Venturi and orifice volumetric flow measurement

key words: Volumetric and mass flux, venturi and orifice meter, device calibration, .
goals: The objective of this exercise is to gain knowledge in volumetric methods employing Venturi effect. Calibration of orifice and Venturi meter.

1 Introduction

As the fluid flows through a constriction it experiences a drop in fluids pressure. Although it is referred to as the Venturi[1] effect it was probably known in times of a Roman engineer Frontinus[2].

To satisfy the **continuity equation**, velocity of the flow through a constricting pipe will increase. Which in turn causes a drop in pressure (Bernoulli's principle). Figure 1[3] illustrates the phenomena named Venturi effect.

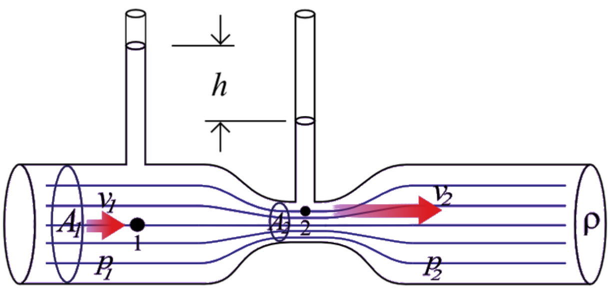

Figure 1: The Venturi effect. As the pipe contracts, the pressure of the fluid decreases.

Assuming a **steady-state**, **inviscid**, **incompressible** ($\rho = const$) and **laminar** flow, continuity and Bernoulli equation form the following set of equation:

$$\begin{cases} Q_t = v_1 D^2 = v_2 d^2 \leftarrow \text{continuity equation} \\ \frac{\rho V_1^2}{2} + p_1 = \frac{\rho V_2^2}{2} + p_2 \leftarrow \text{Bernoulli equation,} \end{cases} \tag{1}$$

[1]Giovanni Battista Venturi (March 15, 1746 - April 24, 1822) was an Italian physicist.
[2]Sextus Julius Frontinus (ca. 40-103 AD)
[3]From http://en.wikipedia.org/wiki/Venturi_effect

introducing an **area ratio** $m = (\frac{d}{D})^2$ and solving for the volumetric flow rate (in fact just a theoretical value) Q_t one would get:

$$Q_t = \frac{m}{\sqrt{1-m^2}} \frac{\pi D^2}{4} \sqrt{\frac{2(p_1 - p_2)}{\rho}} \tag{2}$$

Equation 2 states that for a given geometry the flow rate might be calculated simply by measuring the pressure difference $p_1 - p_2$. While deriving equation 2 some idealistic assumptions were made. Due to that equation 2 will **overestimate** the actual flow rate if used for a real fluid. Therefore to calculate the actual flow rate a modification is required. The following equation is used:

$$Q = C_d Q_t \tag{3}$$

where C_d is so called coefficient of discharge. In general it is a function of device type and geometry, but also depends on the Reynolds number of the flow. Figure 2 shows a values of $\frac{C_d}{\sqrt{1-m^2}}$ plotted as a function of Re for different area ratio of a Venturi meter[4].

2 Venturi effect based meters

The flow meters employing the Venturi effect do come in different shapes and sizes. From crude orifices (just a plate with a drilled hole) having high hydraulic loses, lower accuracy and high discharge coefficient dependence on area ratio and the type of flow. To more sophisticated Venturi meters and nozzles with strictly defined geometry. Figure 2 shows some examples of orifices (a, b), a Venturi meter (d) and a nozzle (c, e).

3 Orifice and Venturi meter calibration

1. Note the the dimension of device to be calibrated (orifice and/or Venturi meter).

2. Start the flow through the installation, manipulate the flow rate with a valve.

3. Using a stopwatch measure a time t necessary to fill the reference tank of volume V.[5]

[4]Value of $\frac{C_d}{\sqrt{1-m^2}}$ instead of C_d is used for better plot resolution.

[5]Now how do you calculate the volumetric flow rate?

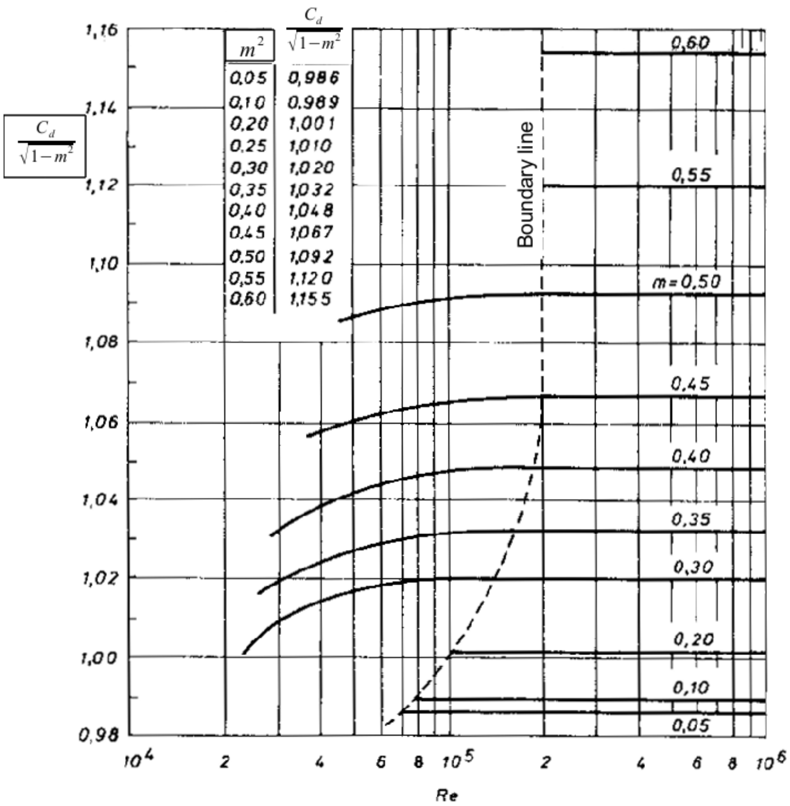

Figure 2: Discharge coefficient dependency on geometry and Reynolds number for a Venturi meter.

4. Measure the pressure drop at the device being calibrated.
5. Repeat the measurements at different flow rates. Ask the tutor for the number of test you should perform.
6. Calculate the theoretical volumetric flow rate using eq.2.
7. Calculate the actual flow rate using data from experiment and the discharge coefficient.
8. Calculate the Reynolds number. $Re = \frac{VD}{\upsilon}$
9. Repeat the calibration for each of the measurements and plot C_d as a function of Re.

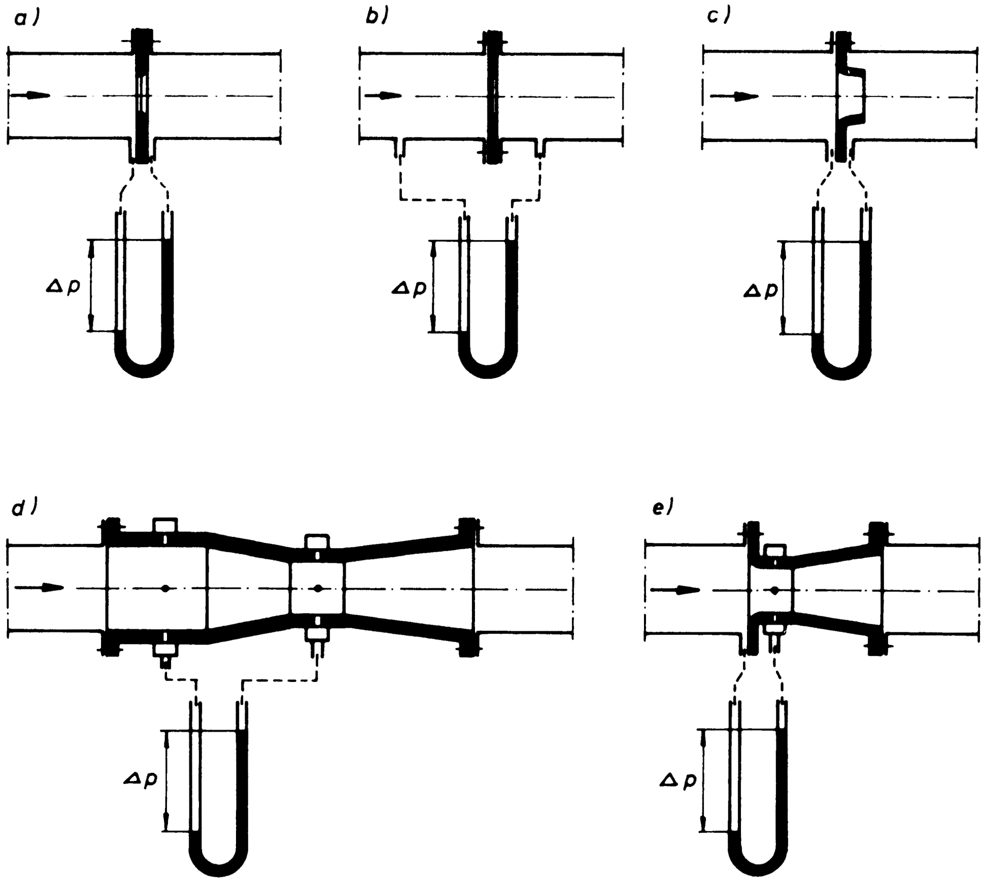

Figure 3: Different types of constriction flow meters. a,b - orifices, c - nozzle, d - Venturi constriction meter, e - Venturi nozzle.

Dear student,
should you have any remarks, observations or comments concerning this instruction. Please do not hesitate to make them.