Study and Calibration of Pressure Sensor and Flow meter

By Aditya Raghuwanshi

(170052)

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OBJECTIVE

1. To study the pressure sensor and flow meter.
2. To calibrate the differential pressure sensor.
3. To characterize the different flow meters (Orifice, Nozzle and Venturi).

INTRODUCTION AND THEORY

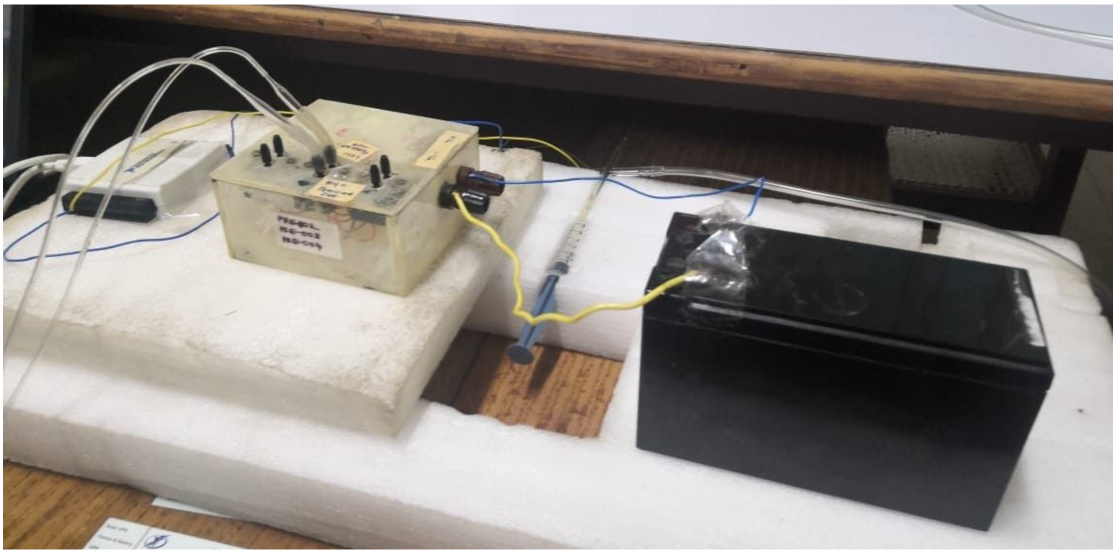
CALIBRATION

Calibration refers to the act of evaluating and adjusting the precision and accuracy of measurement equipment. Instrument calibration is intended to eliminate or reduce bias in an instrument's readings over a range for all continuous values.
We are calibrating the differential pressure sensor in our experiment. We will apply pressure using a piston system and sensor will generate a potential difference which is being saved in the system. We will also measure that pressure using a manometer (filled with water) and note that down. After doing this process for different pressure values, we can plot a polynomial curve for pressure (P) as a function of voltage generated (V). And we can use this voltage to measure pressure (P) for our rest of our experiments.

MANOMETER

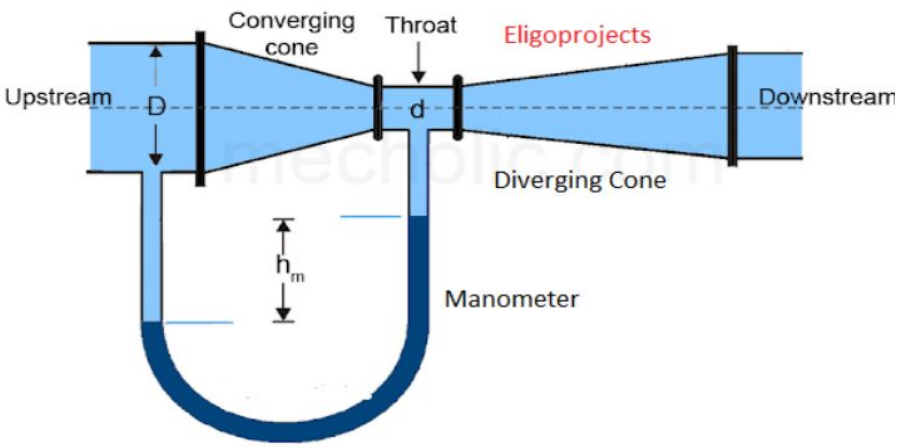
A Manometer is a pressure measuring instrument that consists of a U tube filled with a liquid (generally Mercury and Water). The manometer is placed against a measured scale to allow any difference in the height of the two columns. This height difference can be used directly to calculate different test pressures.
One end of the tube is connected with an air tight seal to a test pressure source. The other end of the tube is left open to the atmosphere and will therefore be subjected to a pressure of approximately 1 atmosphere (atm). If the test pressure is greater than the reference pressure of 1 atm, the liquid in the test column is forced down the column. This causes the fluid in the reference column to rise by an equal amount. Height difference is noted from the scale and pressure difference can be calculated. Manometer measures Gauge Pressure with respect to atmospheric pressure.

DIFFERENTIAL PRESSURE SENSOR



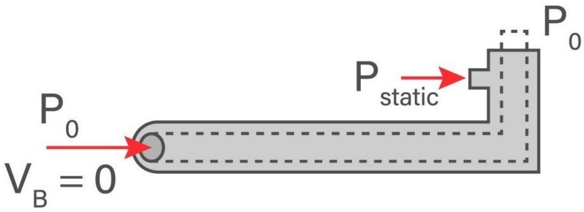
The differential pressure sensor will give you a comparative measurement between two points. The differential pressure measurement is not concerned whether the lower of the two pressures is at a vacuum, atmospheric or some other pressure. It is only interested in the difference between the two.
Differential pressure sensors are typically packaged with two ports to which pipes can be attached. The pipes are then connected to the system where the measurement is to be made. The two pressures to be measured are applied to opposite sides of a single diaphragm. The deflection of the diaphragm, either positive or negative with respect to the resting state, determines the difference in pressure.

VENTURIMETER



It is a device used to measure the speed and flow rate or discharge of fluid through a pipe. This flow measurement device is based on the principle of Bernoulli’s equation. It contains a convergent part, a throat and a divergent part. The Venturimeter is connected to a manometer. The cross sectional area of throat section is smaller than the inlet section, due to this the velocity of flow at the throat section is higher than velocity at inlet section, this happens according to the continuity equation. The increases in velocity at the throat result in decreases in pressure at this section, due to this pressure difference being developed between inlet valve and throat of the venturimeter. This difference in pressure is measured by manometer by placing this between the inlet section and throat. Using pressure difference value we can easily calculate flow rate through the pipe. This difference in pressure is measured with the help of manometer and helps in determining the rate of fluid flow or other discharge from the pipeline.

PITOT TUBE



A pitot tube is a flow measurement device used to measure fluid flow velocity. Usually it is used in aircrafts to measure air speed. It has two holes one facing the direction of incoming flow and other perpendicular to the direction of incoming flow. Hole perpendicular to the incoming flow measures Static Pressure and the hole facing incoming flow measures Total or Stagnation Pressure. We (differential pressure sensor) measure the difference between the two pressures to find the velocity of the incoming flow.

ORIFICE METER

An orifice plate is a device used for measuring flow rate by restricting flow. An orifice plate is a thin plate with a hole in it, which is placed in a pipe.The working principle of Orifice Meter is the same, as that of Venturi meter. When a liquid / gas, whose flow-rate is to be determined, is passed through an Orifice Meter, there is a drop in the pressure between the Inlet section and Outlet Section of Orifice Meter. This drop in pressure can be measured using a differential pressure measuring instrument. In our case, we connected the orifice meter to a manometer to measure the pressure difference.

NOZZLE METER

A flow nozzle meter is another device that is used for measuring flow rates. It consists of a disc with a hole in the center and it also has a circular part excluded outwards. It is usually held in place between two pipe flanges. It is simpler and less expensive than a venturi meter, but not as simple as an orifice meter. The frictional loss in a flow nozzle meter is much less than in an orifice meter, but higher than in a Venturi Meter. Loss is less in this method because it restricts the formation of vorticity.

Dimensions of Flow Meter

	Orifice	Nozzle	Venturi	
			Outer Dia	Throat Dia
Diameter	50mm	48mm	82.61mm	43.4mm

EQUIPEMENTS

Three Manometers, an Orifice Disc, a Nozzle Disc, Venturi Meter, a differential pressure sensor, a Pitot Tube, a 12V battery and a computer.

PROCEDURE

1. Connect the 12V battery to the pressure sensor. Connect one side of connecting tubes to the pressure sensor and other to a piston. We will apply pressure using the piston and sensor will generate a potential difference which is being saved in the system. We will also measure that pressure using a manometer (filled with water) and note that down. We will repeat this for different pressure values.
2. For the next part, we will allow a flow through the duct and note pressure readings in the three manometers (of orifice, nozzle and venturi meter). We will then place a pitot tube at the duct exit and will measure the flow velocity at different locations. We will repeat this process for four different conditions.

MEASUREMENTS

Pressure Sensor Calibration:

Height in Left Arm (mm)	Height in Right Arm (mm)	Height Difference (mm)	Sensor Output (Volts)
-0.8	0.9	1.7	6.85560
-2.1	2.4	4.5	18.18985
-3.3	3.5	6.8	28.03258
-4.4	4.6	9.0	35.93348
-5.5	5.7	11.2	44.99149
-6.4	6.6	13.0	52.12270
-7.4	7.8	15.2	60.53589

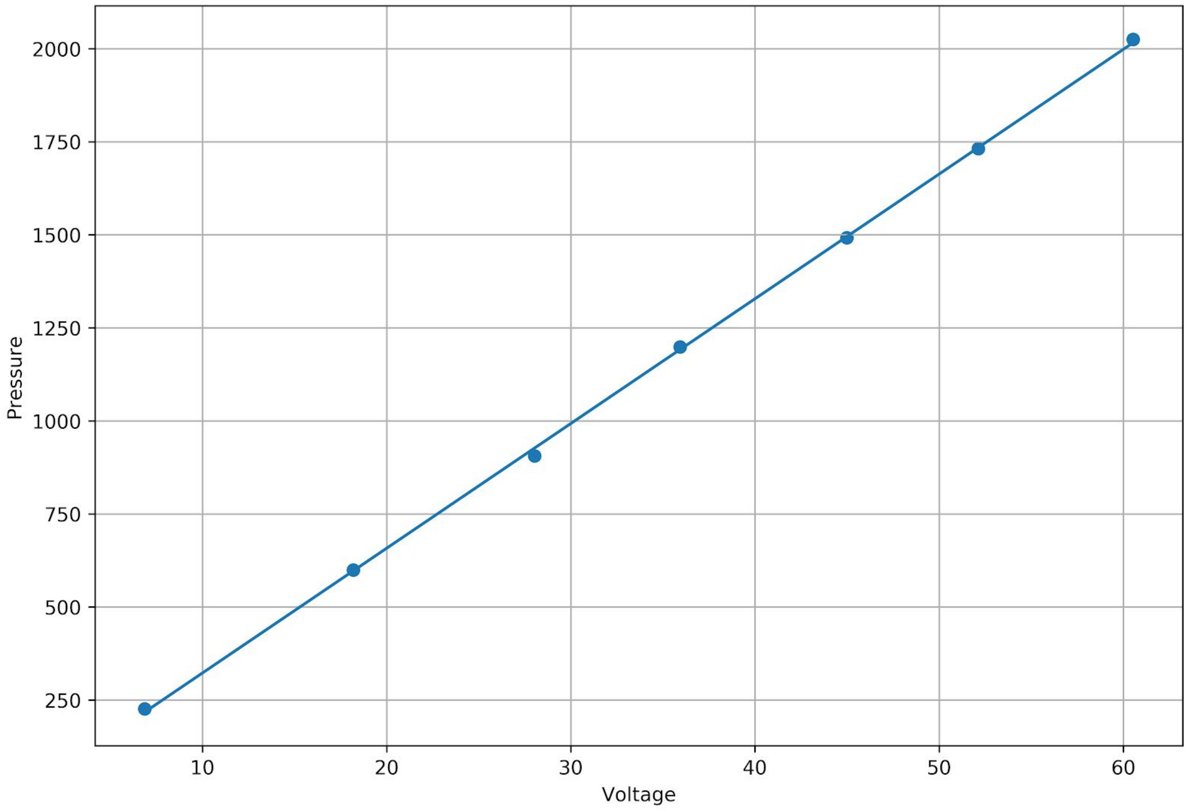
Pressure difference across different flow meters:

Condition	Orifice		Nozzle		Venturimeter	
	Left	Right	Left	Right	Left	Right
1	0.06	-0.06	0.8	-0.7	1.3	-1.0
2	0.12	-0.12	1.6	-1.4	2.4	-2.2
3	0.30	-0.30	4.1	-4.0	6.2	-6.1
4	0.7	-0.7	7.6	-7.4	11.4	-11.3
5	1.0	-1.0	10.1	-9.8	15.5	-15.3

Velocity measurement at the end of the duct:
We took measurement with the help of a pitot tube at 17 different points for each 5 conditions which were saving in the system with the help of a LabView Program.

RESULTS

Best Fit Curve:



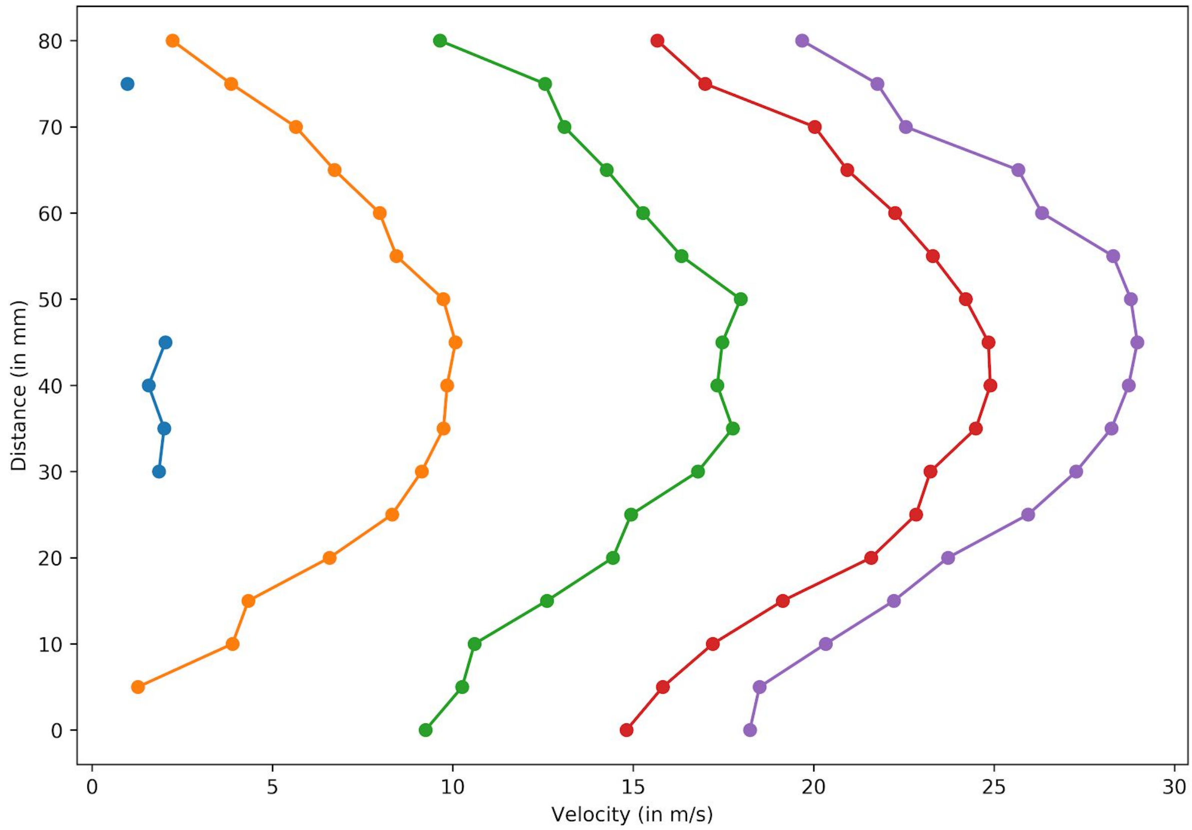
Line Equation is: $\mathbf{y = 33.511598\ x - 12.40394}$

Mass Flow Rates (Kg/s) at different flow meters and at different conditions:

Condition	Orifice	Nozzle	Venturimeter
1	0.01348387	0.01173749	0.01156526
2	0.01906907	0.01659931	0.01635575
3	0.03015084	0.02727545	0.02674509
4	0.04605617	0.03711719	0.03633326
5	0.05504766	0.04275196	0.04232207

These are the **Actual Mass Flow Rates** measured by different flow meters.

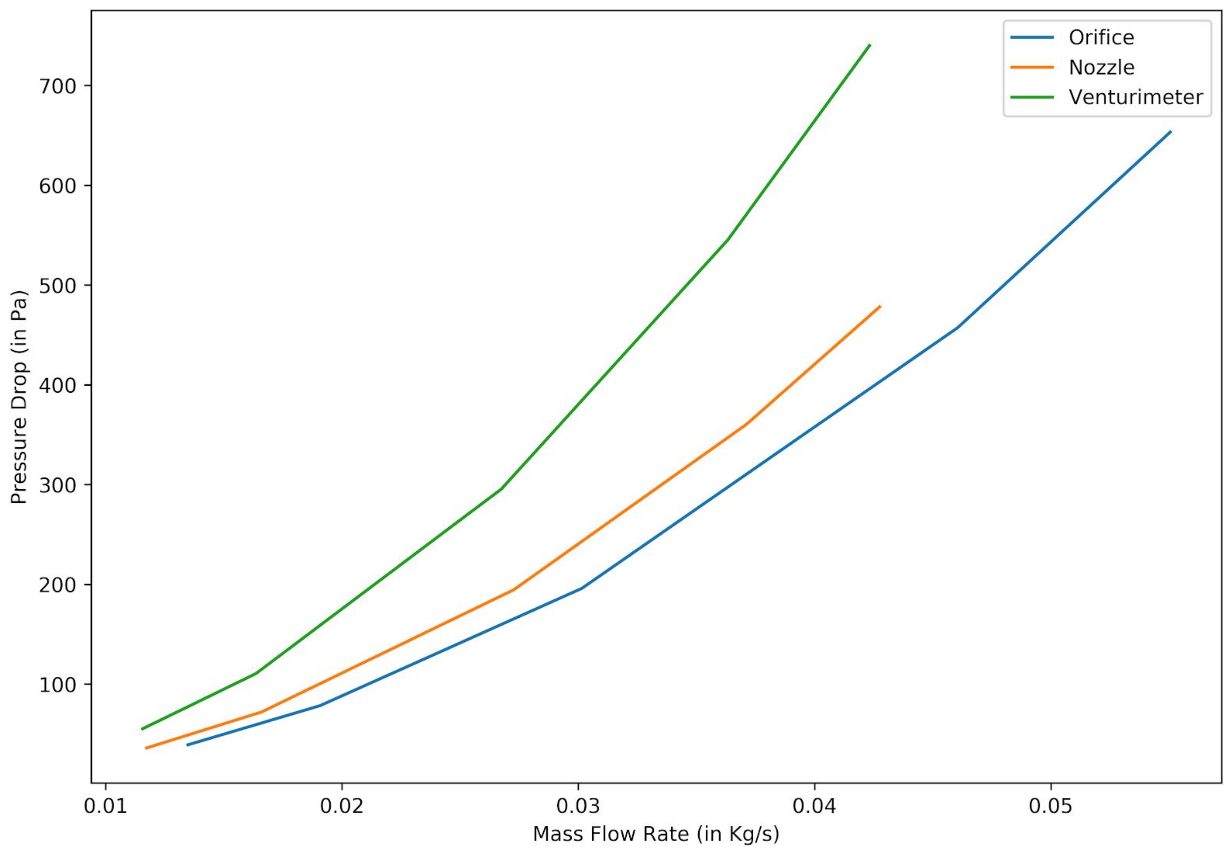
Velocity Profile for different conditions:

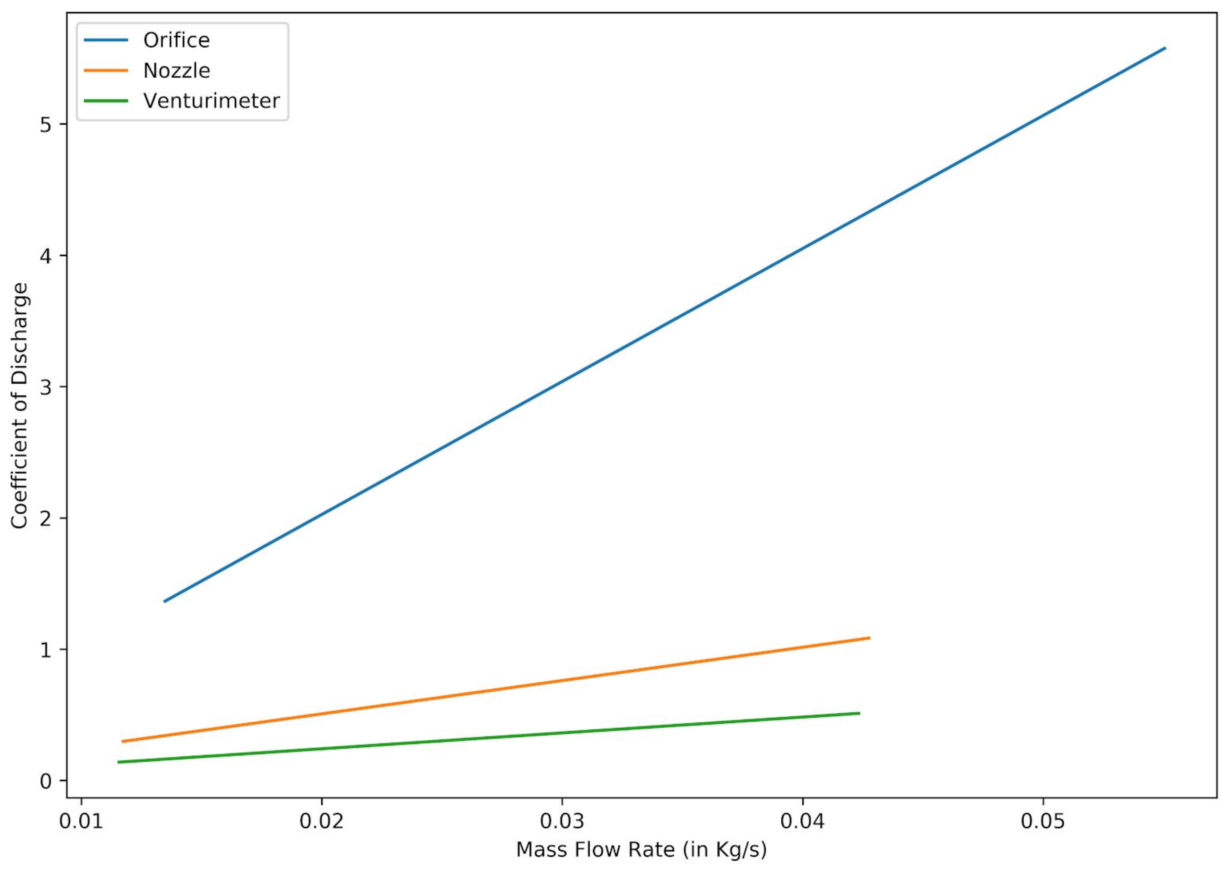


Condition	Mean Velocity (m/s)	$\dot{m}_{theoretical}$ (Kg/s)
1	1.68689	0.00987
2	6.73638	0.03943
3	14.15010	0.08283
4	20.72071	0.12129
5	24.42643	0.14298

Coefficient of Discharge (C_D) = $\dot{m}_{exp}/\dot{m}_{theoretical}$

Condition	C_D (Orifice)	C_D (Nozzle)	C_D (Venturimeter)
1	1.36556	0.29767	0.13963
2	1.93119	0.42097	0.19747
3	3.05349	0.69172	0.32290
4	4.66428	0.94131	0.43866
5	5.57488	1.08421	0.51096


Orifice
Nozzle
Venturimeter
700
600
500
400
300
200
100
Pressure Drop (in Pa)
0.01
0.02
0.03
0.04
0.05
Mass Flow Rate (in Kg/s)


Orifice
Nozzle
Venturimeter
5
4
3
2
1
0
Coefficient of Discharge
0.01
0.02
0.03
0.04
0.05
Mass Flow Rate (in Kg/s)

ERROR ANALYSIS

	Orifice	Nozzle	Venturimeter
Mean of C_D	3.31788	0.68717	0.32192
Variance of C_D	2.54224	0.08896	0.01962
Std Deviation of C_D	1.59444	0.29827	0.14006

We can see the variance and the standard deviation of the Venturimeter is least and that of Orifice is maximum, which shows that Venturimeter is most efficient amongst the rest.

DISCUSSION

As expected we see as the mass flow increases, the discharge coefficients decreases. A major reason for this behaviour is the separation of flow. Also, the data suggests that Venturi meter is the most efficient in terms of discharge Coefficient.

A. Explain the difference between Absolute, Gauge and Differential Pressure.

a. Absolute Pressure a perfect vacuum as its reference. This type of pressure reference is the gauge pressure of the media plus the pressure of the atmosphere. As locations change, especially when dealing with elevation changes, the reference points can change because of atmospheric pressure differences. Using an absolute pressure sensor eliminates the reference to a varying atmospheric pressure and relying on a specific pressure range for reference.

b. Differential Pressure can be a little more complex than gauge or absolute, but is simply measuring the difference between two medias. Although most gauge pressures are technically a differential pressure sensor—measuring the difference between the media and atmospheric pressure—a true differential pressure sensor is used to identify the difference between the two separate physical areas. For example, differential pressure is used to check the pressure drop—or loss—from one side of an object to the other.

c. Gauge Pressure uses a reference to the atmosphere around the sensor. Because the sensing element has a deflection due to a pressure change, a reference point is needed to know exactly what pressure is being measured. Pressure sensors that use gauge pressure—typically seen in PSIG, BARG, and kPaG —have some type of vent. This vent can be built into the sensor or even through a tube in the electrical connection. The vent is positioned to use atmospheric pressure as a reference point for the sensor to measure the media. One common reason for using gauge pressure is to ensure that with any location throughout the world, the sensor will always reference the location in which it is installed.

B. Explain difference between Piezoresistive strain, Capacitive, Electromagnetic, Piezoelectric, Optical, pressure sensing technology.

a. Piezoresistive strain gauge: Uses the piezoresistive effect of bonded or formed strain gauges to detect strain due to applied pressure, resistance increasing as pressure deforms the material. Common technology types are Silicon (Monocrystalline), Polysilicon Thin Film, Bonded Metal Foil, Thick Film, and Sputtered Thin Film. Generally, the strain gauges are connected to form a Wheatstone bridge circuit to maximize the output of the sensor and to reduce sensitivity to errors. This is the most commonly employed sensing technology for general purpose pressure measurement.

b. Capacitive : Uses a diaphragm and pressure cavity to create a variable capacitor to detect strain due to applied pressure, capacitance decreasing as pressure deforms the diaphragm. Common technologies use metal, ceramic, and silicon diaphragms.

c. Electromagnetic: Measures the displacement of a diaphragm by means of changes in inductance (reluctance), LVDT, Hall Effect, or by eddy current principle.

d. Piezoelectric: Uses the piezoelectric effect in certain materials such as quartz to measure the strain upon the sensing mechanism due to pressure. This technology is commonly employed for the measurement of highly dynamic pressures.

e. Optical: Techniques include the use of the physical change of an optical fiber to detect strain due to applied pressure. A common example of this type utilizes Fiber Bragg Gratings. This technology is employed in challenging applications where the measurement may be highly remote, under high temperature, or may benefit from technologies inherently immune to electromagnetic interference. Another analogous technique utilizes an elastic film constructed in layers that can change reflected wavelengths according to the applied pressure (strain).

C. Coefficient of Discharge: Coefficient of discharge is stated as the ratio between the actual flow discharge and theoretical flow discharge. It is also referred to as the ratio of mass flow rate at nozzle's discharge edge to the standard nozzle which enlarges an exact working fluid maintained at the similar initial conditions and pressures.

It has no dimensions and depends directly on the rate of flow and velocity of working fluid. It is symbolized by Cd and its value is different for each fluid depending on the kind of measurement of flow. In nozzle flow measurement, the efficiency of Cd is higher when compared to the flow measurement at the orifice. The discharge coefficient is raised by increasing the overall pressure ratio and reducing the convergence semi angle.

This parameter is useful for determining the irrecoverable losses associated with a certain piece of equipment in a fluid system, or the "resistance" that piece of equipment imposes upon the flow.

$$C_\mathrm{d} = \frac{\dot{m}}{\rho \dot{V}} = \frac{\dot{m}}{\rho A u}$$

$$C_\mathrm{d} = \frac{Q_\mathrm{exp}}{Q_\mathrm{theo}}$$

CONCLUSION

We learnt about the Pressure Sensor and how to calibrate it. We learnt about different flow meters (Orifice, Nozzle and Venturi Meter). We also learnt about their properties and differences. With the help of graphs and error analysis we also concluded the efficiency of the flow meters.

APPENDIX

Working formulas:

1. Coefficient of Discharge $C_d = \frac{\dot{m}}{\dot{m}_{the}}$

2. Theoretical Mass flow rate $\dot{m}_{the} = \sqrt{\frac{2\rho\Delta P}{\frac{1}{A^2{}_2} - \frac{1}{A^2{}_1}}}$

3. Flow Velocity $V = \sqrt{\frac{2(P_0 - P_{static})}{\rho}}$

4. Experimental Mass Flow Rate $\dot{m}_{exp} = \rho A V$

Bernoulli's Equation:

$$\frac{v^2}{2} + gz + \frac{p}{\rho} = \text{constant}$$

PRECAUTIONS

1. Fit the connecting tubes tightly to get the best results.
2. There are two ports on the pressure sensor: High speed port and Low speed port. Connect the tubes in the correct port carefully.

1. ~~what is~~ Pressure drop. reason

inched dia of pipe 78mm

2. C_d (orifice), nozzle, ventu
0.55 - 0.65

Samplemeans

A = [0 1 0; 0 0 1; -6 -11 -6];
[V,D] = eig(A);
Eigenvalues = D*[1; 1; 1]

Cond^n	Orifice (Hg) L.A	Orifice (Hg) R.A	Nozzle L.A	Nozzle R.A	Venturi meter L.A	Venturi meter R.A
1 → v_1	0	0	0.8	-0.7	1.3	-1.0
2 → v_2			1.6	-1.4	2.4	-2.2
3 → v_3			4.1	-4.0	6.2	-6.1
4 → v_4	0.7	-0.7	7.6	-7.4	11.4	-11.3
5 → v_5	1.0	-1.0	10.1	-9.8	15.5	-15.3

$$m_{exp} = \frac{\sqrt{2\rho\Delta P}}{\sqrt{\frac{1}{(A_2)^2} - \frac{1}{(A_1)^2}}}$$

		orv	nozzle		
Q_1	$m_{1 the}$	C_{d_1}	C_{d_1}	v_c	C_d
Q_2		C_{d_2}	C_{d_2}		
Q_3		C_{d_3}	C_{d_3}		
Q_4		C_{d_4}	C_{d_4}		
Q_5	m_{the}	C_{d_5}	C_{d_5}		

$\frac{m_{exp}}{m_{th}}$

$$C_d = \frac{\sum_{i=1}^{5} C_{di}}{5}$$