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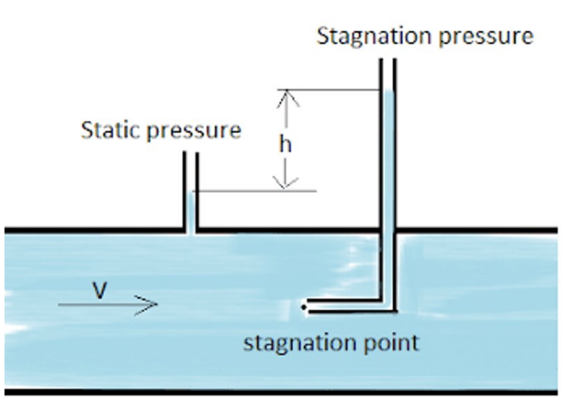
Pitot Tube

Aim

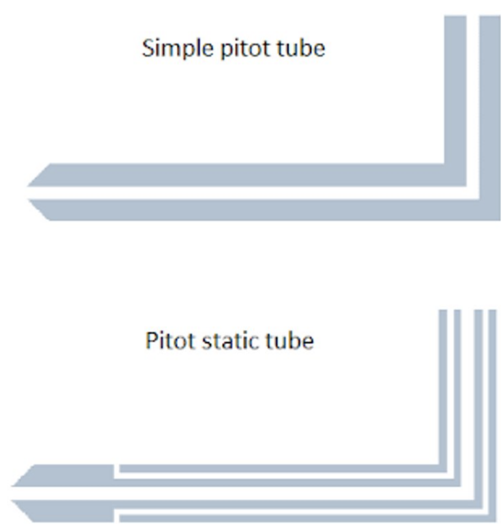
To determine the coefficient of discharge of the pitot tube.

Theory

A Pitot tube is a pressure measurement instrument used to measure fluid flow velocity. The pitot tube can be used to measure the speed of water in an open channel and in a closed pipe. For an open channel, a simple pitot tube will serve the purpose. However, for a closed line in which the water is flowing under pressure, it is necessary to measure the static pressure. Then the velocity head will be equal to the total Pitot-tube reading minus the static pressure. The static pressure is measured by inserting another L-shaped tube with its end pointing towards the flow downstream. A Pitot tube is fixed inside a pipe connected to a supply water tank. The Pilot tube is connected to an inverted water manometer.

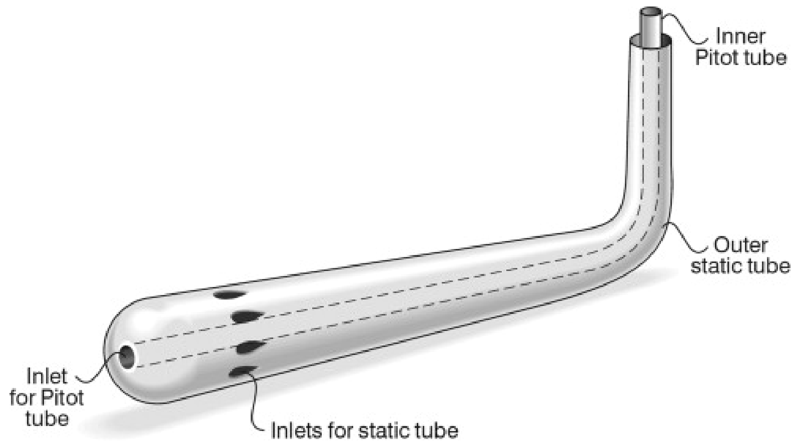


Simple pitot tube



Working Principle

If the fluid is not flowing, the pressure will be the same in the inner and outer tubes. This pressure is called static pressure. As soon as the fluid starts to flow, a part of the fluid will enter the pitot tube through its front hole, but it has nowhere to go because the inner tube is closed at the back as it is connected to the pressure manometer. So, once the tube has filled up, the fluid will come to a standstill (stagnation) inside the tube. However, the fluid continues to flow through the conduit and the molecules build up kinetic energy. Because the fluid can no longer enter the pitot inner tube, all molecules will collide at the front hole. This brings them to a full stop and they lose their kinetic energy With every collision, the kinetic energy is converted into pressure energy. The pressure built up at the tip of the pitot tube is called the stagnation pressure, sometimes also called the total pressure. It is the sum of the static pressure, equally distributed in all directions, and the dynamic pressure, caused by the conversion of the kinetic energy and effective in the flow direction only.



Stagnation pressure = static pressure + dynamic pressure

A pitot tube that measures both the stagnation and the static pressure is called a pitot-static tube or Prandtl tube. If the two tubes coming out of the pitot-static tube are connected to a differential pressure transmitter (as shown in the animation), we can measure the dynamic pressure of the fluid flow.

$$\textbf{Dynamic pressure} = \Delta P = P_{stagnation} - P_{static}$$

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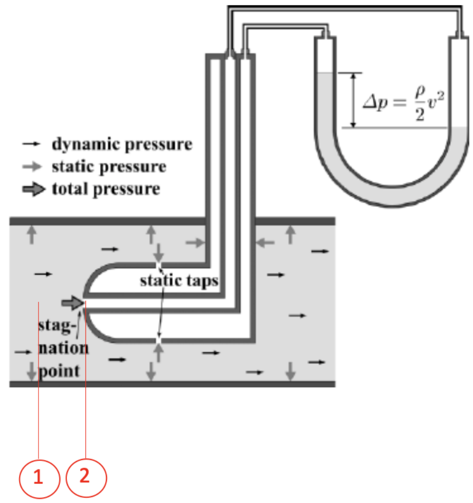
Consider a steady, incompressible, streamlined flow through a pipe as shown in the figure.

Consider two points, as shown, the first one at the mouth of the pipe and the second at a distance very close to the mouth of the pipe.



Since the points are on the same horizontal line,

$z_1 = z_2$

Neglecting the losses, from Bernoulli's equation,

$$\frac{P_1}{\rho} + \frac{V_1^2}{2} = \frac{P_2}{\rho} + \frac{V_2^2}{2}$$

.... (1)

The velocity v2 at the front hole of the pitot tube is stagnated. This means V2=0

From equation (1),

$$V_1 = \sqrt{\frac{2(P_2 - P_1)}{\rho}} = V_T$$

The theoretical flow rate can be calculated using

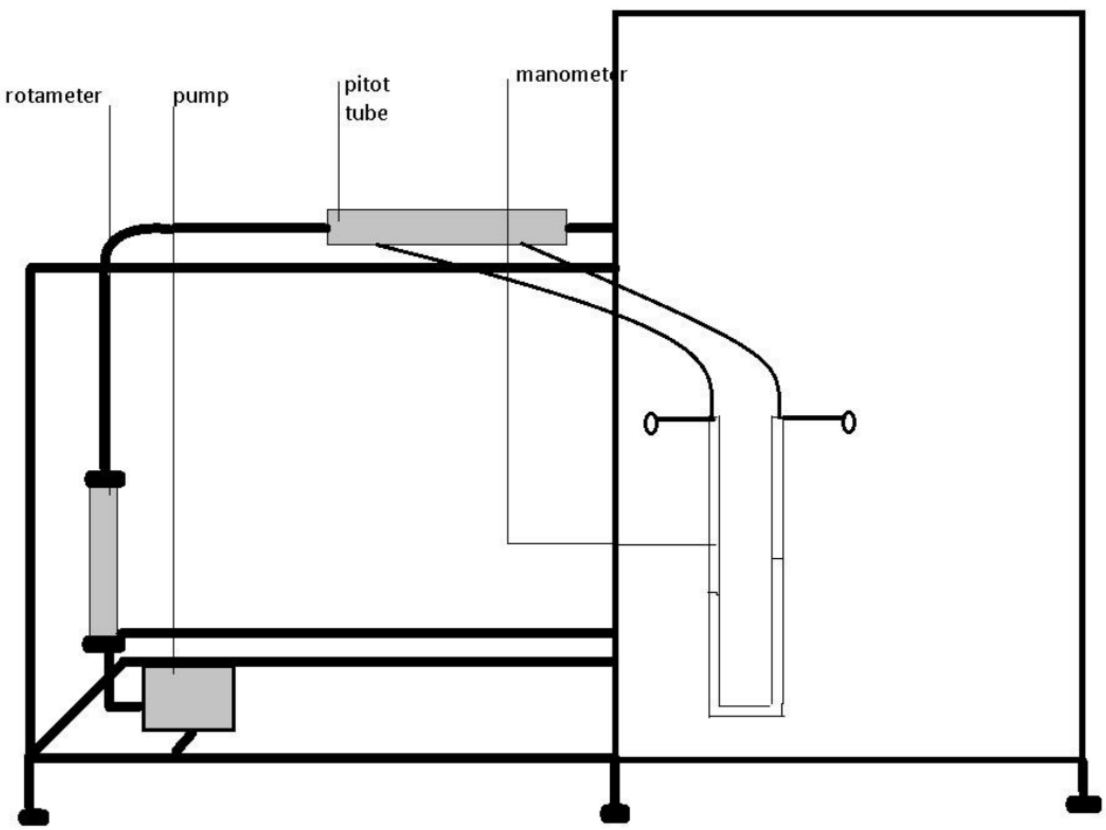
$$Q_T = \int_A 2\pi r V(r)\, dr$$

Thus, taking all losses into consideration, (Cv is the coefficient in the pitot tube)

$$V_A = C_v \sqrt{\frac{2(P_2 - P_1)}{\rho}}$$ where, $$C_v = \frac{Q_A}{Q_T}$$

$$\therefore V_T = \sqrt{2y(s-1)g}$$

Experimental Setup



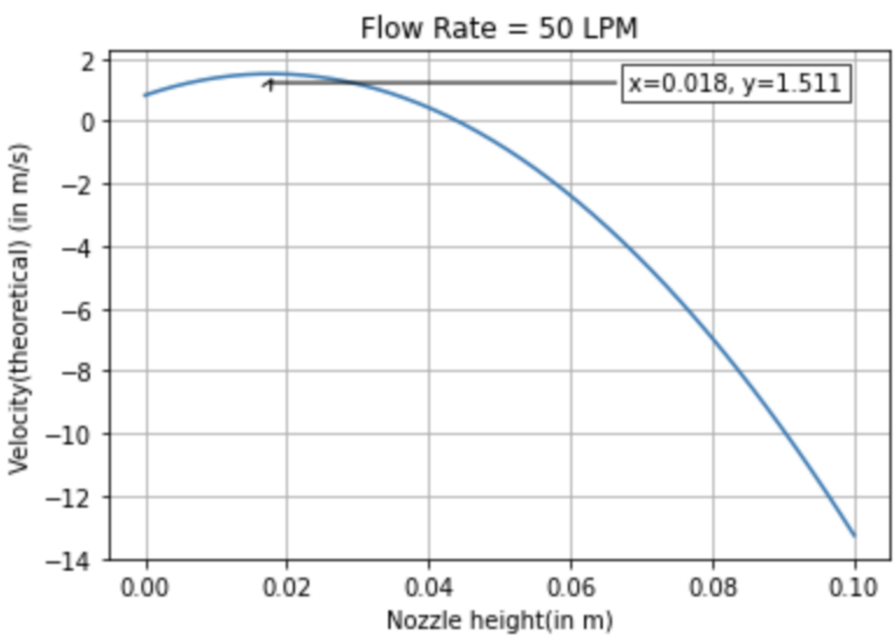
Observation Table in Pitot tube

Sr. No.	Flow Rate LPM	Nozzle height (cm)	Manometer reading h	Vt
1	50	0	6	84
		0.5	10.5	111.122
		1.0	17	141.393
		2.0	19	149.479

From the above data,
Using python we fit the following curve,

$$V(r) = -2184r^2 + 77 \cdot 54r + 08321$$

With the graph,



Theoretical Calculations

We calculate velocity using,

$$V = \sqrt{2y(s-1)g}$$

From the data, we get

$$V(r) = ar^2 + br + c$$

Considering a symmetric flow along the center,

The radius of the tube will be magintude of sum of roots /2,

$$R = \frac{\left|\frac{-b+\sqrt{b^2-4ac}}{2a}\right| + \left|\frac{-b-\sqrt{b^2-4ac}}{2a}\right|}{2}$$

This is because, the velocity at the two ends of the tube is zero, thus their sum would be the diameter of the pipe

$\therefore$ The radius of the tube is R

The theoretical volumetric flow rate is,

$$Q_t = \int_A 2\pi r\, V(r)\, dr$$

Thus, $C_v = \frac{Q_A}{Q_t}$

The slope of the Q_A v/s Q_t graph gives us C_v.

Consider the above case,

we get $v(r) = -2184\, r^2 + 77.54\, r + 0.8321$

Thus radius, $R = 1.12\,cm$

$$Q_t = \int_0^{0.012} 2\pi r\,(-2184 r^2 + 77.54 r + 0.8321)\,dr$$

$$= \int_0^{0.012} 2\pi\,(-2814\, r^3 + 77.54\, r^2 + 0.8321\, r)\,dr$$

$$= 2\pi\left[-2814\,\frac{r^4}{4} + 77.54\,\frac{r^3}{3} + 0.8321\,\frac{r^2}{2}\right]_0^{0.012}$$

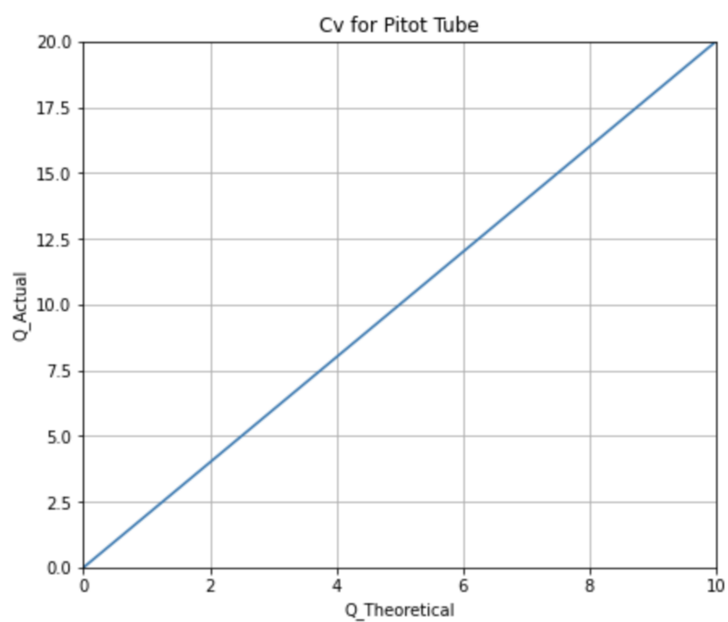
$$= 0.00058\ m^3/s$$

$\therefore\ Q_t = 58$ LPM

$Q_A = 50$ LPM

$C_v = \dfrac{Q_A}{Q_t} = \dfrac{50}{58} = 0.862$

Rough plot for Q_A v/s Q_t



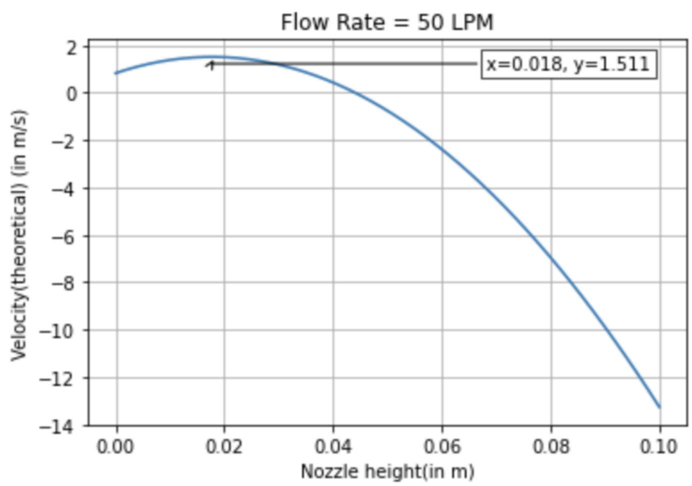
Fitting the Curve

To fit the curve I have used the following python code

```
import numpy as np
import matplotlib.pyplot as plt

nozzle_height = [0,0.005,0.01,0.02]
Vt_50_values=[0.84,1.11122,1.41393,1.49479]
Vt_50 = np.poly1d(np.polyfit(nozzle_height, Vt_50_values, deg=2))
print("The curve is given by the equation: \n",Vt_50)

def annot_max(x,y, ax=None):
    xmax = x[np.argmax(y)]
    ymax = y.max()
    text= "x={:.3f}, y={:.3f}".format(xmax, ymax)
    if not ax:
        ax=plt.gca()
    bbox_props = dict(boxstyle="square,pad=0.3", fc="w", ec="k", lw=0.72)
    arrowprops=dict(arrowstyle="->",connectionstyle="angle,angleA=0,angleB=60")
    kw = dict(xycoords='data',textcoords="axes fraction",
              arrowprops=arrowprops, bbox=bbox_props, ha="right", va="top")
    ax.annotate(text, xy=(xmax, ymax), xytext=(0.94,0.96), **kw)

print("\nPlot:")
x = np.linspace(0,0.1)
y_50 = -2184*x**2 + 77.54*x + 0.8231
plt.plot(x,y_50)
plt.grid()
annot_max(x,y_50)
plt.xlabel('Nozzle height(in m)')
plt.ylabel('Velocity(theoretical) (in m/s)')
plt.title("Flow Rate = 50 LPM")
plt.show()
```

Obtained Result:

```
The curve is given by the equation:
        2
-2184 x + 77.54 x + 0.8231

Plot:
```



Interpretation of Results

The errors in the values are because

- The flow is a viscous flow that is not accounted for in our calculations.
- If the manometer tube is significantly small, due to the surface tension there is a capillary rise which is neglected.
- Pitot tube might get clogged, which might lead to error in readings of the manometer
- Frictional losses are also not taken into account.
- If the rotameter isn't calibrated then there could be errors in the readings.

Once we calculate the C_v, our pitot tube is calibrated.