Experimental determination of mass flow rate using Venturi meter

(AS2100: Basic Aerospace Engineering Lab)

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A Venturi meter is used for measuring the mass flow rate of a fluid by providing a restriction to the flow through reduction in the cross section length downstream with the minimum diameter at the throat as shown in the schematics in figure 2. The pressure heads ΔH are measured using a differential manometer. Using the pressure heads ΔH and the diameters of the pipe d_1 and throat d_2, the mass flow rate(Q_m) is estimated. The experiment is performed for 5 different flow rates indirectly indicated by significantly different pressure heads ΔH. The whole experiment is repeated 100 times thus giving us 100 observations for each flow rate.

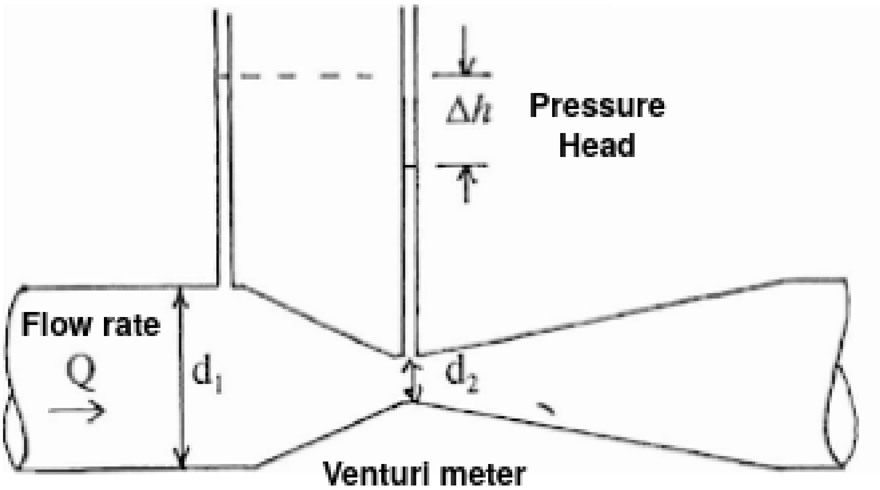

Figure 1: Schematics of the experimental setup.

The parameters used in this experiment are as follows:

- Acceleration due to gravity, $g = 9.81m/s^2$
- Density $\rho_{water} = 997kg/m^3$ at mean ambient temperature of $25°C$
- Kinematic Viscosity, $\nu = 8.917E - 07m^2/s$
- Diameter of the pipe cross section $d_1 = 50cm$
- Diameter of throat $d_2 = 20cm$.

The data set provided in `P1_VenturiMeter.mat`) contains the following:

- Pressure head measurements ("`DeltaH_Exp`") for 5 different flow conditions:

$$\boldsymbol{\Delta H} = \{\Delta H_1^{(i)}, \Delta H_2^{(i)}, \Delta H_3^{(i)}, \Delta H_4^{(i)}, \Delta H_5^{(i)}\}_{i=1}^{N=100}$$

- True mass flow rates (given as "`QmTrue`") for 5 different flow conditions:

$$\boldsymbol{Q_m^{True}} = \{Q_{m1}, Q_{m2}, Q_{m3}, Q_{m4}, Q_{m5}\}$$

Using the given data, do the following:

1. Explain the theory behind the experiment. Detail the assumptions made. Given, the pressure head ΔH, throat diameter d_2, pipe diameter d_1, density of the fluid ρ_{water}, derive the theoretical relationship for mass flow rate $Q_m^{Theoretical}$.

2. Obtain the relationship for error in mass flow rate as a function of errors in pressure heads(Hint: Refer to "function of errors/propagation of errors" in your textbooks.). What are the possible sources of error in this experiment and how to minimise them?

3. Using the mean pressure difference values obtained from the experimental data as true pressure differences, plot the normalised histograms of the errors in pressure difference measurements. Also, plot the smoothened probability density trends over the corresponding histograms and determine if the probability density functions are normal in nature. Using the mean and standard deviations of the errors for each case, plot the corresponding normal distribution curve over the histograms and smoothened trends and compare.

4. Using the obtained theoretical relationship for mass flow rate $Q_m^{Theoretical}$ in question 1), estimate the mean mass flow rate $\bar{Q}_{mk}^{Theoretical}$ for $k = 1 \cdots 5$ from the pressure head data provided in `P1_VenturiMeter.mat`.

5. Given true mass flow rates in the data set(given as "`QmTrue`"), obtain the true Reynolds number values:
$$\{Re_D^{(1)}, Re_D^{(2)}, Re_D^{(3)}, Re_D^{(4)}, Re_D^{(5)}\}$$
Where,
$$Re_D^{(k)} = \frac{V_1^{(k)} d_1}{\nu}$$
for $k = 1 \cdots 5$ and V_1 is the fluid velocity at inlet, d_1 is the diameter of pipe cross section and ν is the kinematic viscosity of the fluid.

6. With the mean theoretical flow rates $\bar{Q}_{mk}^{Theoretical}$ for $k = 1 \cdots 5$ estimated previously from the data as in question 4), obtain the discharge coefficient C_d^k for $k = 1 \cdots 5$ as follows:
$$C_d^k = Q_{mk}^{True} / \bar{Q}_{mk}^{Theoretical}.$$

7. Using the given data, obtain a linear($y = a_1 x + a_0$) and polynomial($y = \Sigma_{i=1}^n a_i x^i + a_0$ with $n = 2, 3$) for coefficient of Discharge(C_d) as a function of Reynolds number(Re_D). Calculate the Mean Square Error for each fit.

8. On a conclusive note, outline the limitations/advantages of using a Venturi meter for estimating the flow rate. What other alternatives exist to measure the fluid flow rate experimentally?

In addition to answers to the above questions each report should also include introduction about the experiment , schematics of the experimental setup, a results and discussion section and a conclusion section.