Flow Measurements

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I. Introduction

The rate at which a fluid moves through a conduit is measured in terms of the quantity known as the flow rate. This chapter discusses some of the most common and accepted methods for measuring flow rate. Flow rate can be expressed in terms of a flow volume per unit time, known as the volume flow rate, or as a mass flow per unit time, known as the mass flow rate. Flow rate devices, called flow meters, are used to quantify, totalize, or monitor flowing processes. Type, accuracy, size, pressure drop, pressure losses, capital and operating costs, and compatibility with the fluid are important engineering design considerations for choosing a flow metering device. All methods have both desirable and undesirable features that necessitate compromise in the selection of the best method for the particular application, and many such considerations are discussed in this chapter. Inherent uncertainties in fluid properties, such as density, viscosity, or specific heat, can affect the accuracy of a flow measurement. However, some techniques, such as those incorporated into coriolis mass flow meters, do not require knowledge of exact fluid properties, allowing for highly accurate mass flow measurements in demanding engineering applications.

II. Flow Rate Concepts

The flow rate through a conduit, be it a pipeline, duct, or channel, depends on fluid density, average fluid velocity, and conduit cross-sectional area. Consider fluid flow through a circular pipe of radius r_1 and having a velocity profile at some axial pipe cross section given by $u(r, \theta)$. The mass flow rate depends on the average mass flux flowing through a cross-sectional area; that is, it is the average product of fluid density times fluid velocity and area, as given by

$$\dot{m} = \iint\limits_A \rho u(r, \theta) dA = \rho \bar{U} A \tag{1}$$

The pipe area is simply $A = \pi r_1^2$. We see that to directly make a mass flow rate measurement, the device must be sensitive to the area-averaged mass flux per unit, volume, $\rho\bar{U}$, or to the fluid mass passing through it per unit time. Mass flow rate has the dimensions of mass per unit of time (e.g., units of kg/s, lbm/s, etc.).

The volume flow rate depends only on the area-averaged velocity over a cross section of flow as given by

$$Q = \iint\limits_A u dA = \bar{U} A \tag{2}$$

So to directly measure volume flow rate requires a device that is sensitive either to the average velocity,

U, or to the fluid volume passing through it per unit time. Volume flow rate has dimensions of volume per unit time (e.g., units of m^3/s, ft^3/s, etc.).

The difference between the above two equations is quite significant, in that either requires a very different approach to its measurement: one sensitive to the product of density and velocity or to mass rate, and the other sensitive only to the average velocity or to volume rate. In the simplest case, where density is a constant, the mass flow rate can be inferred by multiplying the measured volume flow rate by the density. But in the metering of many fluids, this assumption may not be good enough to achieve necessary accuracy. This can be because the density changes or it may not be well known, such as in the transport of polymers or petrochemicals, or because small errors in density accumulate into large errors, such as in the transport of millions of cubic meters of product per day.

The flow character can affect the accuracy of a flow meter. The flow through a pipe or duct can be characterized as being laminar, turbulent, or a transition between the two. Flow character is determined through the nondimensional parameter known as the Reynolds number, defined by

$$Re_{d_1} = \frac{\bar{U} d_1}{\nu} = \frac{4Q}{\pi d_1 \nu} \tag{3}$$

where ν is the fluid kinematic viscosity and d_1 is the diameter for circular pipes. In pipes, the flow is laminar when $Re_{d_1} < 2000$ and turbulent at higher Reynolds number. The Reynolds number is a necessary parameter in estimating flow rate when using several of the types of flow meters discussed. In estimating the Reynolds number in noncircular conduits, the hydraulic diameter, $4r_H$, is used in place of diameter d_1, where r_H is the wetted conduit area divided by its wetted perimeter.

III. Procedure

- ➪ There are three pipes (1-inch, 2-inch and 3-inch dia) connected to the overhead tank. Open the valve of the 1-inch dia. pipe completely. Make sure that the water level in the tank stays cnstant by adjusting the inlet valve. Ask the TA for help.
- ➪ Measure the height of the water level in the tank.
- ➪ Calculate the mass flow rate. Repeat the procedure for the 2-inch and 3-inch pipes.
- ➪ Now close all the valves of the pipes as well as the inlet valve.
- ➪ Open the 1-inch valve completely and note down the time it takes for the water level in the tank to reach each each marking (ask the TA for help). Note down the time at each marking until the water completely drains from the tank.
- ➪ Repeat the procedure for the 2-inch and 3-inch pipes.
- ➪ Calculate the mass flow rate fom these measurements. Plot a graph of height vs. velocity.

IV. Report

For this lab you will write the Results and Discussion of Results sections of a full report.