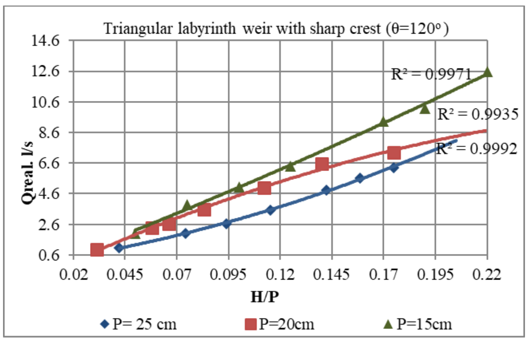

Figure 13. Real discharge (Qreal.) and the non - dimensional variable (H/P) connection (θ=120°)

The Figures 13-15 show the connection between the real discharge (Qreal.) and the dimensionless factor (H/P), it was noted the type of relationship between them directly proportional. The discharge increases with an increase height of the water above the crest of the weir (H) and this is normal, but a noticeable change is observed in the amount of discharge when the vertex angle (θ) changes, where the triangular labyrinth weirs with small vertex angle (θ) gave the highest value of the discharge, this means that weirs with the lowest vertex angle value are the more efficient to pass the largest discharge because it has a longer flow path.

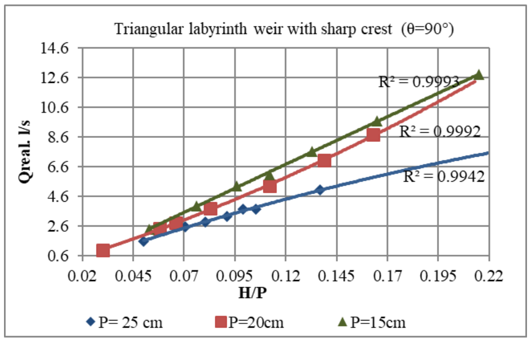

Figure 14. Real discharge (Qreal.) and the non - dimensional variable (H/P) connection (θ=90°)

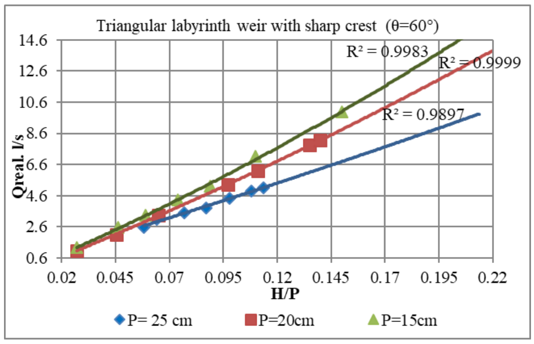

Figure 15. Real discharge (Qreal.) and the non - dimensional variable (H/P) connection (θ=60°)

5.4 The relationship between (Cd) and (Fr)

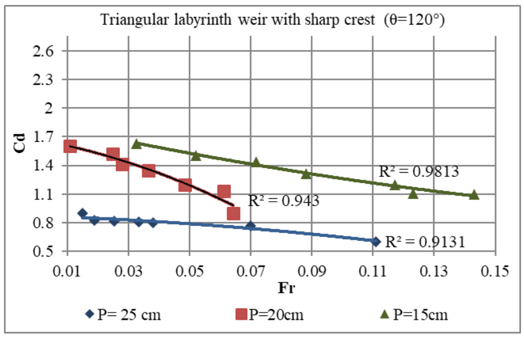

Figure 16. The discharge coefficient (Cd) and the non - dimensional variable (Fr) connection (θ=120°)

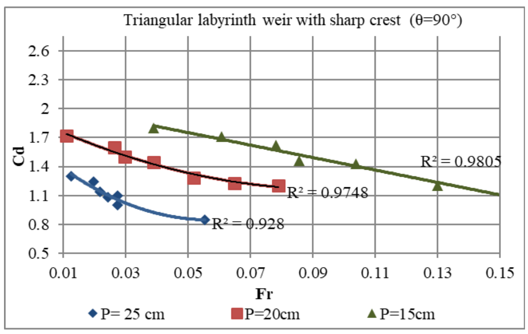

Figure 17. The discharge coefficient (Cd) and the non - dimensional variable (Fr) connection (θ=90°)

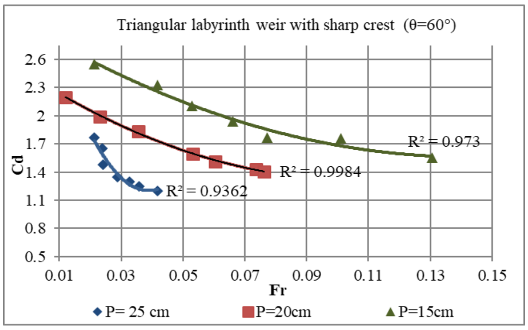

Figure 18. The discharge coefficient (Cd) and the non - dimensional variable (Fr) connection (θ=60°)

The relationship was sketched between (Fr) and (cd) as shown in Figures 16-18. The value of the Froude number was found by using equation F=V/√(gy), It is noticed from these figures that the discharge coefficient decreases by increasing the Froude number within the limits of the sub-critical flow. Also, it was observed that the model with the smallest vertex angle and height of triangular labyrinth weirs that gave the highest values for this hydraulic behavior.

6. CONCLUSIONS

The hydraulic properties of flow above triangular labyrinth weirs are investigated experimentally in this study (from the upper perspective) with sharp crest under free flow conditions by using range of experiments, where the main purpose of labyrinth weirs is to have more discharge compared to conventional weirs. From the analysis of results of this study showed that the efficiency of triangular labyrinth weirs increases with decrease of vertex angle(θ), this is due to the increasing in the path of the crest of weir and this performance is low to high vertex angle(θ) and decreases with increase (H/P) due to intrusion of the jets downstream, in other meaning for the low value of (H/P) and low vertex angle the, Cd is high and gradually decreases when H/P increases. Also the triangular labyrinth weirs is more efficient than the linear weirs since triangular labyrinth weirs gave longer lengths for flow to pass more discharge, and it has better performance as it increase the magnification ratio(Le/w) (Le is effective crest length and w is the channel width), where gave the triangular labyrinth weir with an angle of 60° the highest value of the magnification ratio and the discharge coefficient reached its greatest value (2.55) followed by the triangular weir with an angle of 90° and 120° respectively.

The results also showed that for any value to ratio (H/P) noticed that discharge capacity for the triangular labyrinth weirs is higher than the rectangular weirs, this means flow discharge Q greater than the one corresponding to that of the linear weirs , also it was found that the weir height P has great effected on (Cd), where gave the lowest height the highest values for this parameter for all study models ,In other words, decrease height of weir increase its ability to pass more discharge and more performance. In additional that the number of Froud has an effect on Cd which the discharge coefficient decreases by increasing the Froude number within the limits of the sub-critical flow.

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NOMENCLATURE

B	Channel width (L)
Cd	Discharge coefficient of wire
Fr	Froude number
g	Acceleration gravity ($\frac{L}{T^2}$)
H	Height of the water upstream above the crest of the labyrinth weir (L)
H_{tw}	Depth of water above the Typical triangle weir (L)
L	Crest length of the weir (L)
Le	Effective length of labyrinth weir (L)
P	Height of weir above channel bed (L)
Q_L	Discharge over triangular labyrinth weir with sharp crest ($\frac{L^3}{T}$)
Q_{tw}	The discharge over a typical triangle weir ($\frac{L^3}{T}$)
Re	Reynold's No.
w	Width of a single labyrinth weir cycle (L)

Greek symbols

μ	Dynamic viscosity of water (M/LT) Hydraulics
θ	Apex angle of triangular labyrinth weirs (°)
ρ	Mass density of water (M/T^3)