Pressure measurements.

Exercise No 2

Theory

Definitions

Pressure is one of the key thermodynamic parameters. It is an intensive property. Pressure is defined as a ratio between a force and a unit area, perpendicular to the direction of that force, on which the force acts. Mathematically this definition is expressed as:

$$p = \frac{F}{A}$$

where p – pressure, F – normal force, A – area.

Total pressure of a fluid in a nominated point consists of two elements:

- Static pressure, defined as a pressure not associated with the fluid motion, but its state. It is the pressure which would be indicated by a gauge moving together with the fluid
- Dynamic pressure, which is a measurement of kinetic energy of a moving fluid and depends on its velocity and density. Dynamic pressure is expressed by the equation:

  $$p_D = \frac{\rho\omega^2}{2}$$

  where ρ – fluid density, ω – fluid velocity.

Units

The primary unit of pressure in the International System of Units (SI) is pascal, abbreviated Pa. It is defined as:

Despite the theoretically universal character of the International System of Units, many other units of pressure are still commonly used in both science and industry. Most popular ones are:

- Pound-force per square inch (psi or lbf/in²) – used mainly in the USA,
  1 psi = 6,894.8 Pa
- Kilogram-force per square centimetre (kgf/cm², in Poland abbreviated as kG/cm²),
  1 kgf/cm² = 98,066.5
- Millimetre of mercury (mmHg),
  1 mm Hg = 133.3 Pa
- Torr (Tr) – equal to 1/760th of standard atmosphere and thus practically equal to 1 mm Hg
- Standard atmosphere (atm) – so-called standard pressure,
  1 atm = 101,325.0 Pa

- Technical atmosphere (at) – defined as one kilogram-force per square centimetre, thus 1 at = 98,066.5 Pa
- Bar (bar) – defined as 100 kilopascals,
  1 bar = 100,000.0 Pa.

Please note that bar, technical atmosphere, standard atmosphere and kilogram-force per square centimetre are roughly similar and for estimation purposes can be assumed practically equal.

Gauge pressure vs absolute pressure

In most cases pressure measurement devices actually measure pressure difference (either between two areas or between the measured area and reference level), not absolute pressure. One commonly used reference level is the standardised atmospheric pressure. Two types of standard pressure values are commonly used:

- p = 100,000 Pa – according to standard conditions for temperature and pressure (STP) as defined by International Union of Pure and Applied Chemistry (IUPAC)
- p = 101,325 Pa - according to e.g. National Institute of Standards and Technology (NIST).

In Polish language the latter reference pressure is known as the *normal* pressure (Polish: *ciśnienie normalne*).

Pressure measured in reference to atmospheric pressure is called gauge pressure. The value can be either positive or negative.

Absolute pressure is measured in reference to total vacuum, and as such can only have positive values.

Sometimes the type of measurement (reference condition) is indicated next to the unit designation:

- For gauge pressure by adding letter g to the unit symbol, e.g. barg, kPag, psig or possibly bar(g) etc
- For absolute pressure by adding letter a to the unit symbol, e.g. bara, kPaa, psia or possibly bar(a) etc.

It is very important to check whether the specified pressure is gauge or absolute value, especially in case of near-atmospheric values – a difference between 1 bara and 1 barg is very significant!

Pressure measurements

There are multiple types of pressure measurement devices (manometers) based on various principles. They can be either direct-reading gauges, where working elements are directly influenced by the pressure, or indirect-reading gauges, where actually measured are some other pressure-dependant parameters. Some of the gauge types are listed below.

- Hydrostatic gauges – which are based on comparison between the pressure and hydrostatic force of a column of fluid
  - Piston type
  - Liquid column

- Aneroid gauges – based on metallic element which flexes under pressure
    - Bourdon gauge (flattened tube gauge)
    - Diaphragm gauge
    - Bellows gauge
- Electronic pressure sensors .

Pressure gauge calibration

Generally there are two traditional methods for pressure gauge calibration:

- Direct technique, where values indicated by the calibrated gauge are directly compared to:
    - Pressure exerted by a static liquid column – for near-atmosphere pressures
    - Pressure exerted by a solid weight (deadweight test) – for pressures much higher than atmospheric
    - Pressure of wet steam (usually mercury) at known temperature – for very low pressures.
- Indirect technique – where the calibrated gauge is connected to the same pressurised tank as another gauge considered already calibrated, and the indications are compared.

Exercise instructions

During the exercise you will get familiar with various types of pressure gauges. Then you will calibrate a pressure gauge on your own, using a deadweight tester apparatus (based on a hydraulic press). The tester is of a wet (oil) type. You will need to prepare a paper dial disk and then create a scale on it. Put the dial disk on the test pressure gauge. Then by adding weights on the tester you will increase the pressure in the system to which the calibrated gauge is connected. As the test weights are calibrated (scaled in at), you know exactly what gauge pressure occurs in the system, and therefore you are able to calibrate your gauge. In order to verify your work you can use another pressure gauge connected to the same system (although note that it is not calibrated accurately!).

Report

Contents of your exercise report will be specified during the classes by your instructor. Pay attention!