e-ISSN: 2582-5208
International Research Journal of Modernization in Engineering Technology and Science
(Peer-Reviewed, Open Access, Fully Refereed International Journal)
Volume:05/Issue:06/June-2023 Impact Factor- 7.868 www.irjmets.com

DESIGN AND DEVELOPMENT OF VENTURIMETER AND ORIFICEMETER TEST RIG

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ABSTRACT

The venturimeter and orifice meter are widely used devices in fluid mechanics to measure the flow rate of fluid in a pipe or conduit. These devices work based on the principle of Bernoulli's equation and the concept of pressure difference.

The venturimeter consists of a converging section, a throat, and a diverging section. As the fluid flows through the converging section, its velocity increases, resulting in a decrease in pressure according to Bernoulli's equation. At the throat, the fluid velocity reaches its maximum, causing the pressure to be at its lowest point. Finally, in the diverging section, the fluid velocity decreases, leading to a pressure recovery. By measuring the pressure difference between the converging section and the throat, the flow rate of the fluid can be determined.

The orifice meter, on the other hand, utilizes a plate with a small hole (or orifice) inserted in the pipe. As the fluid passes through the orifice, its velocity increases and the pressure decreases. The pressure difference across the orifice is measured, and based on this pressure difference and the geometry of the orifice, the flow rate can be determined.

Both the venturimeter and orifice meter have their advantages and disadvantages. The venturi meter offers higher accuracy and lower pressure drop compared to the orifice meter, but it requires a larger installation space. On the other hand, the orifice meter is more compact and cost-effective but may introduce more pressure losses.

Keywords: Venturimeter, Bernoulli's Equation, Orificemeter.

I. INTRODUCTION

In fluid mechanics, accurate measurement of flow rate is crucial for various industrial and engineering applications. Two commonly used devices for flow rate measurement are the venturimeter and the orifice meter. These devices operate based on the principles of fluid dynamics and pressure difference.

The venturimeter and orifice meter are designed to measure the flow rate of fluid in a pipe or conduit. They are widely used in industries such as oil and gas, chemical processing, water supply systems, and HVAC (Heating, Ventilation, and Air Conditioning) systems.

The venturimeter is named after its inventor, Italian physicist Giovanni Battista Venturi. It consists of a tapered tube with a narrow throat section. As the fluid flows through the converging section, its velocity increases, causing a decrease in pressure according to Bernoulli's equation. At the throat, the fluid velocity reaches its maximum, resulting in the lowest pressure point. The fluid then flows into the diverging section, where the velocity decreases, and the pressure recovers. By measuring the pressure difference between the converging section and the throat, the flow rate can be determined.

The orifice meter, on the other hand, utilizes a plate with a small hole or orifice inserted in the pipe. The fluid passes through the orifice, causing an increase in velocity and a corresponding decrease in pressure. The pressure difference across the orifice is measured, and based on this pressure difference and the geometry of the orifice, the flow rate can be calculated.

Both the venturimeter and orifice meter have their advantages and limitations. The venturimeter offers higher accuracy and lower pressure drop compared to the orifice meter. However, it requires a larger installation space due to its tapered tube design. On the other hand, the orifice meter is more compact and cost-effective but may introduce higher pressure losses.

These flow measurement devices play a crucial role in process control, efficiency optimization, and system design. They are used to monitor and control fluid flow in various applications, such as monitoring water flow in pipelines, measuring fuel consumption in combustion systems, or regulating flow rates in industrial processes. Understanding the principles and operation of the venturimeter and orifice meter is essential for engineers, technicians, and researchers involved in fluid dynamics, fluid measurement, and process control. Proper selection and accurate calibration of these devices ensure reliable flow rate measurements and efficient operation of fluid systems.

II. PRINCIPLE OF OPERATION

The principle of operation for a venturimeter and orifice meter combo is based on combining the benefits of both devices to improve flow measurement accuracy and range ability.

The venturimeter and orifice meter work on similar principles of fluid flow measurement, utilizing the relationship between fluid velocity and pressure. In the combo setup, the venturimeter is used for high flow rates, while the orifice meter is used for low flow rates.

The venturimeter is placed in the flow path to measure high flow rates accurately. It consists of a converging section, throat, and diverging section. As the fluid flows through the venturimeter, the converging section increases fluid velocity, resulting in a decrease in pressure. The pressure drop across the venturimeter is measured to determine the flow rate.

For low flow rates, the orifice meter is employed. It involves a plate with a precisely machined orifice hole placed in the flow path. The orifice plate creates a restriction that causes a pressure drop across the plate. The pressure difference is measured to determine the flow rate.

In the combo setup, the venturimeter and orifice meter are arranged in series or parallel to allow for flow measurement across a wider range. The venturimeter is positioned in the main flow path to measure high flow rates accurately, while the orifice meter is installed in a bypass or smaller pipe to measure low flow rates.

By combining the two meters, the combo setup offers advantages such as improved accuracy, increased turndown ratio (the ratio of maximum to minimum measurable flow rate), and extended flow range capability. The venturimeter provides accurate measurements at high flow rates, while the orifice meter enhances accuracy at low flow rates. The combined readings from both meters help provide a more comprehensive and reliable flow measurement solution.

It's important to note that the combo setup requires appropriate calibration and consideration of correction factors to account for the specific characteristics of the venturimeter, orifice meter, and their configuration.

III. DESIGN AND MATERIAL SELECTION

Materials :-

In selecting materials for the venturimeter apparatus, the following factors were considered:

- Size and weight of the materials
- Strength of material
- Resistance to service conditions
- Availability, material cost and manufacturing cost.

This design of this venturimeter apparatus for laboratory use was based on component by component method of design. In this process of fabrication, some of the components were bought based on design specification, whileothers were designed and fabricated.

Component Selection :

1. Venturimeter
2. Orificemeter
3. U – tube mercury manometer
4. Pump
5. Measuring tank
6. Sump tank
7. PVC pipe & fitting
8. Nuts , Bolts & Washer

DESIGN AND CALCULATION

1. CALCULATION OF SUMP TANK VOLUME

To calculate the volume of a rectangular water tank with dimensions of 900 mm (length) x 410 mm (height) x 410 mm (width)

1. Convert the dimensions to a consistent unit: Since the dimensions are given in millimetres (mm), it's best to convert them to a common unit, such as cubic centimetres (m^3), to ensure consistency.
2. Length: 900 mm = 0.900 m (since 1 mm = 0.001 m) Height: 410 mm = 0.410 m Width: 410 mm = 0.410 m
3. Calculate the volume: Use the formula V = l * w * h, where V represents the volume, l is the length, w is the width, and h is the height. V = =0.900m * 0.410 m * 0.410 m = 0.15129m^3 = 151.29 Litre
4. Convert the volume to a more convenient unit if desired: The volume obtained above is in cubic centimetres. You can convert it to litters (L) by dividing by 1000 or to cubic meters (m^3) by dividing by 1,000,000.
5. Volume in litters: 0.15129m^3 ÷ 1000 = 151.29 L Volume in cubic meters: 0.15129m^3
6. So, the rectangular water tank with dimensions 900 mm x 410 mm x 410 mm has a volume of 151.29 litters or 0.15129 cubic meters.

Length (mm)	Height (mm)	Width (mm)	Volume (m^3)	Volume (L)
900	410	410	0.15129	151.29

2. CALCULATION OF MEASURING TANK VOLUME

To calculate the volume of a rectangular water tank with dimensions of 410 mm (length) x 310 mm (height) x 310 mm (width), follow these steps:

1. Convert the dimensions to a consistent unit: Since the dimensions are given in millimeters (mm), it's best to convert them to a common unit, such as cubic centimeters (m^3), to ensure consistency.
2. Length: 410 mm = 0.410 m (since 1 m = 1000 mm) Height: 310 mm = 0.310 m Width: 310 mm = 0.310 m
3. Calculate the volume: Use the formula V = l * w * h, where V represents the volume, l is the length, w is the width, and h is the height.
4. V = 0.410m * 0.310m * 310 m = 0.0039401 m^3
5. Convert the volume to a more convenient unit if desired: The volume obtained above is in cubic centimeters. You can convert it to liters (L) by dividing by 1000 or to cubic meters (m^3) by dividing by 1,000,000. Volume in liters: 0.0039401 m^3 ÷ 1000 = 39.4 L Volume in cubic meters.
6. So, the rectangular water tank with dimensions 410 mm x 310 mm x 310 mm has a volume of 39.4 liters or 0.0039401 cubic meters.

Length (mm)	Height (mm)	Width (mm)	Volume (m^3)	Volume (L)
410	310	310	0.00394	39.4

3. PUMP SELECTION

Max discharge required = 6x10-4 m3/sec. = 0.0006 LPS (Litre Per Second).

By considering by-pass flow = 0.0006/0.6 = 0.001 LPS.

Concerned with availability of pump in market, we have selected pump of 0.5 HP.

IRJMETS
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The discharge of that pump = 800LPH = 0.222 LPS (Litre Per Second)

The details of pump are as below:

Criteria	Value
Tank Volume	39.4 litres
Desired Flow Rate	800 LPH = 0.222 LPS
Total Head	18 meters
Pump Type	Regenerative centrifugal pump
Item Dimensions	**LxWxH** - 24x 22x 24Centimetres
Required power supply	220-440V
Expert Consultation	Selected Market Available Pump is sufficing the requirement of Volume.

We are having Measuring tank capacity of 39.4 Litres; we are using pump of max. discharge than the required discharge.

So, to control the discharge by reducing it, we have provided one more by-pass pipeline and the outlet of by-pass line is released in Sump tank.

4. Pipe Selection

As per above mentioned point of Pump selection, 0.5 HP pump is having standard inlet and outlet of 1" so, All the pipes are used of 1" diameter.

Pipe Dia. = 1"

5. Venturimeter Selection

Specifications of Venturimeter :

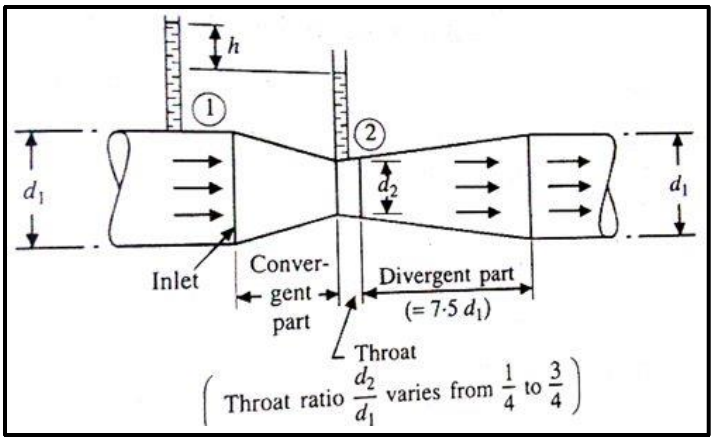

Fig . Venturimeter

1. Convergent cone included angle **- 21°±1°**
2. Convergent cone length = 2.7 x (d_1 - d_2) = 2.7 (0.025-0.013) = 0.0324m
3. Throat length – L = 0.5 x d_1
   0.5 x 0.025= 0.0125m
4. Throat Diameter – d_2= 0.5 d_1 = 0.013m
5. Divergent cone included angle – 5° to 15° (Preferably about **6**°)
6. Divergent cone length – 7.5 d_1 = 7.5 x 0.025 = 0.1875 m

6. Orificemeter Selection

Specifications of Orificemeter :

The orifice diameter is kept 0.5 times the diameter of pipe, though it may vary from 0.4 to 0.8 times pipe diameter.

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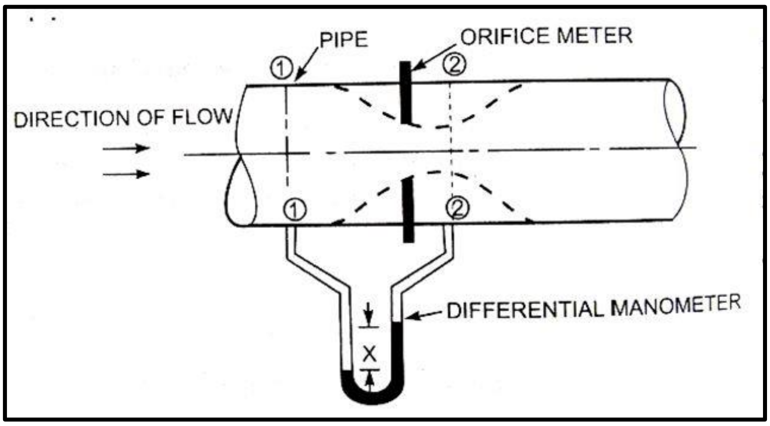

Fig . Orificemeter

1) Convergent cone included angle **- 21°±1°**
2) Convergent cone length = 2.7 x (d_1 **-** d_2) = 2.7 (0.025-0.013) = 0.0324m
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5) Divergent cone included angle – 5° to 15°(Preferably about **6**°)
6) Divergent cone length – 7.5 d_1 = 7.5 x 0.025 = 0.1875 m

7. U - tube Manometer Selection

Pressure Head (H) = 18 m

Specific gravity of mercury (Sm) =13.6

Specific gravity of flowing liquid (S_1)= 1

$$\text{Pressure Head (H)} = y\,(\frac{S_m}{S_1} - 1)\ \text{in meter}$$

$18 = y\,(\frac{13.6}{1} - 1)$

18 = y x 12.6

$y = \frac{12.6}{18}$

Hence, Manometer mercury = y = 0.7 m = 70 mm hg.

Hence, we had selected manometer of 400 mm range considering availability at market,cost, accuracy and saftey factors.

8. Valve Selection

1. As per above mentioned point of Pipe selection,

Pipe is having standard diameter of 1” so, All the standard valves are used which are suitable for 1” dia. Pipe.
Pipe is having standard diameter of 1” so, All the standard valves are used which are suitable for 1” dia. Pipe.

2. We have to release the water from Measuring tank to the Sump tank so the valve which can be used at to release this water that should be bigger in size to release the water quickly and user can take another measurement quickly.

So, we have selected valve of 2” to release the water from Measuring tank

IV. MANUFACTURING OF COMPONENT AND EXPERIMENTATION

It should include proposed layout of test rig. Process for manufacturing. Procedure for carrying out experimentation. Plastic crusher designed and constructed comprises of the following parts:-

1. Pump

A half horsepower (HP) motor typically refers to a motor with a power output of 0.5 horsepower, or approximately 373 watts. The power output of a motor is a measure of its ability to perform work or generate mechanical power.

A pump is a device that moves fluids (liquids or gases), or sometimes slurries, by mechanical action, typically converted from electrical energy into hydraulic energy.

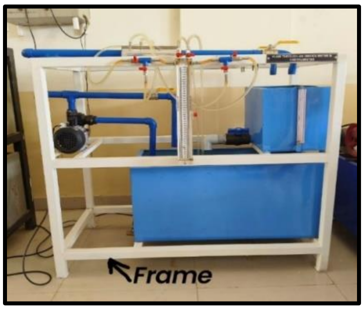
The special pumps are mainly categorized into three different types regarding the process they use to move the fluids: direct lift, displacement, and gravity pumps. The special effect pumps run on some averages which are reciprocating or rotary and consume power to perform automatic jobs striding the liquid.

2. Sump Tank:

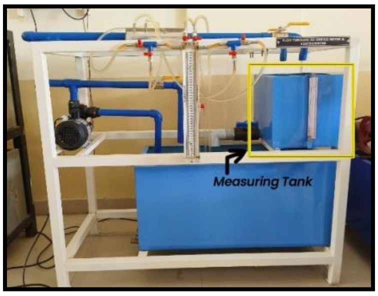
It is made up of MS sheet. It is made up of 18-gauge sheet. The size of sump tank is 900 x 410 x 410 (L x W x H). It is main device to store the water/liquid which can be used to perform the experiment.

3. Supporting frame:

Supporting Frame, it's made up of mild steel. Its length is 1250 mm height is 1065 mm and the width is 550 mm. It is main component of test rig. All the parts are mounted on this frame. This is made up of MS square pipe.



4. Measuring Tank:



It is made up of MS sheet. It is made up of 18-gauge sheet. The size of sump tank is 410 x 310 x 310 (LxWxH). It is main device to store the water/liquid which is discharged from Notch to measure the coefficient of discharge.

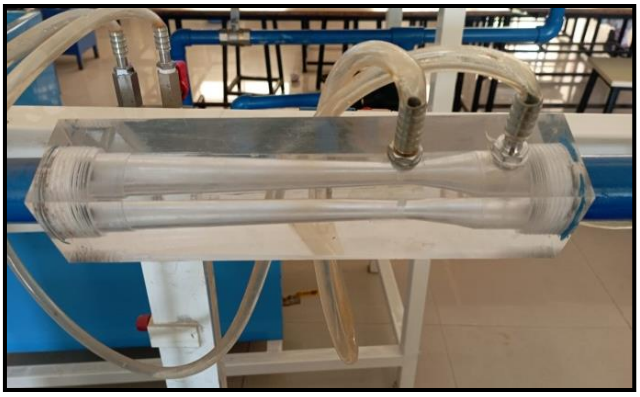
5. Pipe

Pipes are connected to inlet and outlet of a pump. When the pump is started to lift the water from sump tank to measuring tank, the water is travelled from inside of pipes.

Here, we have used pipe made up of Galvanizes Iron (GI) round shaped. Total pipe used for this apparatus is 3.5mtr.

6. Venturimeter :-

A venturimeter is a flow measurement device used to measure the flow rate of fluids, typically liquids or gases, in a pipe. It is named after its inventor, Giovanni Battista Venturi, an Italian physicist.



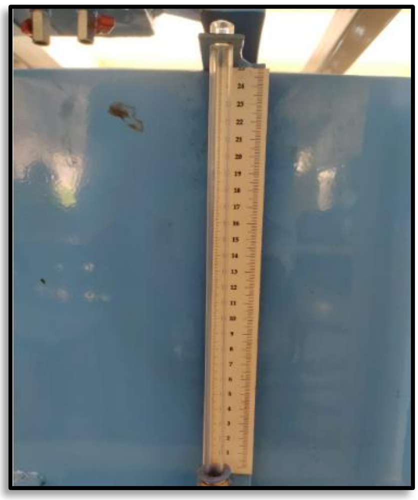
7. Orificemeter :-

An orifice meter is a flow measurement device used to measure the flow rate of fluids, typically liquids or gases, in a pipe. It consists of a thin plate with a precisely machined hole, known as an orifice plate, installed in a pipe. The orifice plate creates a constriction in the flow path, causing the fluid to accelerate as it passes through the smaller opening.

8. U - tube Manometer :-

A U-tube manometer is a device used to measure pressure differences or pressure differentials between two points in a fluid system. It consists of a U-shaped glass tube filled with a liquid, usually a manometer fluid such as mercury, water, or oil. The U-tube is typically transparent, allowing for visual observation of the liquid levels.

9. Measuring scale



To measure the water level in venturimeter orifice meter and Measuring tank we 2 measuring scales are provided. The LC of measuring scale is 1 mm.

10. Release valve

The function of release valve is to drain the water from Measuring tank to Sump tank.

The water from measuring tank should be drained immediately to take readings quickly. Thus, we have selected release valve of diameter 2”.

IRJMETS

e-ISSN: 2582-5208

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V. TESTING AND MEASUREMENT

1. Calibration of Venturimeter

Objective: - To Calibrate and find out coefficient of discharge value for given venturimeter.

Apparatus: - Venturimeter,' U'tube manometer, measuring tank, stopwatch etc.

Theory: -

The venturimeter is a device which is used for measuring tank rate of flow of liquid through pipes. Its basic principle is that by reducing the cross-sectional area of flow passage, a pressure difference increases then its measuring enables the determination of discharge through the pipes.

1) Actual Discharge $$Q_{act} = \frac{volume\,of\ tank}{time}$$

2) When the loss of energy is not considered the theoretical discharge is given by -

$$Q_{th} = \frac{a_1 a_2 \sqrt{2gh}}{\sqrt{a_1^2 - a_2^2}}$$

Where,

a_1 = area of venturimeter at inlet in m^2

a_2 = area of venturimeter at throat in m^2

Pressure head $h = y(\frac{S_m}{S_l} - 1)$ in meter

y = difference in level of manometer in meter

S_m=specific gravity of manometer liquid

S_l =specific gravity of flowing liquid

But, in actual practice there is always some loss of energy as liquid flow through manometer on account of which the actual discharge in fraction 'Cd'

3) Coefficient of Discharge

$$Cd = \frac{Q_{act}}{Q_{th}}$$

Procedure: -

1) Check all valves open it if closed.
2) Start the pump.
3) Remove air from manometer by opening the valves and close air removing valves after removing air.
4) Adjust the flow rate of water accordingly.
5) Take readings of manometers.
6) Also measure discharge in measuring tank and note down the time required for collection of water.
7) By changing flow rate take four to five readings.

Observations: -

1) D_1 = Diameter of Inlet of Venturimeter = 25 mm = **0.025 m**
2) D_2 = Diameter of throat of Venturimeter =13mm = **0.013 m**
3) S_m= Specific gravity of manometric fluid =13.6
4) S_l= Specific gravity of flowing fluid =1

5) Volume of tank = 0.31m x0.41 m x 0.1m = **0.01271 m³**

Observation table: -

Sr. No.	'y' in m of hg	'h' in m of water	Volume m³	Time sec	Q_{act} in m³/sec	Q_{th} in m³/sec	Cd
01	0.080	1.008	0.01271	16	5.62×10^{-4}	5.78×10^{-4}	0.96
02	0.072	0.9072		17	5.29×10^{-4}	5.48×10^{-4}	0.96
03	0.069	0.8694		18	5×10^{-4}	5.3×10^{-4}	0.94
04	0.061	0.7686		19	4.7×10^{-4}	5.04×10^{-4}	0.93
05	0.054	0.6804		22	4.09×10^{-4}	4.7×10^{-4}	0.86
Average Cd							0.93

Conclusion

a) Cd value from calculation = 0.93

The calculated Cd value and standard value of Venturimeter are nearly equal 0.6-0.65

hence, orificemeter is calibrated

2. Calibration of Orificemeter.

Objective: - To Calibrate and find out coefficient of discharge value for given orificemeter.

Apparatus: - Orificemeter,'U' tube manometer, measuring tank, stop watch etc.

Theory: -

The orificemeter is a device which is used for measuring flow rate of liquid through pipes. Its basic principle is that by reducing the cross-sectional area of flow passage, a pressure difference is created and its measuring enables the determination of discharge through the pipes.

1) Actual Discharge

$$Q_{act} = \frac{volume\ of\ tank}{time}$$

2) When the loss of energy is not considered the theoretical discharge is given by

$$Q_{th} = \frac{a_1 a_0 \sqrt{2gh}}{\sqrt{a_1^2 - a_0^2}}$$

Where,

a_1 = area of pipe at inlet in m²

a_0 = area of Orificemeter in m²

Pressure head $h = y(\frac{S_m}{S_l} - 1)$ in meter

y = difference in level of manometer in meter

S_m=specific gravity of manometer liquid

S_l- specific gravity of flowing liquid

But, in actual practice there is always some loss of energy as liquid flow through manometer on account of which the actual discharge in fraction 'Cd'

3) Coefficient of Discharge

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$$Cd = \frac{Q_{act}}{Q_{th}}$$

Procedure: -

1) Check all valves open it if closed.
2) Start the pump.
3) Remove air from manometer by opening the valves and close air removing valves after removing air.
4) Adjust the flow rate of water accordingly.
5) Take readings of manometers.
6) Also measure discharge in measuring tank and note down the time required for collection of water. (for 0.1m in glass tube)
7) By changing flow rate take four to five readings.

Observations: -

1) D_1 = Diameter of Inlet of Orificemeter = 25mm = **0.025 m**
2) D_2 = Diameter of throat of Orificemeter =13mm = **0.013 m**
3) S_m= Specific gravity of manometric fluid = 13.6
4) S_l= Specific gravity of flowing fluid = 1
5) Volume of tank = 0.31m x0.41 m x 0.1m = **0.01271 m^3**

Observation table: -

Sr. No.	'y' in m of hg	'h' in m of water	Volume m^3	Time sec	Q_{act} in m^3/sec	Q_{th} in m^3/sec	Cd
01	$175x10^{-3}$	$2205x10^{-3}$	0.01271	16	$5.6x10^{-4}$	$8.53x10^{-4}$	0.65
02	$155x10^{-3}$	$1953x10^{-3}$		17	$5.2x10^{-4}$	$8.03x10^{-4}$	0.64
03	$148x10^{-3}$	$1864x10^{-3}$		18	$5x10^{-4}$	$7.85x10^{-4}$	0.63
04	$145x10^{-3}$	$1827x10^{-3}$		19	$4.73x10^{-4}$	$7.77x10^{-4}$	0.60
05	$140x10^{-3}$	$1764x10^{-3}$		19	$4.73x10^{-4}$	$7.63x10^{-4}$	0.61
Average Cd							0.627

Conclusion:

a) Cd value from calculation = 0.627

The calculated Cd value and standard value of Orificemeter are nearly equal 0.6-0.65

hence, Orificemeter is Calibrated

VI. RESULTS

1. Venturimeter :-

a) Cd value from calculation = 0.93
b) Cd value from graph =0.95

The calculated Cd value and standard value of Venturimeter are nearly equal 0.6-0.65
hence, orificemeter is calibrated

2. Orificemeter :-

a) Cd value from calculation = 0.627
b) Cd value from graph =0.65

The calculated Cd value and standard value of Orificemeter are nearly equal 0.6-0.65
hence, Orificemeter is Calibrated

VII. DISCUSSION

The construction of the venturimeter & orifice meter was based on the knowledge gained from the workshop technology practice, fluid mechanics, engineering drawing and technical drawing and researched work. Before the commencement of the construction, an Engineering Design was done which includes the drawing of the venturi meter & orifice meter apparatus to be constructed with full dimensions and all mathematical modelsfor the component that will be constructed, while selections were made for other components that was bought based on specifications as determined by the calculations, which acts as guide during the measurement and construction of the venturi meter & orifice meter apparatus.

VIII. CONCLUSION

In conclusion, the venturi meter and orifice meter combo have been tested and evaluated in terms of their performance as flow measurement devices. The experimental results, along with the discussions and analyses presented, provide insights into the capabilities and limitations of these meters.

Based on the findings, it can be concluded that both the venturi meter and orifice meter are effective in measuring flow rates and pressure differentials in a variety of applications. They provide reliable and accurate measurements, although each meter has its own advantages and disadvantages.

The venturi meter, with its streamlined design and gradual change in cross-sectional area, offers lower pressure drop and higher accuracy compared to the orifice meter. It is suitable for applications where low-pressure losses and high accuracy are crucial, such as in critical flow measurements.

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