Flow Measurement

7.1 Introduction

It is important to be able to measure and control the amount of material entering and leaving a chemical and other processing plants. Since many of the materials are in the form of fluids, they are flowing in pipes or conduits. Many different types of devices are used to measure the flow of fluids. The flow of fluids is most commonly measured using ***head flow meters***. The operation of these flow meters is based on the Bernoulli's equation.

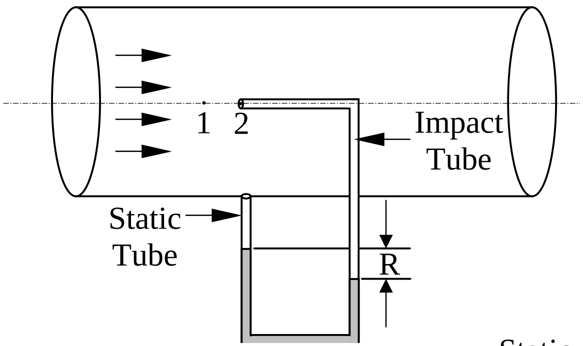
A construction in the flow path is used to increase in the lines flow velocity. This is accompanied by a decrease in pressure intensity or head and since *the resultant pressure drop is a function of the flow rate of fluid*, the latter can be evaluated.

7.2 Flow Measurement Apparatus

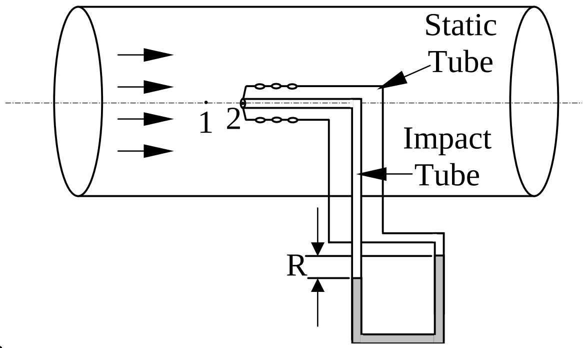
Head flow meters include **orifice, venture meter, flow nozzles, Pitot tubes, and wiers**. They consist of primary element, which causes the pressure or head loss and a secondary element, which measures it.

7.2.1 Pitot Tube

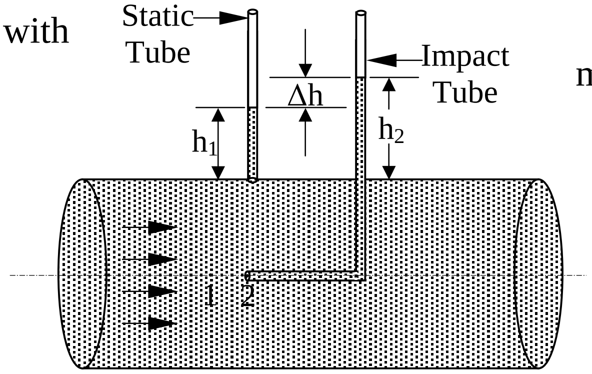
The Pitot tube is used to measure ***the local velocity*** at a given point in the flow stream and not the average velocity in the pipe or conduit. In the Figures below a sketch of this simple device is shown. One tube, ***the impact tube***, has its opening normal to the direction of flow and ***the static tube*** has its opening parallel to the direction of flow.



Simple Pitot tube with manometer



Simple Pitot tube with manometer provided with static pressure holes



Simple Pitot tube

Point 2 called ***stagnation point*** at which the impact pressure is be and $u_2 = 0$.

By applying Bernoulli's equation between points 1 and 2

$$\frac{P_1}{\rho\, g}+\frac{u_1^2}{2\alpha_1 g}+z_1=\frac{P_2}{\rho\, g}+\frac{u_2^2}{2\alpha_2 g}+z_2$$

$$\Rightarrow u_1=\sqrt{\frac{2(-\Delta P)}{\rho}}=\sqrt{2g\Delta h}=\sqrt{\frac{2R(\rho_m-\rho)g}{\rho}}$$ where, $\Delta P = R(\rho_m-\rho)g$

The fluid flows into the opening at point 2, pressure builds up, and then remains stationary at this point, called "***Stagnation Point***". The difference in the *stagnation pressure* (impact pressure) at this point (2) and the static pressure measured by the static tube represents the pressure rise associated with the direction of the fluid.

Impact pressure head = Static pressure head + kinetic energy head

Since Bernoulli's equation is used for ideal fluids, therefore for real fluids the last equations of local velocity become:

$$u_x=Cp\sqrt{\frac{2(-\Delta P)}{\rho}}=Cp\sqrt{2g\Delta h}=Cp\sqrt{\frac{2R(\rho_m-\rho)g}{\rho}}$$

where, Cp: dimensionless coefficient to take into account deviations from Bernoulli's equation and general varies between about 0.98 to 1.0.

Since the Pitot tube measures velocity at one point only in the flow, several methods can be used to obtain the average velocity in the pipe;

The first method, the velocity is measured at the exact center of the tube to obtain u_{max}. then by using the Figure, the average velocity can be obtained.

The second method, readings are taken at several known positions in the pipe cross section and then a graphical or numerical integration is performed to obtain the average velocity, from the following equation;

$$u=\frac{\iint_A u_x\, dA}{A}$$ (see Problem 5.16 Vol.I)

Example -7.1-

Find the local velocity of the flow of an oil of sp.gr. =0.8 through a pipe, when the difference of mercury level in differential U-tube manometer connected to the two tapping of the Pitot tube is 10 cm Hg. Take Cp = 0.98.

Solution:

$$u_x=Cp\sqrt{\frac{2R(\rho_m-\rho)g}{\rho}}=0.98\sqrt{\frac{2(0.1)(13600-1000)9.81}{800}}=5.49\,m/s$$

Example -7.2-

A Pitot tube is placed at a center of a 30 cm I.D. pipe line has one orifice pointing upstream and other perpendicular to it. The mean velocity in the pipe is 0.84 of the center velocity (i.e. u/u_x =0.94). Find the discharge through the pipe if: -

i- The fluid flow through the pipe is water and the pressure difference between orifice is 6 cm H_2O.

ii- The fluid flow through the pipe is oil of sp.gr. = 0.78 and the reading manometer is 6 cm H_2O. Take Cp = 0.98.

Solution:

i- $u_x=Cp\sqrt{2g\Delta h}=0.98\sqrt{2(9.81)(0.06)}=1.063\,m/s$

u = 0.84 (1.063) = 0.893 m/s, $Q = A.u = \pi/4(0.3)^2\,(0.893) = 0.063\ m^3/s$