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EFFECT OF VARYING ORIFICE THICKNESS ON THE DISCHARGE COEFFICIENT FOR DIFFERENT ORIFICES SHAPES

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Abstract. One of the most important factors to be studied carefully is the discharge coefficient “Cd” through the orifices, which reflects the efficiency of the flow and plays an important role in the design of hydraulic units. The purpose of this paper is to investigate experimentally the effect of changing orifice thickness on the discharge coefficient for water flow through different orifice shapes and comparing each other. To achieve this goal, four orifices shapes were used: circular, square, equilateral triangle and rectangular, five different thicknesses (9.25, 7.5, 6.75, 4 and 2 mm) were tested. It should be noted that the tests were conducted on four different values of the pressure heads affecting the center of the hole: (35, 40, 45 and 50 cm). Bernoulli's equation was used as a theoretical basis for calculating the discharge coefficient.

The results of the study demonstrated that the changing in the thickness of the orifice affects the coefficient of discharge. The coefficient of discharge gradually decreases when the ratio (orifice thickness “t”/orifice equivalent diameter “d”) increases, with the fixity of both the orifice area and the vertical pressure head located above the center of the orifice. In all the analytical comparisons made in this study it was observed that circular orifices give the highest values of the coefficient of discharge compared to all other shapes followed by equilateral triangular orifices and then square orifices and finally it was observed that rectangular orifices give the lowest values of the coefficient of discharge.

1. INTRODUCTION

Knowledge of the orifice flow performance has a significant importance in several fields, such as flow measurement devices, dams, piping systems, and fuel injection into combustion engines [1]. The coefficient of discharge (C_d) of an orifice is very substantial parameter as it is considered the efficiency of the orifice flow. Also, Orifice flow has been used extensively for flow control and flow restriction. The geometric characteristics associated with orifice flow are the most important factors affecting the discharge coefficient. Previous research attempts emphasized the existence of relationships between the orifice geometric characteristics and the discharge coefficient. For example ***Parshad et al.*** investigated the effect of orifice diameter on the coefficient of discharge [2]. Also, ***Abd, Alomar, and Mohamed*** experimentally investigated the flow characteristics of different diameter sharp-edged orifices [3]. Moreover, the discharge coefficient for water passing through a circular orifice cut into a thin-walled vertical riser pipe was investigated by ***Prohaska*** [4]. In the same context, ***McLemore et al*** made an interesting study about studying the discharge coefficients for orifices cut into rounded pipes [5]. Additionally, ***Ramamurthi and Nandakumar*** investigated the discharge coefficients for flow passing through small sharp edged cylindrical orifices [6]. However, no researches were showed the effect of orifice thickness on the discharge coefficient as a comparative study between different orifice shapes. Accordingly, this research was initiated with the objective of comparing the thickness effect on the discharge coefficient (C_d) for four different orifice shapes (circle, square, equilateral triangle and rectangle) under four different vertical pressure heads. Moreover, this research aims to establishing design equations and charts for each orifice shape that can be used in hydraulic design.

2. THEORITICAL BACKGROUND

Before describing the experimental works, a brief explanation about underlying theory of fluid mechanics must be provided. The governing theory utilized in this paper is Bernoulli's Theorem that comes originally from the integral form [7]:

$$\int_1^2 \frac{\partial V}{dt} ds + \int_1^2 \frac{dP}{\rho} + \frac{1}{2}(V_2^2 - V_1^2) + g(z_2 - z_1) = zero \qquad \textit{Eq. 1}$$

Where, P is the pressure, ρ is density of fluid, v_1, v_2 are average (uniform) flow velocity at points 1 and 2, respectively, and g is the gravitational acceleration.

This is Bernoulli's equation for unsteady frictionless flow along a streamline. It is in differential form and can be integrated between any two points 1 and 2 on the streamline ***Figure 1***.

To evaluate the integrals, the unsteady effect ∂V/dt and the variation of density with pressure must be estimated. Currently, we consider only steady (∂V/dt = 0) incompressible (constant- density) flow, for which ***Eq. 1*** becomes:

$$h + \frac{P_1}{\rho g} + \frac{{v_1}^2}{2g} = \frac{P_2}{\rho g} + \frac{{v_2}^2}{2g} + losses \qquad \textit{Eq. 2}$$

The pressure of point (2) can be assumed to be zero because the orifice discharges water into the atmosphere, and the velocity at point (1) is small enough which can be ignored. By replacing (P_1/γ) with ho and solving for v_2. ***Eq. 2*** can be re-written as:

$$v_2 = \sqrt{2g(h - h_L)} \qquad \textit{Eq. 3}$$

It is proper to rewrite the equation with the velocity coefficient rather than subtracting the head loss, resulting in:

$$v_2 = C_v\sqrt{2gh} \qquad \textit{Eq. 4}$$

Coefficient of velocity have been investigated experimentally in one of the previous studies for (2– 6) cm diameter orifices and for heads between (0 – 30) m. The investigation concluded that C_d varies from 0.951 to 0.993 and as the head decreases, the velocity coefficient slightly decreases [8].

By combining the coefficient of contraction C_c and the coefficient of velocity 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:

$$Q = C_d A\sqrt{2gh} \qquad \textit{Eq. 5}$$

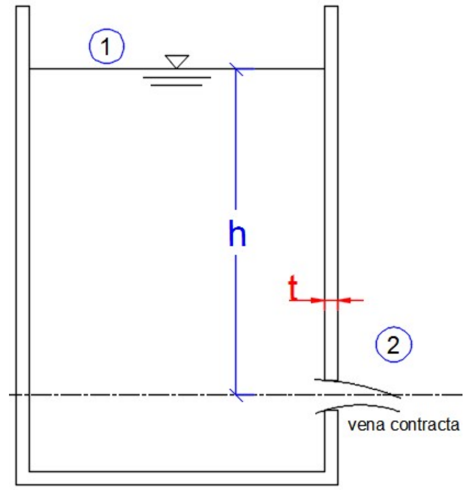


Figure 1: Vena-contracta effect for a sharp-edged orifice [9].

3. DIMENSIONL 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 thicknesses. All parameters and geometry, affecting the discharge coefficient (C_d), are defined in ***Figure 2.***

Functional relationships are obtained between the discharge coefficients (C_d) for all parameter.

In this study: the discharge coefficient (C_d) is the dependent variable. It can be expressed as a function of all other independent variables as follows:

Function of all other independent variables as follows:

$$C_d = \varphi(\rho, g, \mu, v, d, t, h, k) \qquad \textbf{Eq. 6}$$

Where, ρ is the density of fluid, g is the gravity acceleration, μ is the dynamic viscosity, v is the velocity, d is the orifice diameter, t is the orifice thickness, h is the pressure head and k is the coefficient reflecting the orifice shape.

Using Buckingham's π-Theorem, eight variables and three repeated changes were obtained. These changes can be easily coordinated in the following non -dimensional π-terms.

$$\pi_1 = \frac{h}{d}, \quad \pi_2 = \frac{t}{d}, \quad \pi_3 = \frac{v}{\sqrt{gh}}, \quad \pi_4 = \frac{\mu}{\rho h\sqrt{gh}} \text{ and } \quad \pi_5 = k$$

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

$$C_d = \varphi\left(\frac{h}{d}, \frac{t}{d}, \frac{v}{\sqrt{gh}}, \frac{\mu}{\rho h\sqrt{gh}}, k\right) \qquad \textbf{Eq. 7}$$

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

$$C_d = \varphi\left(\frac{h}{d}, \frac{t}{d}, k\right) \qquad \textbf{Eq. 8}$$

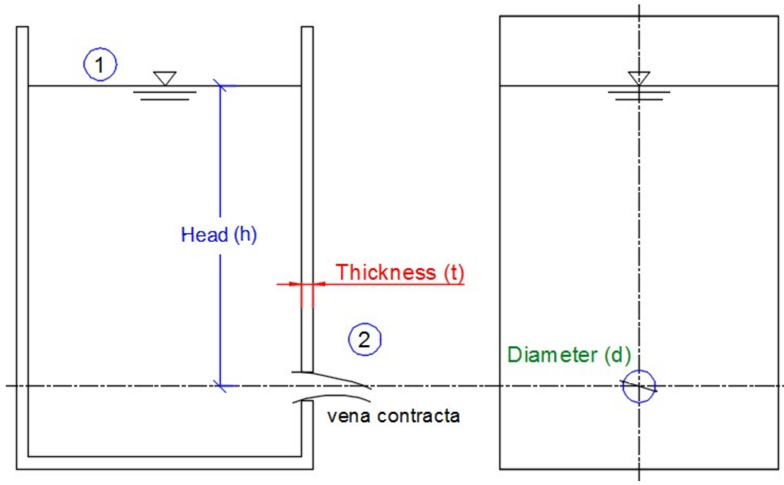


Figure 2: Definition sketch of all parameters.

4. EXPERIMENTAL WORK

4.1. Physical Modeling

In order to achieve the goal of the experimental work, a laboratory physical model was constructed ***Figure 3*** and ***Figure 4***. The model mainly consists of two tanks, lower and upper. Both tanks are formed of transparent acrylic plastic to be easy in laser cutting and to allow visual observation of the water flow. The lower tank (collecting tank) was designed to collect water passing through the orifices and recycle it into the upper tank. To do that, a centrifugal pump was installed to raise water from the lower to the upper tank. The upper tank was designed to keep constant water head above the orifice.

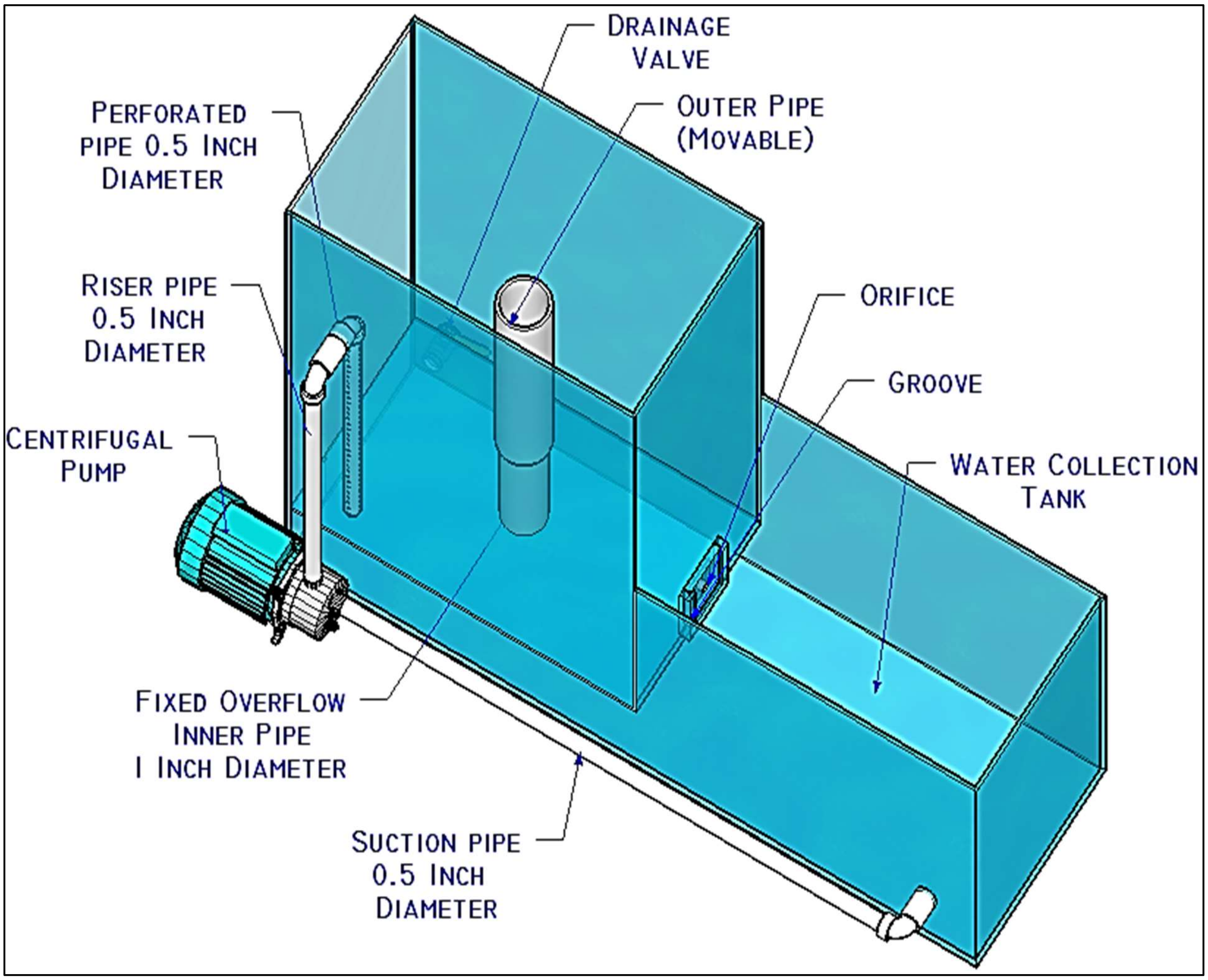


Figure 3: Model isometric definition sketch

Figure 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 thickness on the discharge coefficient, 20 orifice plates (7cm. x 7cm.) each was manufactured from transparent acrylic plastic. Orifices were cut using laser technology. The shown groove ***Figure 5*** was designed to be fixed into the tank wall to facilitate changing the orifice plates.

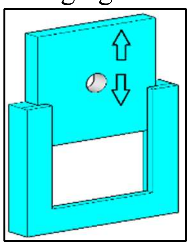


Figure 5: Groove to change the orifice plate

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.

4.2. Discharge Measurement

The discharge was calculated by measuring the water volume discharged out of an orifice in a known time. This volume was determined by collecting water in a graduated container and the discharge was calculated by dividing the collected volume by the time. Each run was carried out three (3) times and the average discharge was taken.

4.3. Experimental Program

The experimental program was designed in order to observe the discharge coefficient for four (4) orifice shapes [circle, square, equilateral triangle and rectangle whose length equals twice its width (Length/Width =2)]. These experiments were done with constant orifice area (A = 78.54 mm^2) which is equivalent to circle of diameter (d = 10 mm). All shapes were tested under the action of four (4) different pressure heads above the center of the orifice (35, 40, 45, and 50 cm.). Also, five (5) orifice thicknesses was tested (9.25, 7.5, 6.75, 4, and 2 mm.). ***Figure 6*** shows samples of real photos of the orifice plates.

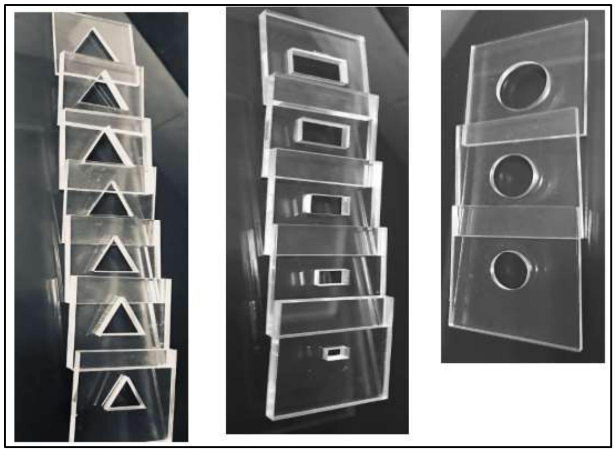


Figure 6: Real photos of the orifice plates (samples).

5. RESULTS ANALYSIS AND DISCUSSIONS

Using the collected experimental data ***Table 1***, the results were represented in comparative way in which all tested shapes (circle, square, equilateral triangle and rectangle) are plotted in the same graph. The charts represent the relation between the ratio (t/d) and the C_d in which ***X-axis*** represents the ratio (t/d) and ***Y-axis*** represents the C_d. (t) is the orifice thickness and (d) is the diameter of equivalent circle which has constant area (A = 78.54 mm^2).

Table 1: Results obtained from the experimental data.

t	h	h/d	t/d	C_d			
				Circular Orifice	Equilateral Triangular Orifice	Square Orifice	Rectangular Orifice
2	35	3.5	0.200	0.585	0.576	0.564	0.556
4	35	3.5	0.400	0.573	0.561	0.549	0.541
6.75	35	3.5	0.680	0.556	0.546	0.532	0.525
7.5	35	3.5	0.750	0.546	0.539	0.524	0.515
9.25	35	3.5	0.930	0.539	0.531	0.516	0.509
2	40	4	0.200	0.570	0.565	0.552	0.547
4	40	4	0.400	0.558	0.550	0.541	0.533
6.75	40	4	0.680	0.539	0.535	0.522	0.519
7.5	40	4	0.750	0.530	0.521	0.512	0.506
9.25	40	4	0.930	0.524	0.515	0.503	0.499
2	45	4.5	0.200	0.563	0.558	0.546	0.536
4	45	4.5	0.400	0.549	0.542	0.533	0.522

6.75	45	4.5	0.680	0.529	0.527	0.515	0.503
7.5	45	4.5	0.750	0.522	0.516	0.505	0.496
9.25	45	4.5	0.930	0.515	0.510	0.499	0.489
2	50	5	0.200	0.548	0.546	0.534	0.522
4	50	5	0.400	0.535	0.533	0.520	0.510
6.75	50	5	0.680	0.516	0.513	0.499	0.489
7.5	50	5	0.750	0.505	0.500	0.490	0.480
9.25	50	5	0.930	0.499	0.494	0.483	0.473

***Figure** 7* to ***Figure** 10* show the relationship between (t/d) and the C_d which was tested at (4) different pressure heads. In this regard, four figures were plotted with twenty 20 measured C_d for each figure. [Four (4) shapes and four (5) measured C_d for each shape].

From the plotted figures, it could be noticed that the discharge coefficient C_d is inversely proportional to the orifice thickness. Also, the increase of (t/d) decreases the discharge coefficient C_d. In nearly every case of pressure head, the discharge coefficient C_d decreases by almost constant trend as the ratio (t/d) increases for all tested shapes. Additionally, it is obvious that the circular shape has the highest values of C_d compared to other shapes.

The following details describes each graph individually [from (t/d) = 0.2 to (t/d) = 0.93]:

- ***Figure 7*** shows that at head = 35 cm [from (t/d) = 0.2 to (t/d) = 0.93], the value of the discharge coefficient ranges from 0.585 to 0.539 with average value of 0.560 for circular shape, from 0.576 to 0.531 with average value of 0.551 for triangular shape, from 0.564 to 0.516 with average value of 0.537 for square shape, and from 0.556 to 0.509 with average value of 0.529 for rectangular shape.
- ***Figure 8*** shows that at head = 40 cm [from (t/d) = 0.2 to (t/d) = 0.93], the value of the discharge coefficient ranges from 0.570 to 0.524 with average value of 0.544 for circular shape, from 0.565 to 0.515 with average value of 0.537 for triangular shape, from 0.552 to 0.503 with average value of 0.526 for square shape, and from 0.547 to 0.499 with average value of 0.521 for rectangular shape.
- ***Figure 9*** shows that at head = 45 cm [from (t/d) = 0.2 to (t/d) = 0.93], the value of the discharge coefficient ranges from 0.563 to 0.515 with average value of 0.536 for circular shape, from 0.558 to 0.510 with average value of 0.531 for triangular shape, from 0.546 to 0.499 with average value of 0.520 for square shape, and from 0.536 to 0.489 with average value of 0.509 for rectangular shape.
- ***Figure 10*** shows that at head = 50 cm [from (t/d) = 0.2 to (t/d) = 0.93], the value of the discharge coefficient ranges from 0.548 to 0.499 with average value of 0.521 for circular shape, from 0.546 to 0.494 with average value of 0.517 for triangular shape, from 0.534 to 0.483 with average value of 0.505 for square shape, and from 0.522 to 0.473 with average value of 0.495 for rectangular shape.

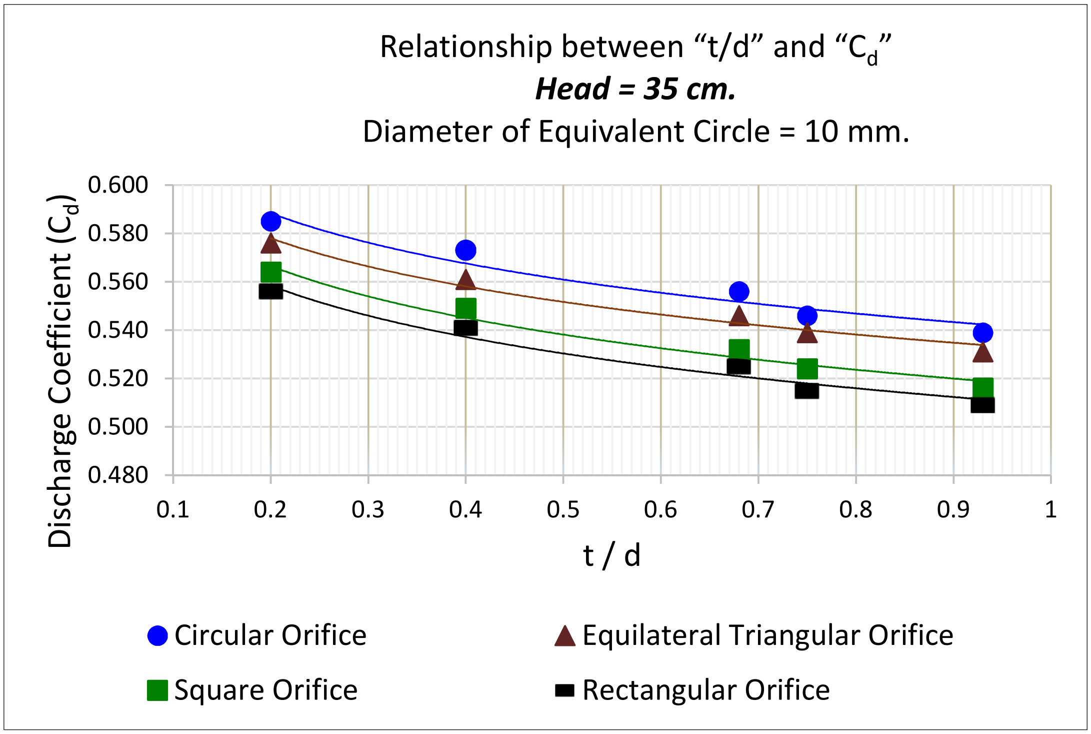


Figure 7: Relationship between "t/d" and "C_d" (at h = 35 cm).

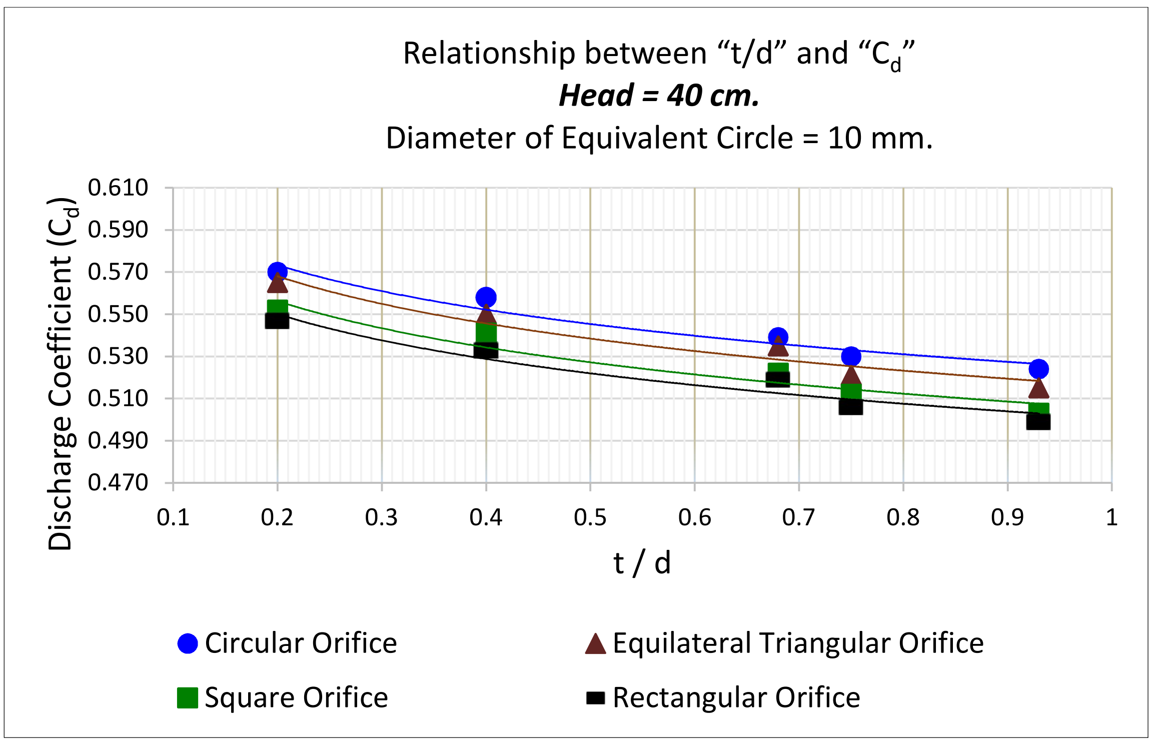


Figure 8: Relationship between "t/d" and "C_d" (at h = 40 cm).

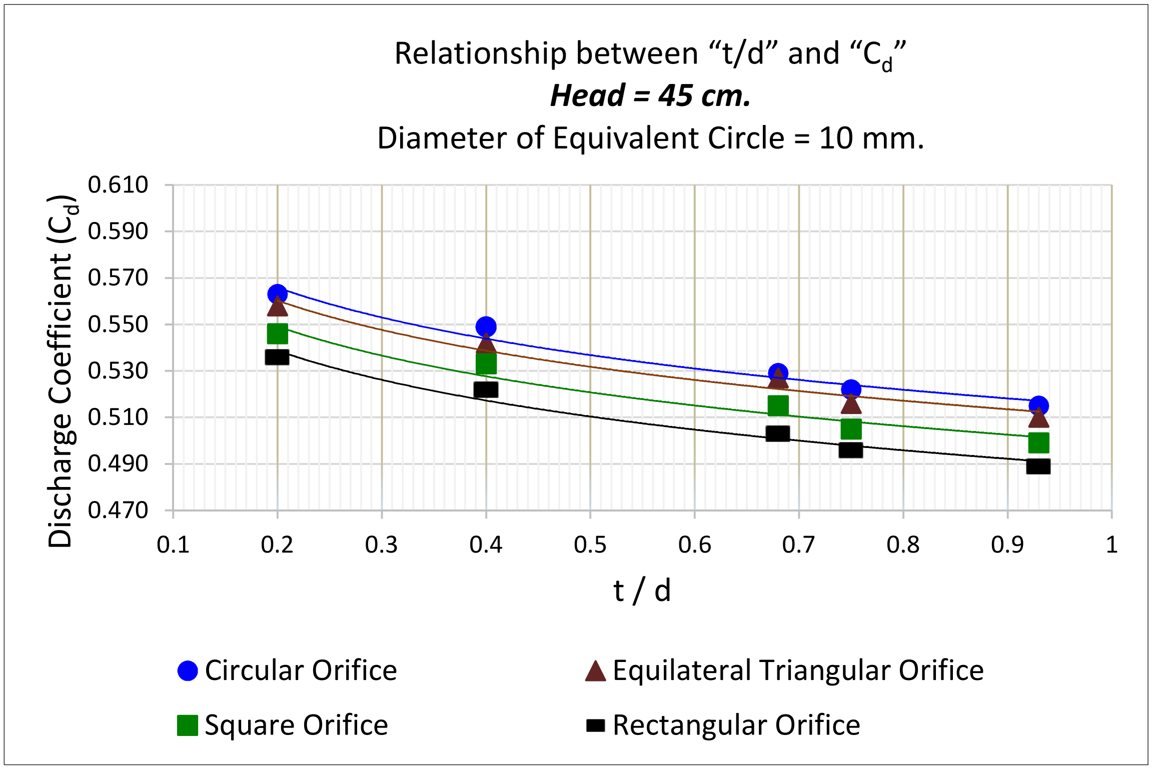


Figure 9: Relationship between “t/d” and “C_d” (at h = 45 cm).

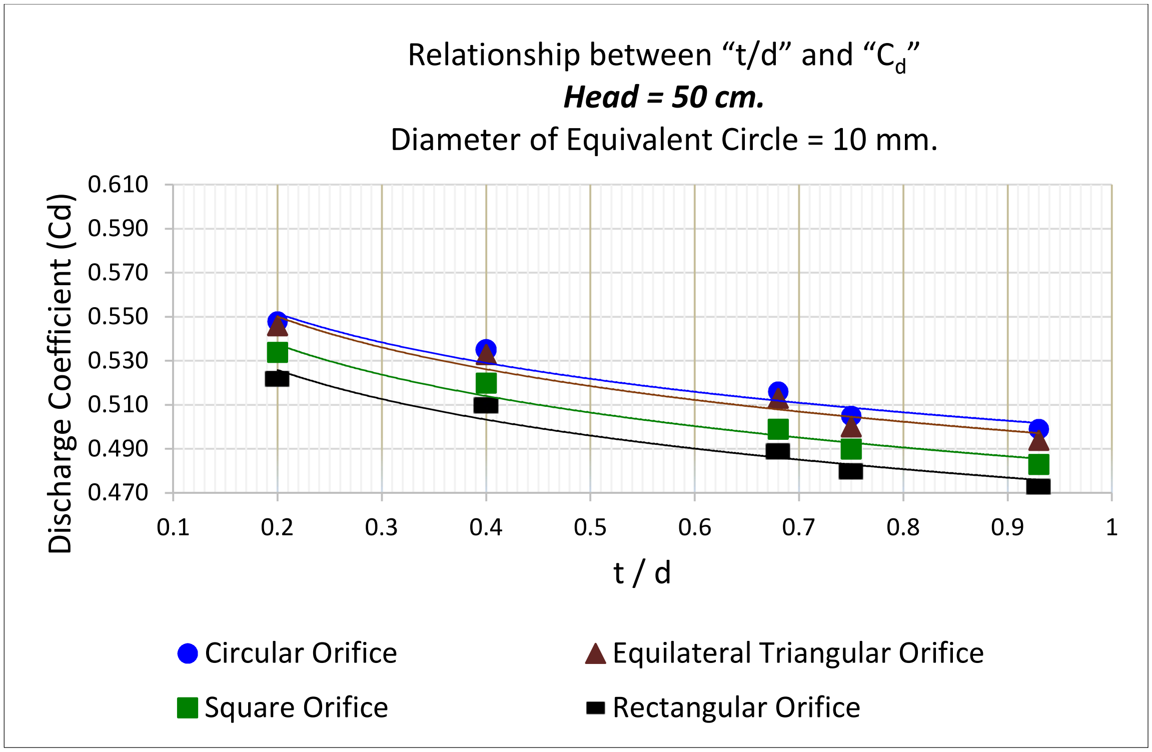
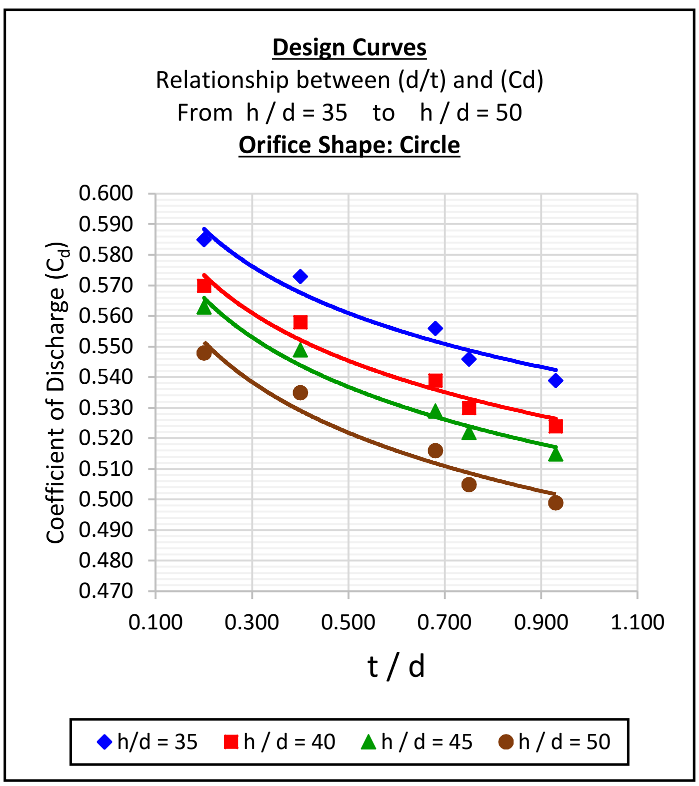


Figure 10: Relationship between “t/d” and “Cd” (at h = 50 cm).

6. DESIGN EQUATIONS AND CHARTS

After examining and discussing the effect of the orifice thickness on the C_d, it is essential to correlate them into one empirical equation. The significance of this empirical equation lies in its being fit for design purpose. To achieve this target, a relationship between the ratio (t/d) and the C_d was plotted at four (4) different ratios of (h/d). These plots were done for all tested shapes.

Figure 7, ***Figure 8***, ***Figure 9*** and ***Figure 10*** show that the C_d decreases as the ratio (t/d) increases. The curves begin with high rate of decreasing and then the C_d decreases in asymptotic manner. Therefore, the logarithmic function is the most appropriate to correlate the parameters (area (A), thickness (t), and head (h)).



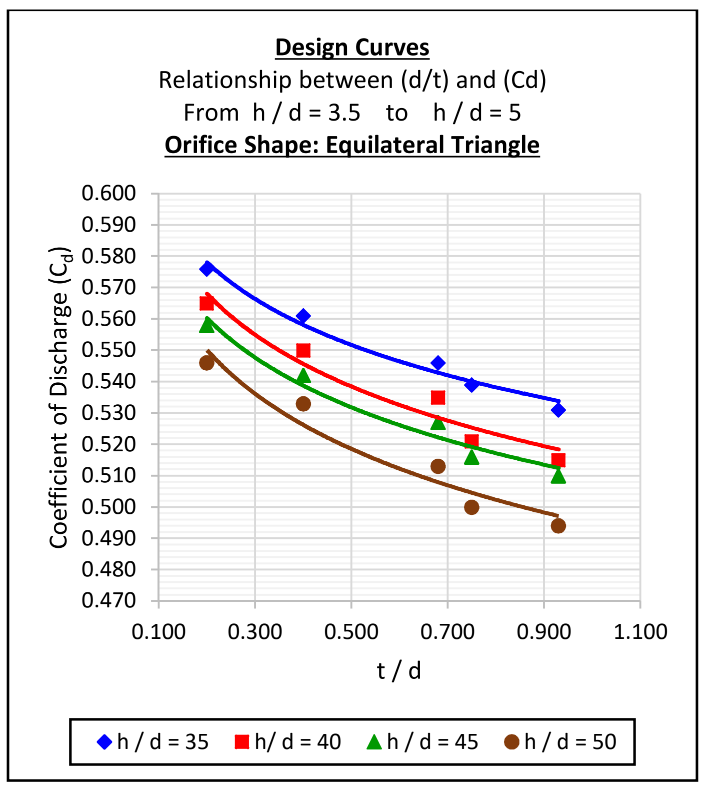


Figure 12: **(t/d) vs. (C_d) for circular orifice at h/d = 35 to h/d = 50**

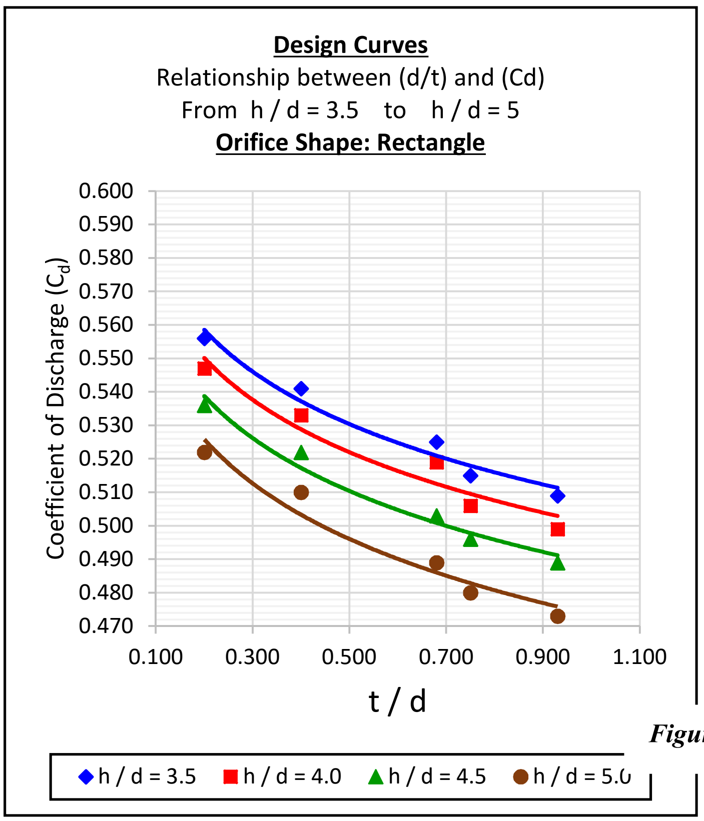


Figure 11: **(t/d) vs. (C_d) for eq. triangular orifice at h/d = 35 to h/d = 50**

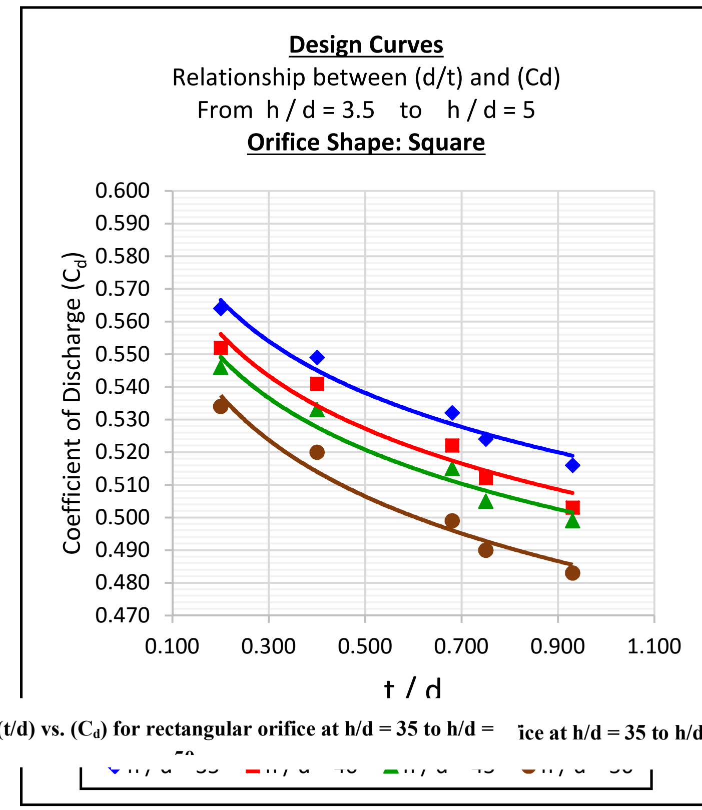


Figure 14: **(t/d) vs. (C_d) for rectangular orifice at h/d = 35 to h/d = ice at h/d = 35 to h/d = 50**

The logarithmic regression was applied the experimental results, the following shows the deduced empirical equations:

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

For (h/d) = 35: $$C_d = -0.03\ ln\left(\frac{t}{d}\right) + 0.5402$$ ***Eq. 9***

For (h/d) = 40: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.5242$$ ***Eq. 10***

For (h/d) = 45: $$C_d = -0.032\ ln\left(\frac{t}{d}\right) + 0.5148$$ ***Eq. 11***

For (h/d) = 50: $$C_d = -0.032\ ln\left(\frac{t}{d}\right) + 0.4994$$ ***Eq. 12***

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

For (h/d) = 35: $$C_d = -0.029\ ln\left(\frac{t}{d}\right) + 0.5318$$ ***Eq. 13***

For (h/d) = 40: $$C_d = -0.032\ ln\left(\frac{t}{d}\right) + 0.5160$$ ***Eq. 14***

For (h/d) = 45: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.5102$$ ***Eq. 15***

For (h/d) = 50: $$C_d = -0.034\ ln\left(\frac{t}{d}\right) + 0.4947$$ ***Eq. 16***

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

For (h/d) = 35: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.5167$$ ***Eq. 17***

For (h/d) = 40: $$C_d = -0.032\ ln\left(\frac{t}{d}\right) + 0.5053$$ ***Eq. 18***

For (h/d) = 45: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.4993$$ ***Eq. 19***

For (h/d) = 50: $$C_d = -0.034\ ln\left(\frac{t}{d}\right) + 0.4831$$ ***Eq. 20***

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

For (h/d) = 35: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.5091$$ ***Eq. 21***

For (h/d) = 40: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.5007$$ ***Eq. 22***

For (h/d) = 45: $$C_d = -0.031\ ln\left(\frac{t}{d}\right) + 0.4890$$ ***Eq. 23***

For (h/d) = 50: $$C_d = -0.033\ ln\left(\frac{t}{d}\right) + 0.4735$$ ***Eq. 24***

7. GENERALIZING EQUATIONS INTO GENERAL FORMULA

All of the above equations ***Eq. 9*** to ***Eq. 23*** can be grouped into one general form as follows:

$$\boldsymbol{C_d = -a\ ln\left(\frac{t}{d}\right) + b}$$ ***Eq. 25***

The two constants (a) and (b) are functions of (h/d). The behavior of the two constants was scrutinized by correlating them with (h/d) as independent variable and the two constants (a) and (b) as dependent variable. Tables (1), shows the constants (a) and (b) for all tested shaped.

8. FORMULATING THE CONSTANTS (A) AND (B)

Constant (a) increases logarithmically by increasing (h/d). The following shows the relation correlating the constant (a) with (h/d) for all tested orifice shapes:

Table 2: (h/d) vs. constants (a) and (b) for all tested shapes

Orifice Shape	h / d	a	b
Circular Orifice	35	0.03	0.5402
	40	0.031	0.5242
	45	0.032	0.5148
	50	0.032	0.4994
Equilateral Triangular Orifice	35	0.029	0.5318
	40	0.032	0.516
	45	0.031	0.5102
	50	0.034	0.4947
Square Orifice	35	0.031	0.5167
	40	0.032	0.5053
	45	0.031	0.4993
	50	0.034	0.4831
Rectangular Orifice	35	0.031	0.5091
	40	0.031	0.5007
	45	0.031	0.4890
	50	0.033	0.4735

- ***For Circular Orifice:***

$$a = 0.006\, ln\left(\frac{h}{d}\right) + 0.0089 \qquad \textbf{Eq. 26}$$

$$b = -0.111\, ln\left(\frac{h}{d}\right) + 0.9339 \qquad \textbf{Eq. 27}$$

- ***For Equilateral Triangular Orifice:***

$$a = 0.0118\, ln\left(\frac{h}{d}\right) - 0.0125 \qquad \textbf{Eq. 28}$$

$$b = -0.111\, ln\left(\frac{h}{d}\right) + 0.9339 \qquad \textbf{Eq. 29}$$

- ***For Square Orifice:***

$$a = 0.0065\, ln\left(\frac{h}{d}\right) + 0.0076 \qquad \textbf{Eq. 30}$$

$$b = -0.089\, ln\left(\frac{h}{d}\right) + 0.8348 \qquad \textbf{Eq. 31}$$

- ***For Rectangular Orifice:***

$$a = 0.0048\, ln\left(\frac{h}{d}\right) + 0.0134 \qquad \textbf{Eq. 32}$$

$$b = -0.099\, ln\left(\frac{h}{d}\right) + 0.8626 \qquad \textbf{Eq. 33}$$

Now, final equations of calculating the C_d for every single shape can be formulated by substituting from (***Eq. 26*** - ***Eq. 33***) to the general equation ***Eq. 25*** as follow:

- ***For Circular Orifice:***

$$\boldsymbol{C_d} = -0.006\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0089 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.111\, ln\left(\frac{h}{d}\right) + 0.9339 \qquad \textbf{Eq. 34}$$

- ***For Equilateral Triangular Orifice:***

$$\boldsymbol{C_d} = -0.0118\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) + 0.0125 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.111\, ln\left(\frac{h}{d}\right) + 0.9339 \qquad \textbf{Eq. 35}$$

- ***For Square Orifice:***

$$\boldsymbol{C_d} = -0.0065\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0076 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.089\, ln\left(\frac{h}{d}\right) + 0.8348 \qquad \textbf{Eq. 36}$$

- ***For Rectangular Orifice:***

$$\boldsymbol{C_d} = -0.0048\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0134 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.099\, ln\left(\frac{h}{d}\right) + 0.8626 \qquad \textbf{Eq. 37}$$

The previous empirical equations can be used (for all tested shapes) to calculate the C_d for a given orifice area, thickness and head.

9. CONCLUSIONS

From the above-mentioned investigation phases, some conclusions were deduced around the effect of orifice thickness on the discharge coefficient for water flow through orifices. The deduced conclusions are summarized, as follows:

1. For all analysis stages, it is clear that circular orifice is the best where it gives the highest values of (C_d). Equilateral triangular orifice shape gives the second highest value of (C_d) followed by square shape. Finally, rectangular shape always gives the least value of (C_d).
2. In the context of analyzing the effect of orifice thickness on (C_d), it is obvious from the above analysis for certain orifice shape and head, the (C_d) decreases as the ratio (t/d) increases.
3. Overall, empirical equations obtained shows that analysis of the laboratory data indicated that the rate of change of discharge coefficient (C_d) relative to any parameter is logarithmic (asymptotic).
4. The following empirical equations can be used (for all tested shapes) to calculate the C_d for a given orifice area, thickness and head.

- ***For Circular Orifice:***

$$\boldsymbol{C_d} = -0.006\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0089 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.111\, ln\left(\frac{h}{d}\right) + 0.9339$$

- ***For Equilateral Triangular Orifice:***

$$\boldsymbol{C_d} = -0.0118\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) + 0.0125 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.111\, ln\left(\frac{h}{d}\right) + 0.9339$$

- ***For Square Orifice:***

$$\boldsymbol{C_d} = -0.0065\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0076 \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.089\, ln\left(\frac{h}{d}\right) + 0.8348$$

- ***For Rectangular Orifice:***

$$\boldsymbol{C_d} = -0.0048\, ln\left(\frac{h}{d}\right) \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.0134\, \boldsymbol{ln}\left(\frac{\boldsymbol{t}}{\boldsymbol{d}}\right) - 0.099\, ln\left(\frac{h}{d}\right) + 0.8626$$

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