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INVESTIGATION OF THE EFFECT OF CHAINGING ORIFICE ANGLE ON THE DISCHARGE COEFFICIENT

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ملخص البحث

يعتبر معامل التصرف "C_d" خلال الفتحات من أهم المعاملات اللازمة لدراسة سلوك تدفق المياه، والذي يعكس مدى كفاءة السريان ويلعب دورًا مهمًا في تصميم الوحدات الهيدروليكية، والغرض من هذا البحث هو إجراء تحقيق معملي لدراسة تأثير تغيير زاوية الفتحة على معامل التصرف لتدفق المياه خلال الظروف الهيدروليكية المختلفة ومقارنة بعضها ببعض، ولتحقيق هذا الغرض ، تم استخدام شكلين من الفتحات: مثلث متساوي الأضلاع ومستطيل، وتم اختبار خمسة أقطار مختلفة (10 ، 15 ، 20 ، 25 ، 30 ملم). وتجدر الإشارة إلى أن الاختبارات أجريت على ست قيم مختلفة للضغط الواقع عمودياً على مركز الفتحة وهي (25 ، 30 ، 35 ، 40 ، 45 ، 50 سم) وتم إجراء هذه الدراسة المعملية على ثلاثة زوايا مختلفة للفتحات وهي (صفر و 45 و 90) درجة.

أظهرت نتائج الدراسة أن التغير في زاوية الفتحة يؤثر على معامل التصرف، حيث تم ملاحظة أنه بالنسبة للفتحة المثلثة متساوية الأضلاع ، يتناقص معامل التصرف تدريجياً عندما تزيد الزاوية θ بينما في الفتحة المستطيلة ، كلما كانت الفتحة أفقية أكثر، كلما زاد معامل التصرف. بالإضافة إلى ذلك ، تم استنتاج معادلات تجريبية (لجميع الزوايا المختبرة) لوصف طريقة تغيير C_d لست قيم مختلفة من نسبة الضاغط الى سمك الفتحة وأظهرت المعادلات أن الاختلاف يحدث تدريجيًا ويؤول إلى الاستقرار كلما زادت قيمة نسبة القطر المكافئ إلى سمك الفتحة.

ABSTRACT

The coefficient of discharge (C_d) of an orifice is very substantial parameter as it is considered the efficiency of the orifice flow. Also, knowledge of the orifice flow performance has a significant importance in in the design of hydraulic units. The purpose of this paper is to investigate experimentally effect of changing orifice angle on the C_d for water flow through different hydraulic conditions and comparing each other. To achieve this goal, two orifices shapes were used: equilateral triangular and rectangular. Five different diameters (10, 15, 20, 25 and 30 mm) were tested. It should be noted that the tests were conducted on six different values of the pressure heads affecting the center of the hole: (25, 30, 35, 40, 45 and 50 cm). This study was carried out at three different orifice angles (0^o, 45^o and 90^o). The results of the study demonstrated that the changing in the orifice angle affects the C_d. For equilateral triangular orifice the C_d gradually decreases when the angle θ increases while in rectangular orifice, the more horizontal the orifice, the greater the C_d. Additionally, Empirical equations was conducted

(for all tested angles) to describe the manner of variation of the C_d at six values of the ratio (h/t). The equations showed that the variation occurs gradually in asymptotic behavior.

Keywords: Discharge coefficient, flow through orifices, Orifice angles, Orifice shapes.

1. INTRODUCTION

An orifice is an opening with a locked perimeter, made in the walls of a tank, a channel, or a basin holding water (or fluid) in which water can be discharged [1]. The usage of an orifice is the stream flow measurement. Also, an orifice can be exist in the vertical side of a tank or in the bottom, but the previous is more often [2]. Information of the orifice flow performance has a substantial importance in some fields, such as stream flow measurement devices, dams, piping networks, and oil injection into fire engines [3].

As streamlines of water flowing across an orifice originate from all 3 dimensions, the lateral components of velocities of all streamlines must be lavished as the water exits the orifice. This phenomenon causes the jet to contract up to a certain point, known as vena contracta **Fig. 1** [4]. Because of the phenomenon of vena contracta, the real area of flow from an orifice is smaller than the area of the orifice itself.

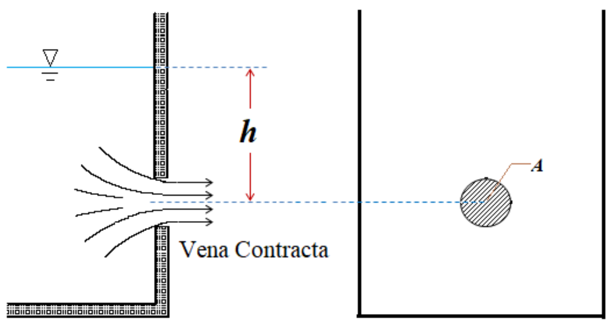


Fig. 1. Vina Contracta.

The discharge can be defined the product of the velocity and area of flow at the vena contracta and can be written as [5]:

$$Q = Av = C_c A_o C_v \sqrt{2gh} \quad \textbf{Eq. 1}$$

Where A is the jet cross-sectional area at the vena contracta, v is the velocity, C_c is the contraction coefficient, A_o is the orifice area, C_v is the velocity coefficient which represents head loss that can be generated as water moves out of the tank through an orifice, g is the gravitational acceleration and h is the pressure head above the orifice. By combining the two coefficients C_c and C_v into one coefficient C_d, standard equation for estimating a flow through small orifice discharging the water into the atmosphere under constant head can be written as:

$$Q = C_d A_o \sqrt{2gh} \quad \textbf{Eq. 2}$$

The discharge coefficient “C_d” is a dimensionless number defined as the ratio of the amount of water discharged through an orifice to the amount theoretically possible at that flow conditions. A smaller value of the C_d shows that the actual discharge is smaller compare to the theoretical or ideal value and vice versa.

Numerous studies underlined the existence of the connection between the orifice geometric properties and the C_d. E.g.; Ramamurthi and Nandakumar (1999) examined the C_d for flow passing through small sharp edged orifices [6]. Similarly, the C_d for water passing through a circular orifice cut into a thin-walled vertical riser pipe was inspected by Prohaska (2008) [5]. McLemore et al. (2013) made an stimulating study about studying the C_d for orifices cut into round pipes [7]. Parshad et al. (2015) studied the effect of orifice diameter on the C_d [8]. Chang et al. (2015) numerically analyzed the C_d in aerostatic bearings with orifice type restrictors [9]. Tharakan and Rafeeque (2016) studied the role of backpressure on the C_d of sharp-edged injection orifices [10]. Fu et al. (2018) investigated the C_d for flow through combined orifice-weir [11]. Additionally, Abd et al. (2019) experimentally investigated the flow characteristics of different diameter sharp-edged orifices [12]. Moreover Abdelrahman (2020) studied effect of the geometric parameters on the C_d and presented analytical comparison between four different orifice shapes (circle, square, equilateral triangle and rectangle).

Nevertheless, no researches were showed the effect of orifice angle on the C_d as a comparative study between two orifice shapes. Accordingly, this research was initiated with the objective of comparing the angle effect on the C_d for two different orifice shapes (equilateral triangular and rectangular) under six different vertical pressure heads. Moreover, this research aims to establishing design equations and charts for two orifice shapes that may be used in hydraulic design.

2. DIMENSIONAL ANALYSIS

Theoretical study has been behaved utilizing dimensional analysis method to discover the relationships among the different measurements and changes for interaction between all orifices' shapes and angles. All parameters and geometry, affecting the C_d, are defined in **Fig. 2.** Functional relationships are obtained between the C_d for all parameter. In this study, the C_d is the dependent variable. It can be expressed as a function of all other independent variables as follows:

$$C_d = \varphi(\rho, g, \mu, v, d, t, h, k, \Theta) \qquad \textbf{Eq. 3}$$

Where, ρ is the density of fluid, g is the gravity acceleration, μ is the dynamic viscosity, v is the velocity, d is the equivalent orifice diameter, t is the orifice thickness, h is the pressure head, k is the coefficient reflecting the orifice shape and Θ is angel of the orifice. Using Buckingham's π-

Theorem, nine variables and three repeated changes were obtained. These changes can be easily coordinated in the following non -dimensional π-terms.

$$\pi_1 = \frac{h}{t}, \qquad \pi_2 = \frac{d}{t}, \qquad \pi_3 = \frac{v}{\sqrt{gh}}, \qquad \pi_4 = \frac{\mu}{\rho h \sqrt{gh}}, \qquad \pi_5 = k \qquad \pi_6 = \Theta$$

and

According to Buckingham Pi-theorem, the general form of relationship between these variables is written as follows:

$$C_d = \varphi\left(\frac{h}{t}, \frac{d}{t}, \frac{v}{\sqrt{gh}}, \frac{\mu}{\rho h \sqrt{gh}}, k, \Theta\right) \qquad \textbf{Eq. 4}$$

Taking the properties of π-terms into account, the following equation was obtained:

$$C_d = \varphi\left(\frac{h}{d}, \frac{t}{d}, k, \Theta\right) \qquad \textbf{Eq. 5}$$

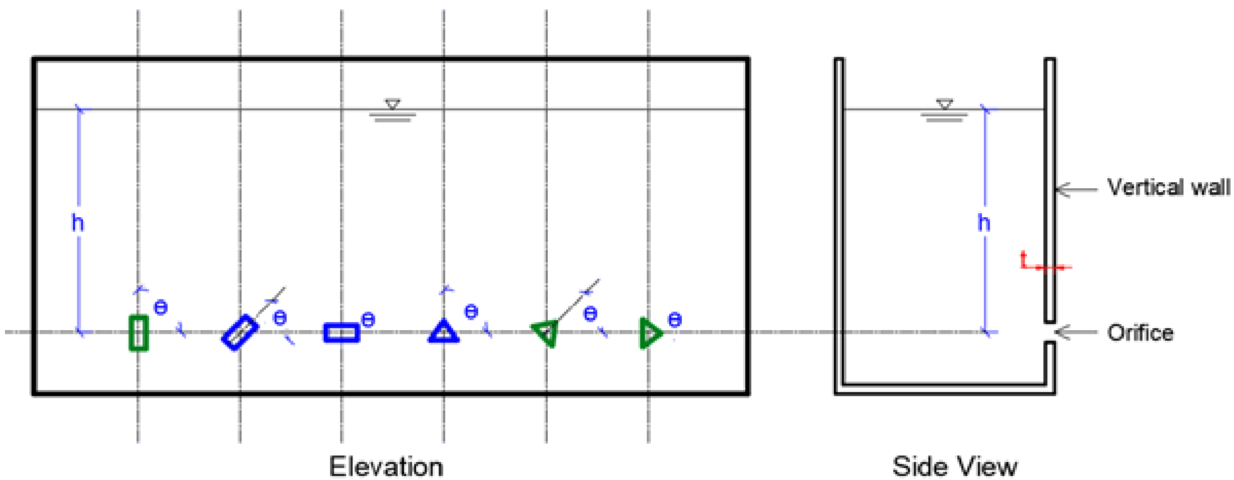


Fig. 2. Definition sketch of all parameters.

3. EXPERIMENTAL WORK

3.1 Physical Modeling:

To achieve the goal of the investigational work, a laboratory model was built **Fig. 3** and **Fig. 4.** The model mainly consists of 2 tanks, lower and upper. Both tanks are formed of transparent plastic to be relaxed in laser cutting and to permit visual observation of the water flow. The lower tank (assembling tank) was designed to collect water passing through the orifices and recycle it into the upper tank. To do that, a centrifugal pump was fixed to raise water from the lower to the upper tank. The upper tank was designed to keep the water level above the orifice.

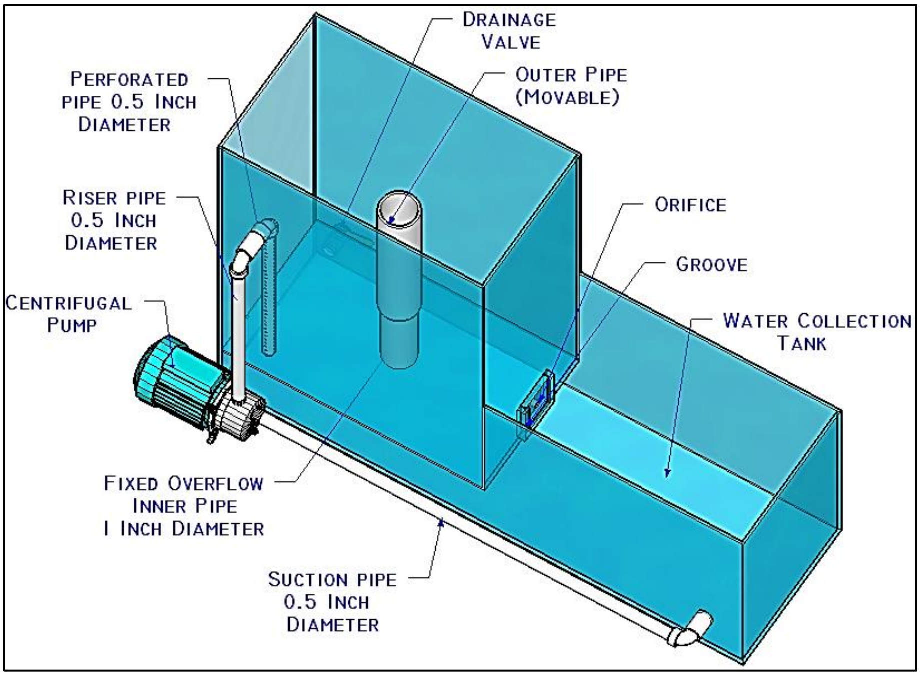


Fig. 3. Model isometric definition sketch.

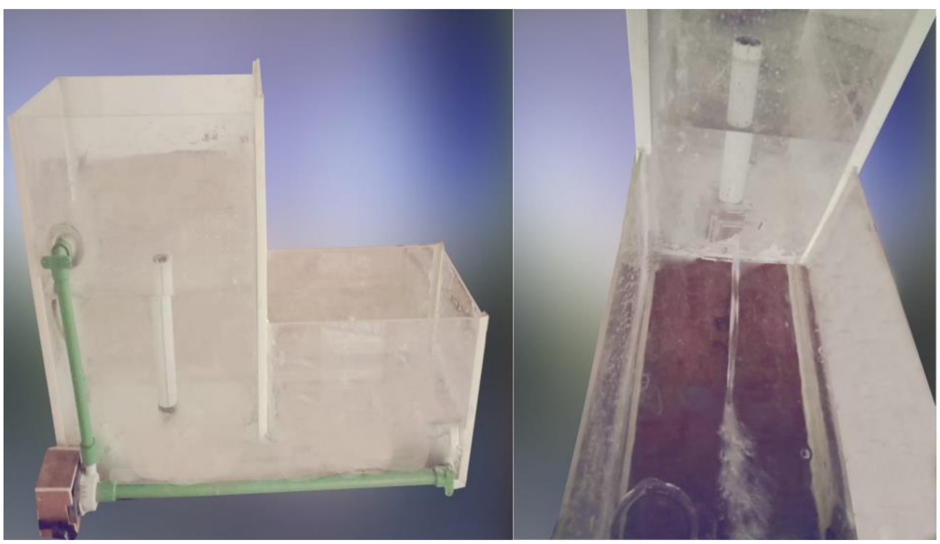


Fig. 4. Real photos of the model.

To control water head, two concentric pipes were installed in the middle of the upper tank in order to return water back to the lower tank. The inner pipe was designed to be fixed on the bottom of the tank and the outer pipe was installed to be moveable in order to control water head above the orifice. In order to study the effect of orifice angle on the C_d, 30 orifice plates (7cm. x 7cm.) each was made from transparent acrylic plastic. Orifices were cut using laser technology. The shown groove **Fig. 5** was designed to be fixed into the tank wall to facilitate changing the orifice plates. In order to supply the system with the needed flow rate, a 0.25 HP centrifugal pump was installed to withdraw water from the lower to the upper tank. The function of the pump is to substitute the water discharged from the orifice to keep constant head pressure above the orifice. The discharge passing through the orifices was calibrated using a graduated container and stopwatch. The graduated container was used to collect passing water in a certain time.

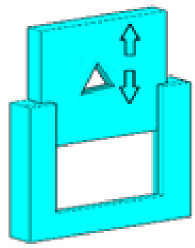
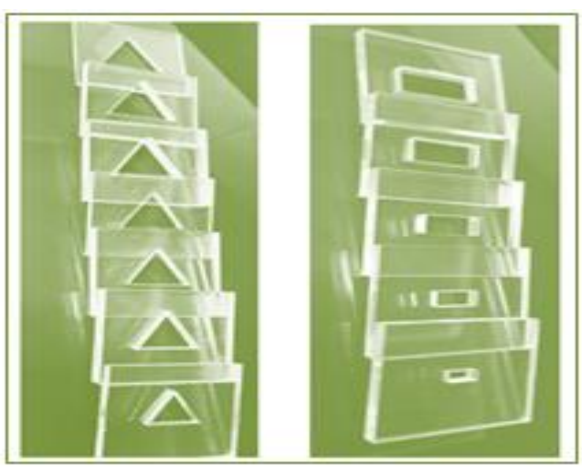


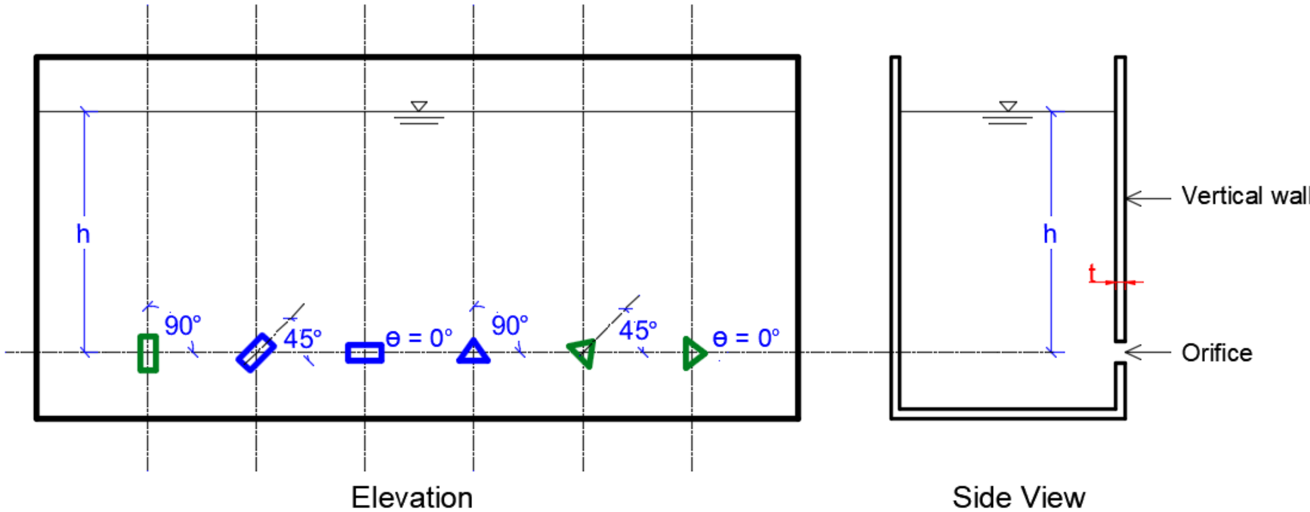
Fig. 5. Groove to change the orifice plate.

3.2 Experimental Program:

In this investigational work 180 runs were carried out in order to study the behavior of the C_d for water flow through orifices. A thoroughly designed experimental program is carried out to investigate these models. Experiments were conducted under clear-water conditions using tow orifice shapes [equilateral triangular and rectangular whose length equals twice its width (Length/Width =2)], each shape was tested with three different angels (Θ = 0^o, 45^o and 90^o) on the vertical wall as shown in **Fig. 6** These experiments were done for five orifice areas (A = 78.54, 176.71, 314.16, 490.87 and 706.86 mm^2) which is equivalent to circles of diameters (d = 10, 15, 20, 25 and 30 mm), respectively. All shapes were tested under the action of six different pressure heads above the center of the orifice (h = 25, 30, 35, 40, 45, and 50 cm.). The orifice thickness (t) in all the experiments was constant and equal to 5 mm. **Fig. 7** shows samples of real photos of the orifice plates. The actual discharge was calculated by measuring the water volume discharged out of an orifice in a known time.

Fig. 6. Shapes and angels of the orifices used in the experiments.





45^o and 90^o) on the C_d for flow through orifice was analyzed. **Table 1** shows the statistical analysis of the results obtained from the experimental data for effect of the values of circle diameter of equivalent area to the orifice thickness ratio (d/t) at three orifice angles on the C_d. This analysis represents minimum and maximum values, the arithmetic mean, and % change (% change = ((Max-Min)/Min) x 100). In addition to that, as shown in **Figs. 8 to 13** the values of (d/t) were plotted on the **X-axis** as independent variable and the C_d was set as dependent variable on the **Y-axis**. The relationship between (d/t) and the C_d was tested at six different values of pressure heads. In that regard, six figures were plotted with thirty measured C_d for each figure [(2) shapes with (3) angles for (5) equivalent orifice diameters].

From these **Figs. 8 to 13** and **Table 1** it could be noticed that in terms of setting (d/t) as independent variables for equilateral triangular orifice, as the angle θ increases, the C_d increases in logarithmic manner. Additionally, the orifice angle also influences the C_d of rectangular orifices, i.e. the more horizontal the orifice, the greater the C_d. At all pressure heads, the mean values of the C_d for the two shapes (equilateral triangle and rectangle) at different angles (0^o, 45^o and 90^o) increases in logarithmic manner with increasing the values of (d/t). It was also observed that the equilateral triangle shape with all its angles gave more value to the C_d compared to the rectangular shape with all its angles

Table 1: Statistical analysis of the results obtained from the experimental data for effect of the values (d/t) at three orifice angles on the C_d.

h/t	Statistics	C_d					
		Equilateral Triangular Orifice			Rectangular Orifice		
		θ = 0°	θ = 45°	θ = 90°	θ = 0°	θ = 45°	θ = 90°
		From (d/t) = 2 to (d/t) = 6					
50	Min	0.557	0.559	0.561	0.524	0.539	0.536
	Max	0.593	0.597	0.600	0.581	0.578	0.575
	Mean	0.575	0.580	0.582	0.563	0.561	0.558
	% Change	**6.46**	**6.71**	**6.95**	**7.19**	**7.24**	**7.27**
60	Min	0.552	0.555	0.557	0.539	0.535	0.531
	Max	0.592	0.596	0.599	0.579	0.577	0.575
	Mean	0.576	0.578	0.581	0.561	0.558	0.555
	% Change	**7.25**	**7.39**	**7.54**	**7.42**	**7.85**	**8.29**
70	Min	0.550	0.551	0.552	0.531	0.528	0.525
	Max	0.592	0.596	0.599	0.579	0.576	0.573
	Mean	0.573	0.576	0.578	0.557	0.555	0.552
	%Change	**7.64**	**8.08**	**8.51**	**9.04**	**9.09**	**9.14**
80	Min	0.536	0.538	0.539	0.523	0.521	0.519
	Max	0.590	0.594	0.598	0.578	0.576	0.573
	Mean	0.568	0.570	0.572	0.553	0.551	0.548
	% Change	**10.07**	**10.51**	**10.95**	**10.52**	**10.46**	**10.40**
90	Min	0.530	0.532	0.534	0.511	0.509	0.507
	Max	0.590	0.594	0.597	0.577	0.574	0.71
	Mean	0.563	0.565	0.568	0.548	0.545	0.542
	% Change	**11.32**	**11.56**	**11.80**	**12.92**	**12.77**	**12.62**
100	Min	0.515	0.518	0.520	0.497	0.496	0.494
	Max	0.589	0.593	0.596	0.576	0.573	0.570
	Mean	0.557	0.560	0.562	0.543	0.540	0.538
	% Change	**14.37**	**14.49**	**14.62**	**15.89**	**15.64**	**1538**

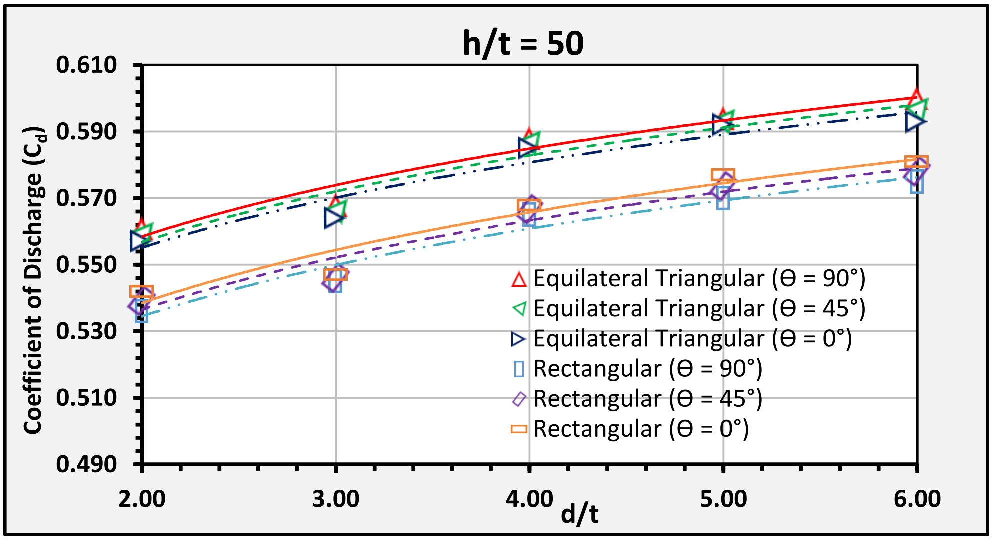


Fig. 8. Relationship between "d/t" and "C_d" (at h/t = 50).

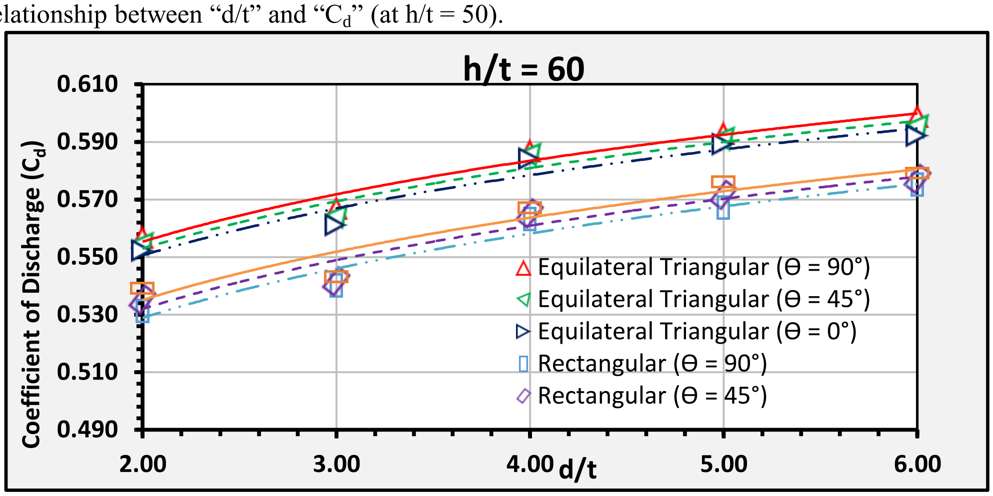


Fig. 9. Relationship between "d/t" and "C_d" (at h/t = 60).

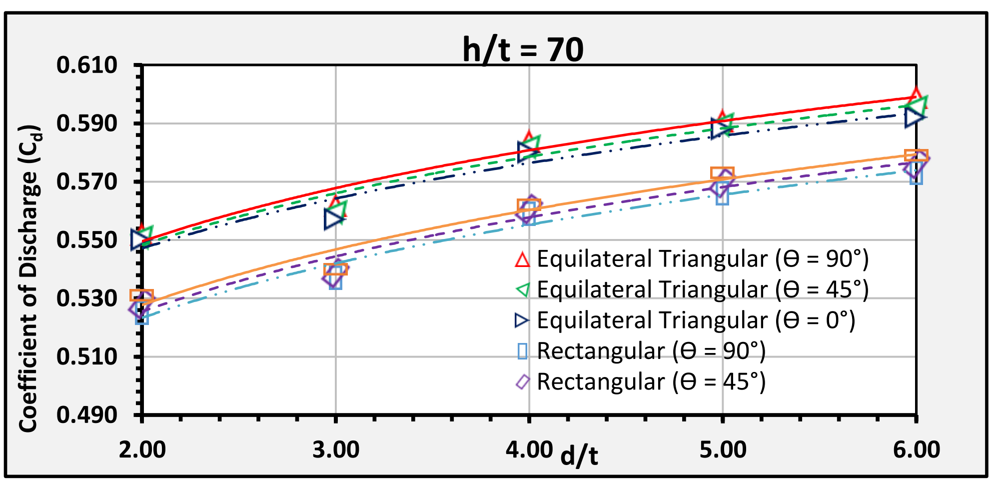


Fig. 10. Relation ship between "d/t" and "C_d" (at h/t = 70).

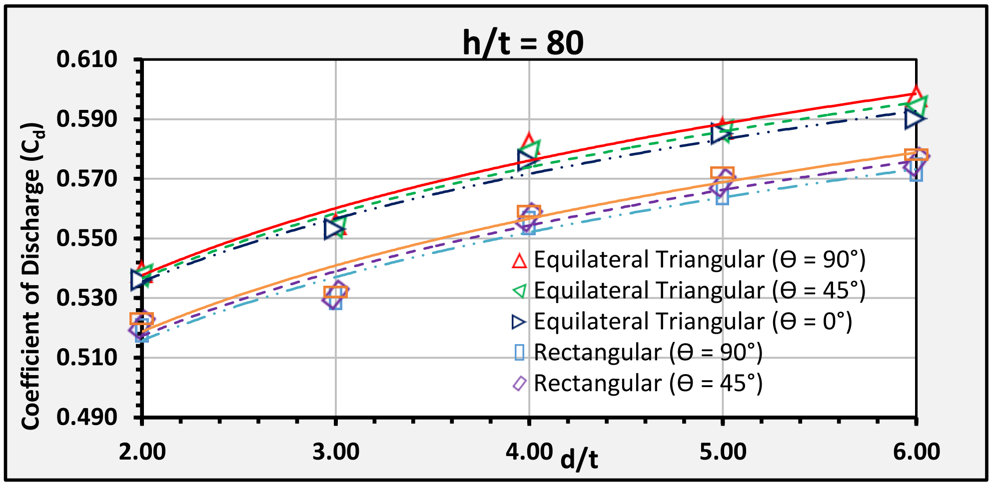


Fig. 11. Relationship between "d/t" and "C_d" (at h/t = 80).

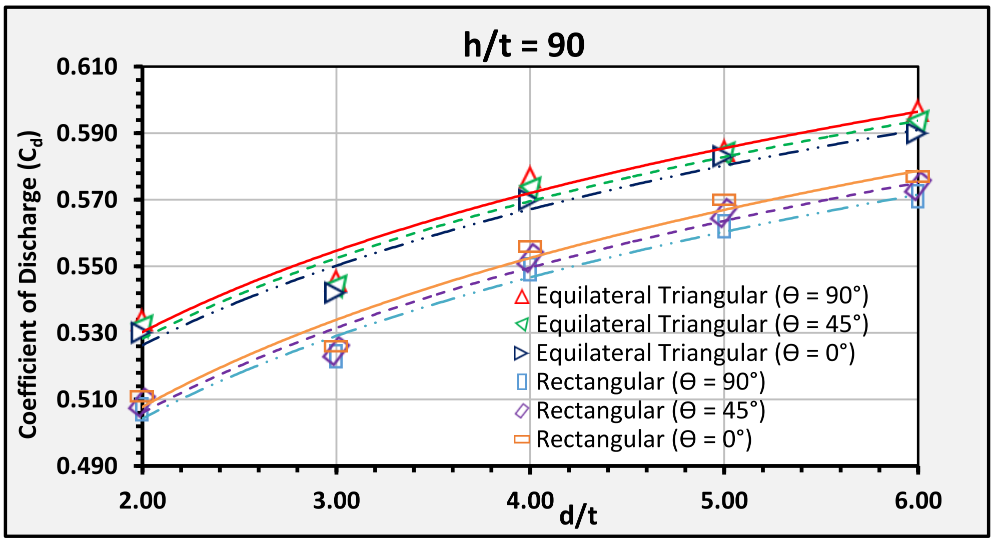


Fig. 12. Relationship between "d/t" and "C_d" (at h/t = 90).

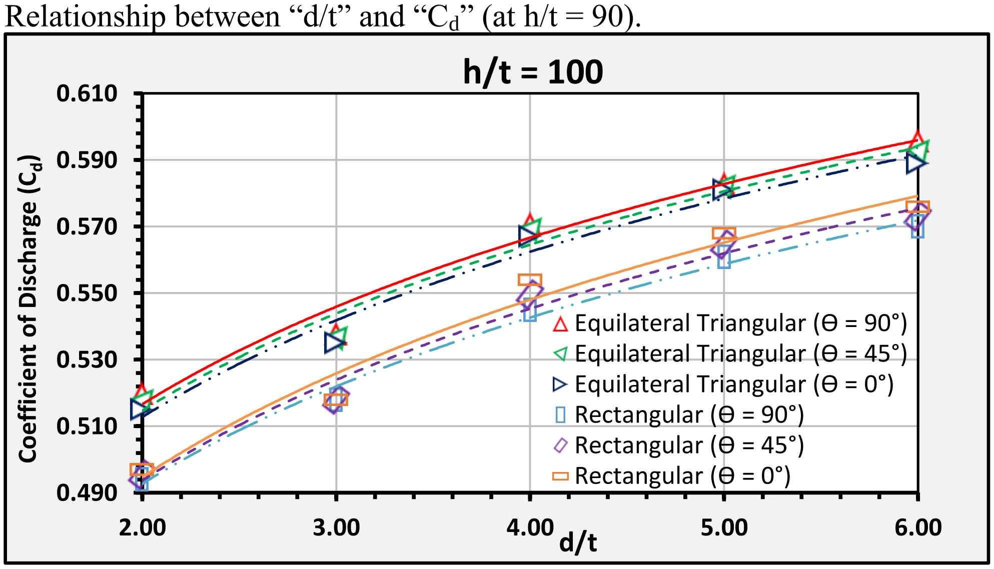


Fig. 13. Relationship **Fig. 13.** Relationship between "d/t" and "C_d" (at h/t = 100).

4.2 Effect of the ration (h/t) at three orifice angles on the C_d:

This part of analysis was done to study if the effect of orifice orientation (θ) on the C_d influenced as the ratio (h/t) changed. To achieve this target, the relationship between head to thickness ratio (h/t) and the C_d was statically analyzed as shown in **Table 2** and plotted as shown in **Figs. 14 to 18** which the X-axis represents the ratio (h/t) and the Y-axis represents the C_d. It is clear from **Figs. 14 to 18** and **Table 2**, the C_d increases by almost constant trend for the tested angles for both shapes. Additionally, the equilateral triangular orifices of $\theta = 90^o$ give the highest values of C_d compared to the other tested angles, while, the rectangular orifices of $\theta = 0^o$ give the highest values of C_d compared to the other tested angles. At all circle diameter of equivalent area, the mean values of the C_d for the two shapes (equilateral triangle and rectangle) at different angles (0^o, 45^o and 90^o) decreases in logarithmic manner with increasing the values of (h/t).

Table 2: Statistical analysis of the results obtained from the experimental data for effect of the values (h/t) at three orifice angles on the C_d.

d/t	Statistics	C_d					
		Equilateral Triangular Orifice			Rectangular Orifice		
		θ = 0°	θ = 45°	θ = 90°	θ = 0°	θ = 45°	θ = 90°
		From (h/t) = 50 to (h/t) = 100					
2	Min	0.515	0.518	0.520	0.497	0.496	0.494
	Max	0.557	0.559	0.561	0.542	0.539	0.536
	Mean	0.540	0.542	0.544	0.524	0.521	0.519
	% Change	**8.16**	**8.02**	**7.88**	**9.05**	**8.78**	**8.50**
3	Min	0.533	0.537	0.538	0.518	0.518	0.518
	Max	0.564	0.566	0.568	0.547	0.546	0.545
	Mean	0.552	0.554	0.556	0.534	0.533	0.532
	% Change	**5.42**	**5.50**	**5.58**	**5.60**	**5.40**	**5.21**
4	Min	0.567	0.569	0.571	0.554	0.550	0.545
	Max	0.385	0.587	0.588	0.568	0.567	0.565
	Mean	0.577	0.579	0.582	0.561	0.559	0.556
	%Change	**3.17**	**3.08**	**2.98**	**2.53**	**3.09**	**3.67**
5	Min	0.581	0.582	0.583	0.568	0.565	0.561
	Max	0.592	0.593	0.594	0.577	0.574	0.570
	Mean	0.586	0.588	0.589	0.573	0.569	0.565
	% Change	**1.89**	**1.89**	**1.89**	**1.58**	**1.59**	**1.60**
6	Min	0.589	0.593	0.596	0.576	0.573	0.570
	Max	0.593	0.597	0.600	0.581	0.578	0.575
	Mean	0.591	0.595	0.598	0.578	0.576	0.573
	% Change	**0.68**	**0.68**	**0.67**	**0.87**	**0.87**	**0.87**

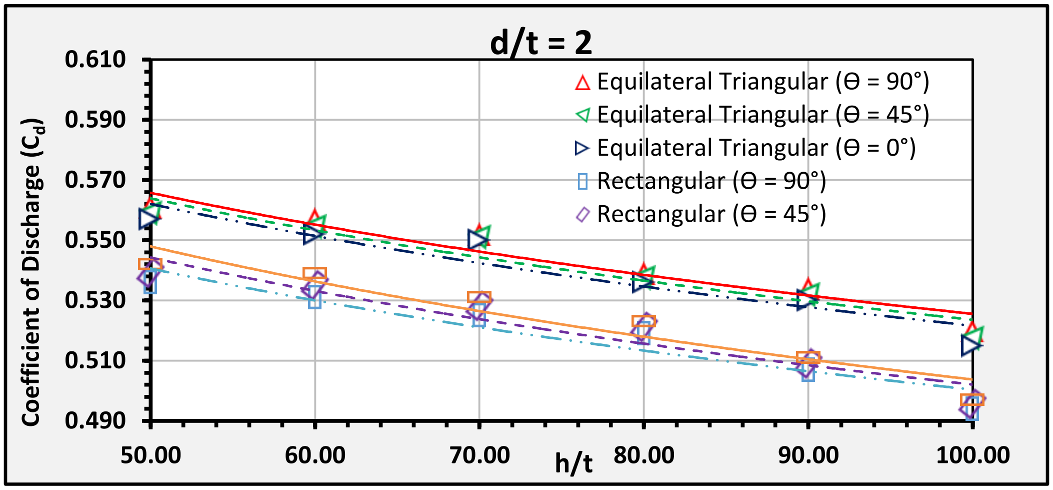


Fig. 14. Relationship between "h/t" and "C_d" (at d/t = 2).

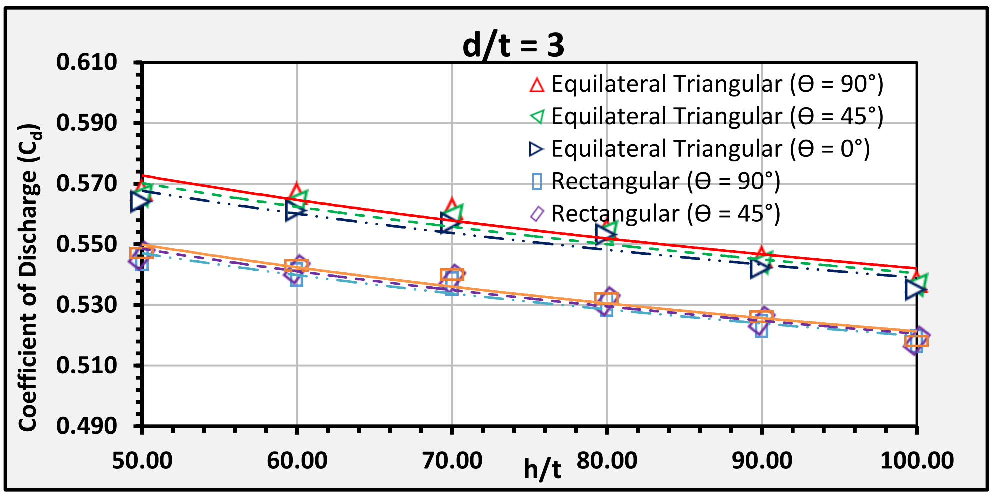


Fig. 15. Relationship between "h/t" and "C_d" (at d/t = 3).

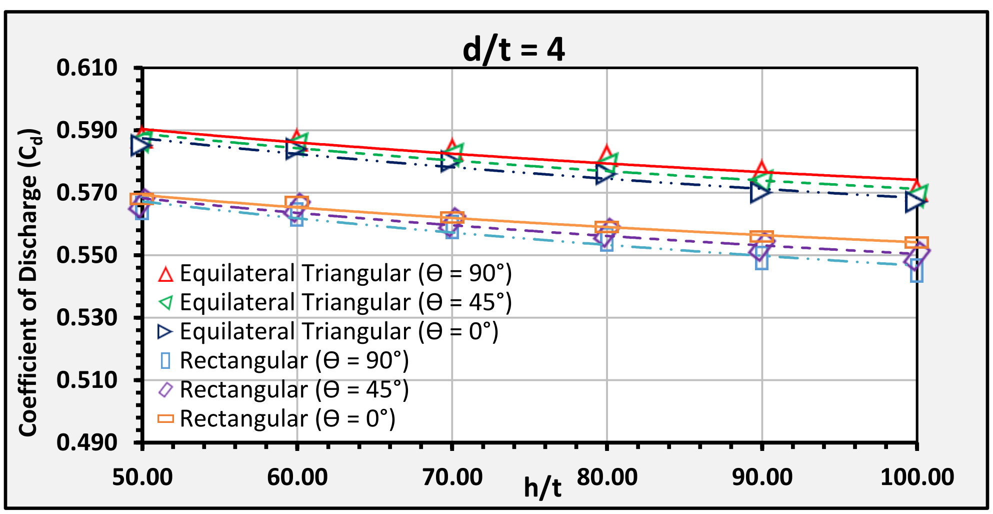


Fig. 17. Relationship between "h/t" and "C_d" (at d/t = 5).

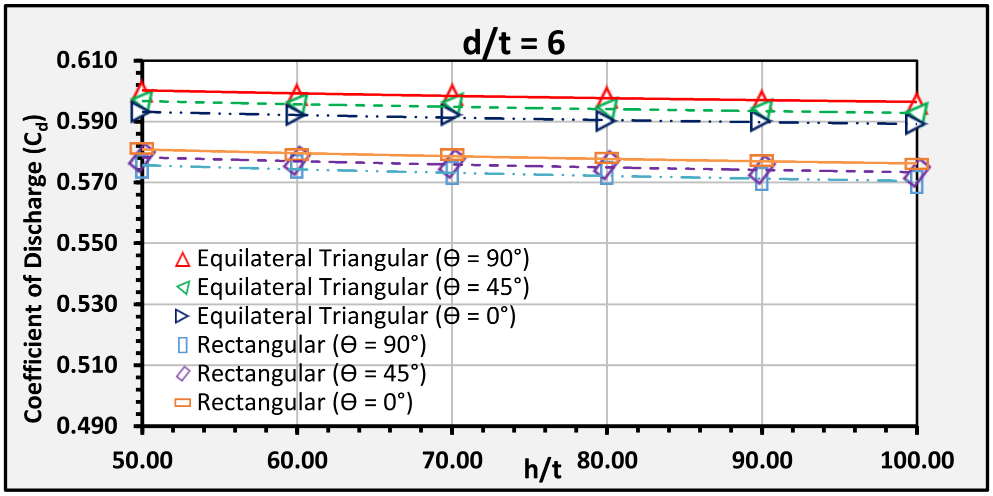


Fig. 18. Relationship between "h/t" and "C_d" (at d/t = 6).

4.3 Design equations and charts:

It is important to associate the factors that may influence the C_d into one general formula. The importance of these formulas lies in its being suitable for design purpose. To achieve this objective, a relationship between the ratio (d/t) and the C_d was plotted at three different angles (0^o, 45^o and 90^o). These plots were done for the two tested shapes.

Fig. 19 to **Fig. 24** show that the C_d increases as the ratio (d/t) increases. The curves begin with high rate of increasing and then the C_d increases in asymptotic manner. Therefore, the logarithmic function is the most appropriate to correlate the parameters.

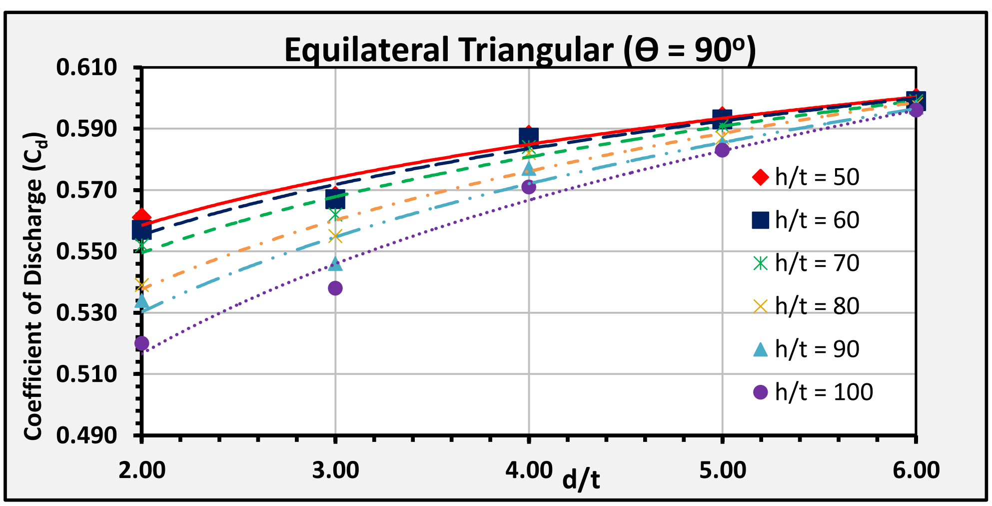


Fig. 19. Relationship between "d/t" and "C_d" (from h/t = 50 to h/t = 100) for Equilateral Triangular (Θ = 90^o).

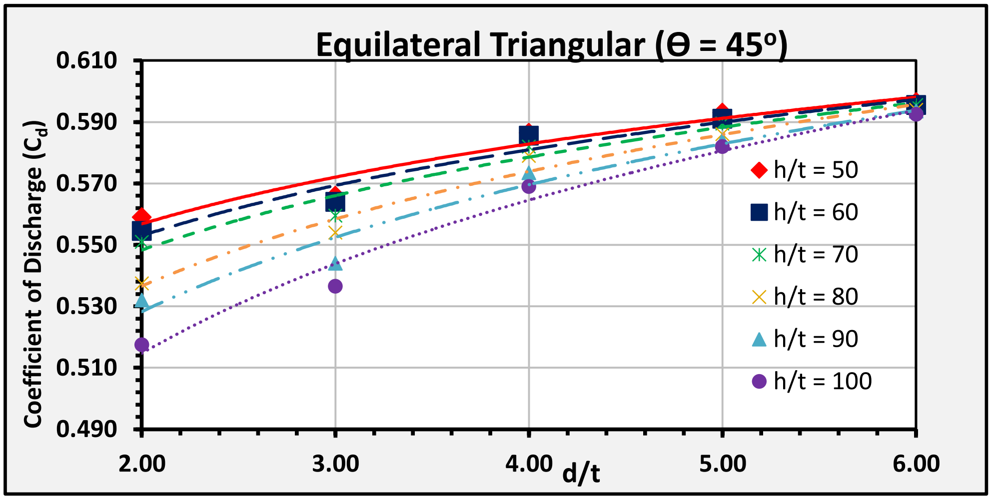


Fig. 20. Relationship between "d/t" and "C_d" (from h/t = 50 to h/t = 100) for Equilateral Triangular (ϴ = 45^o).

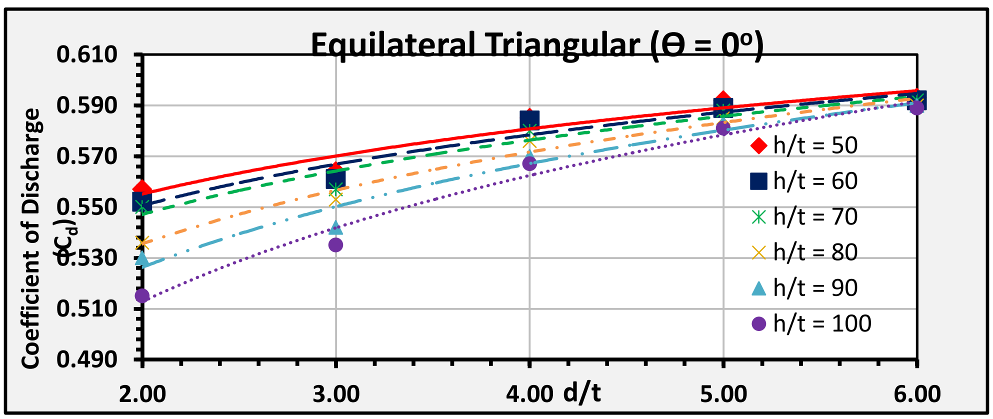


Fig. 21. Relationship between "d/t" and "C_d" (from h/t = 50 to h/t = 100) for Equilateral Triangular (ϴ = 0^o).

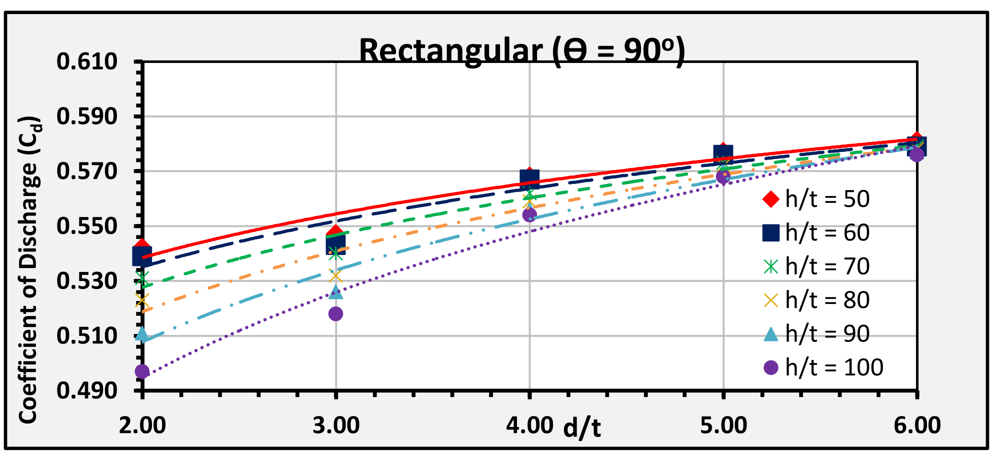


Fig. 22. Relationship between "d/t" and "C_d" (from h/t = 50 to h/t = 100) for Rectangular (Θ = 90°)

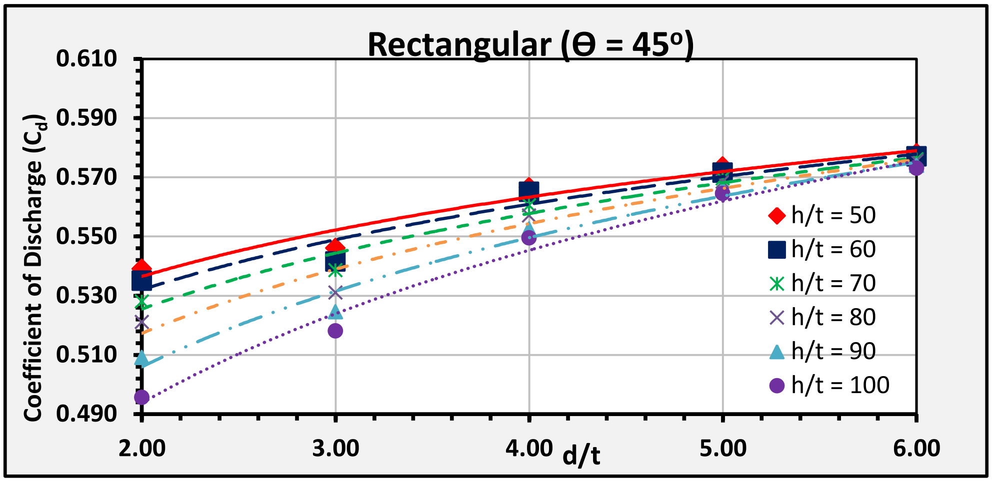


Fig.23 Relationship between "d/t" and "C_d" (from h/t = 50 to h/t = 100) for Rectangular (Θ = 45°).

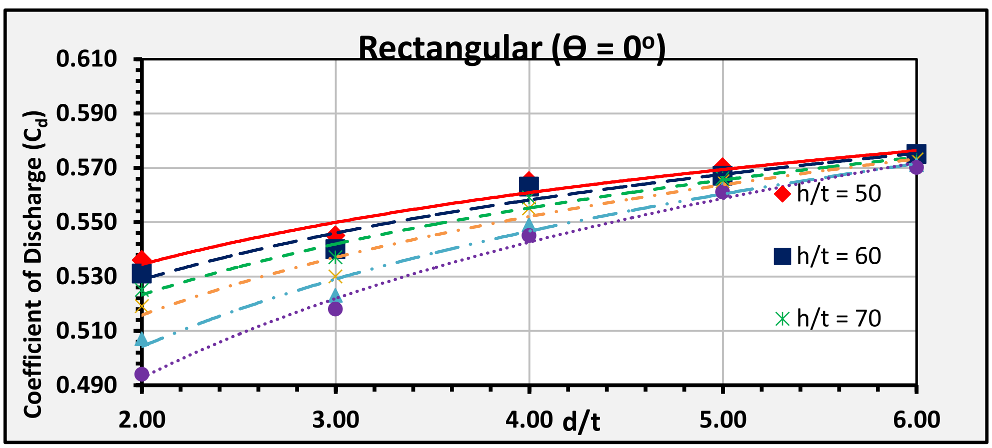


Fig. 24. Relationship between "d/t" and "C_d" (from h/t = 50 to h/t =100) for Rectangular(Θ = 0°).

Logarithmic regression was applied to the experimental results, the following shows the deduced empirical equations and correlation coefficients "R^2":

- **Equilateral triangular orifice equations for calculating C_d:**

($\Theta = 90^o$)

For (h/t) = 50: $$C_d = 0.038 \ln\left(\frac{d}{t}\right) + 0.5321$$ $R^2 = 0.9547$ **Eq. 6**

For (h/t) = 60: $$C_d = 0.0405 \ln\left(\frac{d}{t}\right) + 0.5273$$ $R^2 = 0.9692$ **Eq. 7**

For (h/t) = 70: $$C_d = 0.045 \ln\left(\frac{d}{t}\right) + 0.5273$$ $R^2 = 0.9681$ **Eq. 8**

For (h/t) = 80: $$C_d = 0.0554 \ln\left(\frac{d}{t}\right) + 0.4992$$ $R^2 = 0.9724$ **Eq. 9**

For (h/t) = 90: $$C_d = 0.0630 \ln\left(\frac{d}{t}\right) + 0.4885$$ $R^2 = 0.9597$ **Eq. 10**

For (h/t) = 100: $$C_d = 0.0722 \ln\left(\frac{d}{t}\right) + 0.4666$$ $R^2 = 0.9770$ **Eq. 11**

($\Theta = 45^o$)

For (h/t) = 50: $$C_d = 0.0375 \ln\left(\frac{d}{t}\right) + 0.5308$$ $R^2 = 0.9462$ **Eq. 12**

For (h/t) = 60: $$C_d = 0.0403 \ln\left(\frac{d}{t}\right) + 0.5250$$ $R^2 = 0.9563$ **Eq. 13**

For (h/t) = 70: $$C_d = 0.0436 \ln\left(\frac{d}{t}\right) + 0.5181$$ $R^2 = 0.9576$ **Eq. 14**

For (h/t) = 80: $$C_d = 0.0538 \ln\left(\frac{d}{t}\right) + 0.4993$$ $R^2 = 0.9778$ **Eq. 15**

For (h/t) = 90: $$C_d = 0.0596 \ln\left(\frac{d}{t}\right) + 0.4870$$ $R^2 = 0.9633$ **Eq. 16**

For (h/t) = 100: $$C_d = 0.0719 \ln\left(\frac{d}{t}\right) + 0.4649$$ $R^2 = 0.9786$ **Eq. 17**

($\Theta = 0^o$)

For (h/t) = 50: $$C_d = 0.0370 \ln\left(\frac{d}{t}\right) + 0.5295$$ $R^2 = 0.9318$ **Eq. 18**

For (h/t) = 60: $$C_d = 0.0401 \ln\left(\frac{d}{t}\right) + 0.5228$$ $R^2 = 0.9399$ **Eq. 19**

For (h/t) = 70: $$C_d = 0.0422 \ln\left(\frac{d}{t}\right) + 0.5179$$ $R^2 = 0.9430$ **Eq. 20**

For (h/t) = 80: $$C_d = 0.0521 \ln\left(\frac{d}{t}\right) + 0.4994$$ $R^2 = 0.9793$ **Eq. 21**

For (h/t) = 90: $C_d = 0.0589 \ln\left(\frac{d}{t}\right) + 0.4855$ $R^2 = 0.9640$ **Eq. 22**

For (h/t) = 100: $C_d = 0.0716 \ln\left(\frac{d}{t}\right) + 0.4631$ $R^2 = 0.9784$ **Eq. 23**

- **Rectangular orifice equations for calculating C_d:**

(ϴ = 90°)

For (h/t) = 50: $C_d = 0.0393 \ln\left(\frac{d}{t}\right) + 0.5113$ $R^2 = 0.9362$ **Eq. 24**

For (h/t) = 60: $C_d = 0.0412 \ln\left(\frac{d}{t}\right) + 0.5066$ $R^2 = 0.9169$ **Eq. 25**

For (h/t) = 70: $C_d = 0.0470 \ln\left(\frac{d}{t}\right) + 0.4951$ $R^2 = 0.9627$ **Eq. 26**

For (h/t) = 80: $C_d = 0.0547 \ln\left(\frac{d}{t}\right) + 0.4809$ $R^2 = 0.9519$ **Eq. 27**

For (h/t) = 90: $C_d = 0.0646 \ln\left(\frac{d}{t}\right) + 0.4630$ $R^2 = 0.9698$ **Eq. 28**

For (h/t) = 100: $C_d = 0.0769 \ln\left(\frac{d}{t}\right) + 0.4414$ $R^2 = 0.9734$ **Eq. 29**

(ϴ = 45°)

For (h/t) = 50: $C_d = 0.0387 \ln\left(\frac{d}{t}\right) + 0.5097$ $R^2 = 0.9509$ **Eq. 30**

For (h/t) = 60: $C_d = 0.0417 \ln\left(\frac{d}{t}\right) + 0.5031$ $R^2 = 0.9405$ **Eq. 31**

For (h/t) = 70: $C_d = 0.0466 \ln\left(\frac{d}{t}\right) + 0.4932$ $R^2 = 0.9700$ **Eq. 32**

For (h/t) = 80: $C_d = 0.0535 \ln\left(\frac{d}{t}\right) + 0.4802$ $R^2 = 0.9601$ **Eq. 33**

For (h/t) = 90: $C_d = 0.0629 \ln\left(\frac{d}{t}\right) + 0.4624$ $R^2 = 0.9760$ **Eq. 34**

For (h/t) = 100: $C_d = 0.0745 \ln\left(\frac{d}{t}\right) + 0.4421$ $R^2 = 0.9839$ **Eq. 35**

(ϴ = 0°)

For (h/t) = 50: $C_d = 0.0380 \ln\left(\frac{d}{t}\right) + 0.5081$ $R^2 = 0.9598$ **Eq. 36**

For (h/t) = 60: $C_d = 0.0423 \ln\left(\frac{d}{t}\right) + 0.4996$ $R^2 = 0.9543$ **Eq. 37**

For (h/t) = 70: $C_d = 0.0461 \ln\left(\frac{d}{t}\right) + 0.4914$ $R^2 = 0.9738$ **Eq. 38**

For (h/t) = 80: $C_d = 0.0523 \ln\left(\frac{d}{t}\right) + 0.4796$ $R^2 = 0.9672$ **Eq. 39**

For (h/t) = 90: $C_d = 0.0612 \ln\left(\frac{d}{t}\right) + 0.4618$ $R^2 = 0.9816$ **Eq. 40**

For (h/t) = 100: $C_d = 0.0720 \ln\left(\frac{d}{t}\right) + 0.4428$ $R^2 = 0.9921$ **Eq. 41**

5. CONCLUSIONS

The following conclusions were deduced around the effect of orifice angle on the C_d for water flow through orifices.

1. For all tested angles, (0^o, 45^o and 90^o), it is obvious that in every case of pressure head and orifice area, triangular orifice always gives higher values of the C_d than the rectangular orifice.
2. For equilateral triangular orifice, as the angle θ decreases (Head of the triangle moves from the top to be on left or right), the C_d increases in logarithmic manner.
3. The orifice angle influences the C_d of rectangular orifices, i.e. the more horizontal the orifice, the greater the C_d.
4. For all tested angles, the C_d decreases as the head to thickness ratio (h/t) increases while it increases as the diameter to thickness ratio (d/t) increases.
5. Empirical equations were conducted (for all tested angles) to describe the manner of variation of the C_d at six values of the ratio (h/t). The equations showed that the variation occurs gradually in asymptotic behavior.

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