

4. measurement

MEASUREMENT OF PRESSURE

Aims of the measurement:

- To get familiar with the pressure gauges.
- Pressure measurement with U-tube (liquid column gauge) and Bourdon gauge. Measurement of the pressure difference between two locations of a fluid flow system.
- Flow rate measurement with metering orifice and metering tank.
- Calibration of a Bourdon gauge.

1. Measuring pressure

1.1. *Liquid column gauge (U tube)*

Liquid column gauges consist of a vertical column of liquid in a tube whose ends are exposed to different pressures. The column will rise or fall until its weight is in equilibrium with the pressure differential between the two ends of the tube. A very simple version is a U-shaped tube half-full of liquid, one side of which is connected to the region of interest while the reference pressure (which might be the atmospheric pressure or a vacuum) is applied to the other. The difference in liquid level represents the applied pressure.

Although any fluid can be used, mercury is preferred for its high density (13.534 g/cm^3) and low vapour pressure. For low pressure differences well above the vapour pressure of water, water is commonly used (and "meters of water" is a common pressure unit).

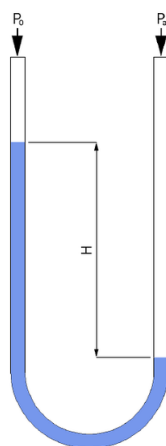


Figure 1 (left) Schematic draw of a liquid column gauge (right) Liquid column gauges

1.2. Bourdon gauge

The Bourdon pressure gauge uses the principle that a flattened tube tends to change to a more circular cross-section when pressurized. Although this change in cross-section may be hardly noticeable, the displacement of the material of the tube is magnified by forming the tube into a C shape or even a helix, such that the entire tube tends to straighten out or uncoil, elastically, as it is pressurized.

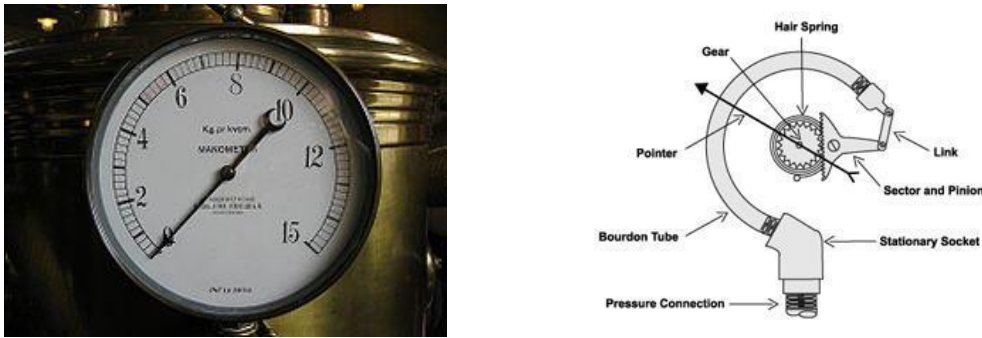


Figure 2 (left) Bourdon gauge (right) Mechanism of the Bourdon gauge

In practice, a flattened thin-wall, closed-end tube is connected at the hollow end to a fixed pipe containing the fluid pressure to be measured. As the pressure increases, the closed end moves in an arc, and this motion is converted into the rotation of a (segment of a) gear by a connecting link which is usually adjustable. A small diameter pinion gear is on the pointer shaft, so the motion is magnified further by the gear ratio. The positioning of the indicator card behind the pointer, the initial pointer shaft position, the linkage length and initial position, all provide means to calibrate the pointer to indicate the desired range of pressure for variations in the behaviour of the Bourdon tube itself.

Bourdon tubes measure gage pressure, relative to ambient atmospheric pressure, as opposed to absolute pressure; vacuum is sensed as a reverse motion. When the measured pressure is rapidly pulsing, such as when the gauge is near a reciprocating pump, an orifice restriction in the connecting pipe is frequently used to avoid unnecessary wear on the gears and provide an average reading; when the whole gauge is subject to mechanical vibration, the entire case including the pointer and indicator card can be filled with an oil or glycerin. Typical high-quality modern gauges provide an accuracy of $\pm 2\%$ of span, and a special high-precision gauge can be as accurate as 0.1% of full scale.

1.3. **Electronic pressure sensors**

A **pressure sensor** measures pressure, typically of gases or liquids. A pressure sensor usually acts as a transducer; it generates an electronic signal as a function of the pressure imposed. Although there are various types of pressure transducers, one of the most common is the strain-gage base transducer. The conversion of pressure into an electrical signal is achieved by the physical deformation of strain gages which are bonded into the diaphragm of the pressure transducer. Pressure applied to the pressure transducer produces a deflection of the diaphragm which introduces strain to the gages. The strain will produce an electrical resistance change proportional to the pressure.

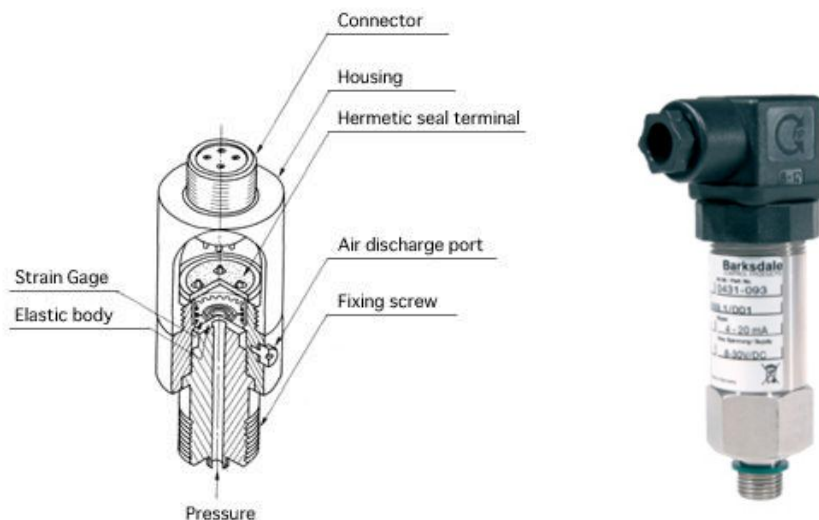


Figure 3 (left) Cut-away of an electronic pressure sensor (right) pressure sensor

1.4. **Calibration**

Calibration is a comparison between measurements - one of known magnitude or correctness made or set with one device and another measurement made in as similar a way as possible with a second device. The device with the known or assigned correctness is called the standard.

The calibration process begins with the design of the measuring instrument that needs to be calibrated. The design has to be able to "hold a calibration" through its calibration interval. In other words, the design has to be capable of measurements that are "within engineering tolerance" when used within the stated environmental conditions over some reasonable period of time.

Suppose that one owns an old Bourdon gauge, whose scale is inaccurate – yet the device itself is working. After a calibration process the gauge can be used again with high accuracy as the calibration results in a relationship between the “read” and “real” value as $p_{real}=f(p_{read})$, e.g. in the form of a “calibration diagram”.

2. Measuring flow rate

2.1. Metering tank (bucket-and-stopwatch)

Perhaps the simplest way to measure volumetric flow is to measure how long it takes to fill a known volume container. A simple example is using a bucket of known volume, filled by a fluid. The stopwatch is started when the flow starts, and stopped when the bucket overflows. The volume divided by the time gives the flow:

$$Q = \alpha \frac{\Delta m}{\Delta t} \left[\frac{dm^3}{s} \right]$$

where

α [dm³/mm] is the constant of the tank being the volume of a 1 mm high quantity of liquid in the tank,

Δm [mm] is the rising of the level

Δt [s] is the time taken for rising.

2.2. Orifice plate

An orifice plate (metering orifice) is a plate with a hole through it, placed in the flow; it constricts the flow, and measuring the pressure differential across the constriction gives the flow rate.

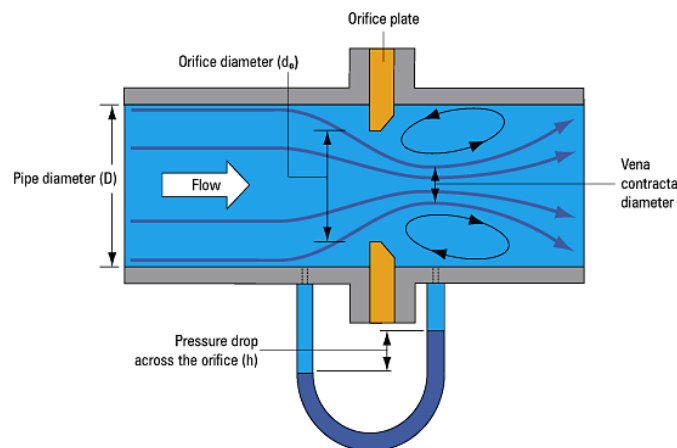


Figure 4 Cut-away of a metering orifice

The square root of measured pressure difference is proportional to the flow rate:

$$Q = K \sqrt{\Delta p}$$

where K is constant (its computation is described by standards).

3. The measurement exercise

3.1. Measurement of flow rate

On the rig presented in Fig. 5 there are two possibilities to measure the flow-rate (i.e. the quantity of liquid delivered per unit time):

- in the horizontal pipe-section there is a metering orifice (OR) and
- a volume meter tank (VMT) is also available at the end of the system.

You will measure the same flow rate with devices and compare the (possibly same) results.

In Fig. 6 there is shown the diagram of the orifice. On the abscissa we have not drawn the pressure-drop but the square root of the level-difference read on the U-tube manometer U1 (see Figure 5) and so the flow-rate is given directly after the reading of the manometer.

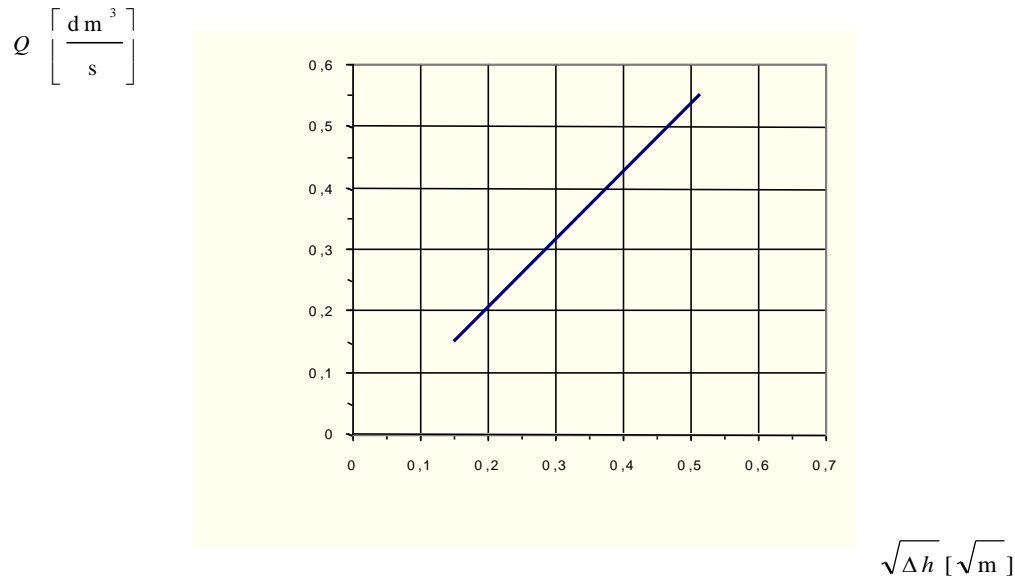


Figure 6. The pressure difference – flow rate relationship of the metering orifice.

3.2. Measurement of pressure

The next task is to determine p_n and p_s pressures, i.e. the pressure before and after a nozzle.

Note that in the nozzle, as the velocity increases (area decreases), thus, based on Bernoulli's equation, we expect a $p_n > p_s$:

$$Q = \text{const} = A_n v_n = A_s v_s, \quad A_n \gg A_s \rightarrow v_n \ll v_s$$

$$p_n + \frac{\rho}{2} v_n^2 + \rho g h_n = p_s + \frac{\rho}{2} v_s^2 + \rho g h_s \rightarrow p_n \gg p_s$$

$\approx h_n$

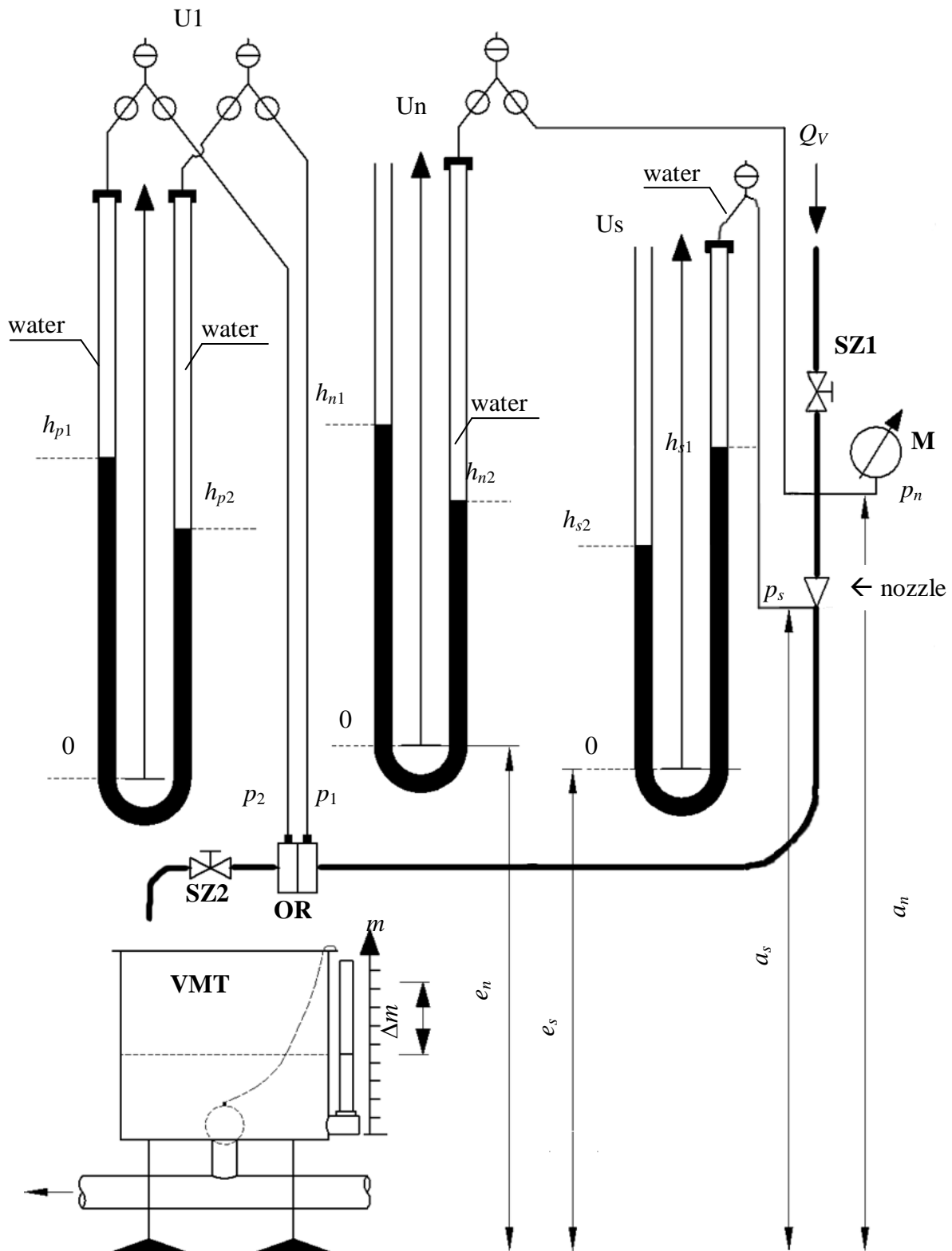


Figure 5 The measuring rig

The actual value of p_n and p_s is calculated as follows. The balance equation for U tube Un is (note that this is again Bernoulli's equation, with zero velocity, as the fluid in the U-tube is at rest):

$$p_0 + (h_1 - h_2) \rho_m g = p_n + (a - (e + h_2)) \rho_w g$$

The balance equation for U tube Us is:

$$p_0 = p_s - (e_s + h_{s1} - a_s) \rho_w g + (h_{s1} - h_{s2}) \rho_m g$$

The data needed for evaluation are:

- $\rho_w = 1000 \text{ kg/m}^3$, $\rho_{Hg} = 136000 \text{ kg/m}^3$
- p_0 will be measured on site and
- geometry (a , a_s , e , e_s) will also be measured on site.

3.3. Calibration of a Bourdon gauge

The third task is to measure the calibration chart of a Bourdon gauge.

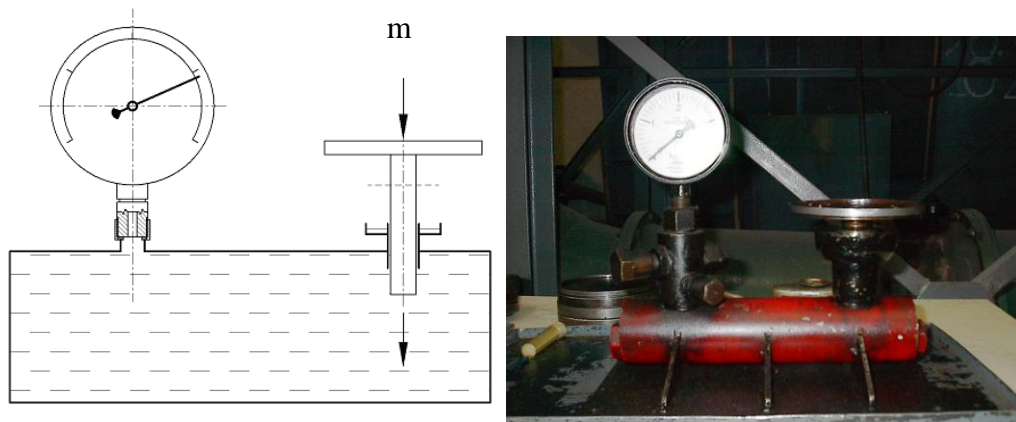


Figure 6 Calibrating a Bourdon gauge.

Figure 6 depicts the simple system used for calibration. By adding weights to the plunger, we create a *known pressure* in the tank, which is compared to the *dial pressure* of the Bourdon gauge. The pressure of the fluid is:

$$p = \frac{(m + m_0) g}{a} ,$$

Where m_0 is the mass of the plunger, $m_0 = 1 \text{ kg}$, “a” stands for the cross section of the plunger, $a=2 \times 10^{-4} \text{ m}^2$. To increase the pressure, several steel disks of 1 and 2 kg mass will be used. You should measure at least 8 points.

3.4. *The report*

You report shall include the following items.

1. Numerical calculations of the flow rate measurement: result of the metering tank and orifice measurement (two flow rates) and an evaluation whether you think if the results are reasonably close to each other (as you measured the same flow rate in two different ways).
2. Numerical calculations and results of the pressure measurement, with an explanation (why does the pressure drop after the nozzle?).
3. Calibration diagram of the Bourdon gauge: the dial (read) pressure as a function of the computed (real) pressure on a **mm paper**.

The calculations have to be well-documented, i.e. every quantity (time, length, pressure) should be included in the report.

4. Preparation questions

1. Explain two ways of measuring flow rate (sketch + equations).
2. Explain three techniques to measure pressure (sketches).
3. Make a sketch of the device used for the Bourdon gauge calibration and explain how it works.
4. We measure the pressure before and after a nozzle. Make a sketch and explain with equations, why the pressure after the nozzle is lower than that one before the nozzle.
5. Give Bernoulli's equation and the continuity equation and explain the terms.