Infrastructure Commission (INFCOM)
Standing Committee on Measurements, Instrumentation and Traceability (SC-MINT)
Expert Team on Quality, Traceability and Calibration (ET-QTC)

Calibration of Pressure Instruments

Part-1: Introduction

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Content

Part 1:

- Introduction to this topic and historical information
- Concepts and definitions

Part 2:

- Methods of measurement
- Pressure standards in calibration laboratory

Part 3:

- Comprehensive calibration procedure
- Calibration equipment and data acquisition

Part 4:

- Measurement uncertainty contributions part #1

Part 5:

- Measurement uncertainty contributions part #2
- References and links

Content

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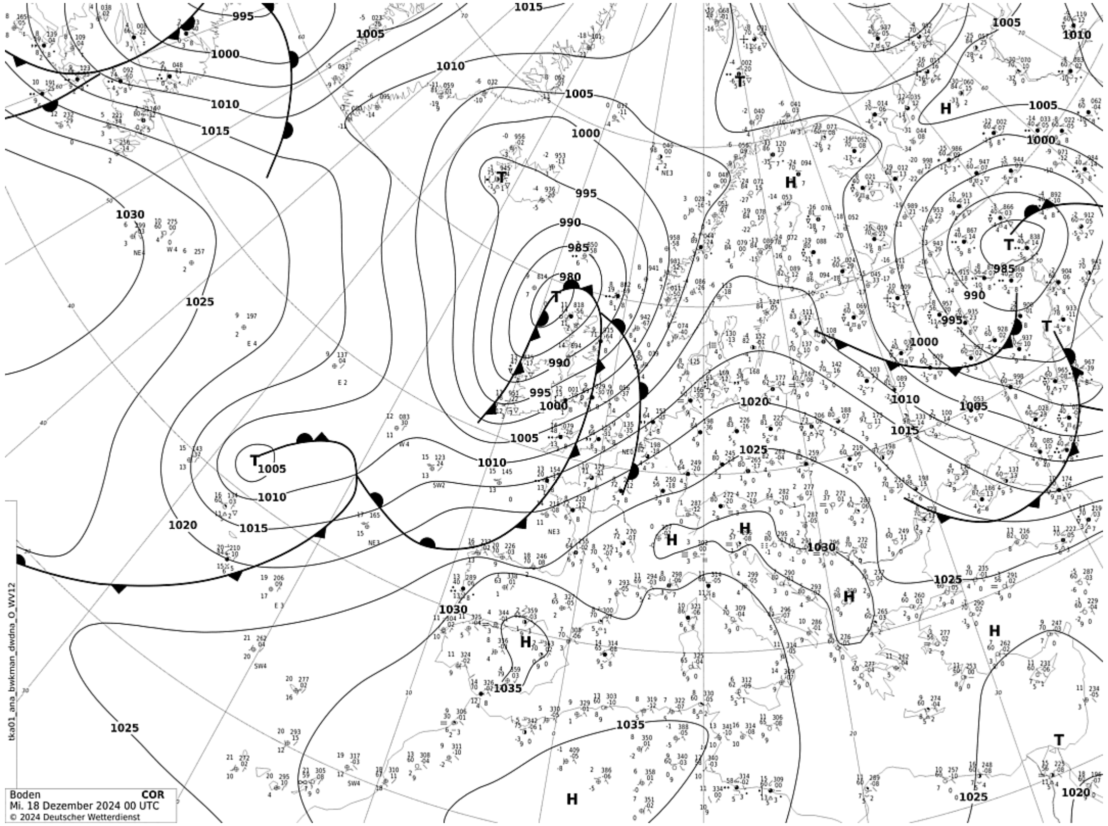
Introduction to this topic

- the air pressure has been discovered relatively recently
- in contrast to other meteorological variables such as temperature, humidity, rain and wind, a human cannot feel the influence of air pressure
- rapid changes in altitude (aeroplane, cable car, lift in high buildings) are an exception, as you can feel these with your ears

Introduction to this topic

- the horizontal air pressure distribution is very important information for analysing, diagnosing and forecasting the weather
- differences in air pressure have the effect of moving the air



Surface pressure chart

- movement of air from areas with high pressure to areas with low pressure

Introduction to this topic

- precise measurement of the air pressure is also very important for aviation
- measuring the pressure of the air is known as **absolute air pressure** measurement
- pressure sensors and instruments used in meteorology usually measure the absolute air pressure and are referred to as **barometers**

Historical information

1640
Galilei and Berti
water barometer

1643
Torricelli and Viviani
mercury barometer

1648
Périer
reduction of absolute pressure with height

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Historical information

1654

Magdeburg hemispheres

von Guericke

https://upload.wikimedia.org/wikipedia/commons/a/aa/Stamps_of_Germany_%28DDR%29_1969%2C_MiNr_1514.jpg

1660

forecast of storms due to decrease of air pressure

von Guericke

1693

temperature dependency of mercury

Halley

1704

first correction of mercury barometers due to temperature

Amontons

Historical information

1702
first idea for an aneroid barometer
Leibnitz

1724
hypsometric effect
Fahrenheit

1787
measurements with a hypsometer at Mont-Blanc
Saussure

1806
reduced scale for mercury barometers

Historical information

1844

first aneroid barometer

L. Vidie

1873

the first Meteorological Congress in Vienna initiated the early meteorological requirements

1876

construction of a barograph

Rédier

Historical information

1904
temperature dependency aneroid barometers
Hergesell/Kleinschmidt

1972
Quartz-Barometer
Digiquartz

1985
introduced the Barocap (2025: 40 years!!!)
Vaisala

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Concepts and definitions

WMO-No. 8

Definition of atmospheric pressure #1:

- The *atmospheric pressure* on a given surface is the **force per unit area** exerted by **virtue of the weight of the atmosphere above**. The pressure is thus **equal to the weight of a vertical column of air above a horizontal projection of the surface**, extending to the outer limit of the atmosphere.

- Apart from the actual pressure, **pressure trend or tendency** has to be determined as well. Pressure tendency **is the character and amount of atmospheric pressure change** for a three-hour or other specified period ending at the time of observation.

Concepts and definitions

WMO-No. 8

Definition of atmospheric pressure #3:

- Pressure tendency is composed of two parts, namely the **pressure change** and the **pressure characteristic**.
  - The **pressure change** is the net difference between pressure readings at the beginning and end of a specified interval of time.
  - The **pressure characteristic** is an indication of how the pressure has changed during that period of time, for example, decreasing then increasing, or increasing and then increasing more rapidly.

Concepts and definitions

- The pressure prevailing in liquids and gases can be easily explained with the particle model:

  - One cubic centimetre of air contains 2.7^{19} molecules. They move disorderly at a speed of about 480 metres per second. One of these molecules has **4.7 billion collisions** with other molecules per second. Also every **surface** is hit by **countless molecules**. The effect of these collisions is called pressure.

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Concepts and definitions

- The pressure acts in all directions.

- The **force** of the sum of the molecules, which are hitting a surface is called **Newton**. One Newton is defined as a **force which will give an acceleration of one meter per second to a mass of one kilogram**.

$$1\,N = 1\,\frac{kg \ * m}{s^2}$$

Concepts and definitions

- Normally the force will **not act to one point** of the surface. It will act to an **area**. The perpendicular force which will act to one square meter is called Pascal.

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

$$1\ Pa = 1\ \frac{N}{m^2} = 1\ \frac{kg\ * m}{s^2 * m^2} = 1\ \frac{kg}{m * s^2}$$

Concepts and definitions

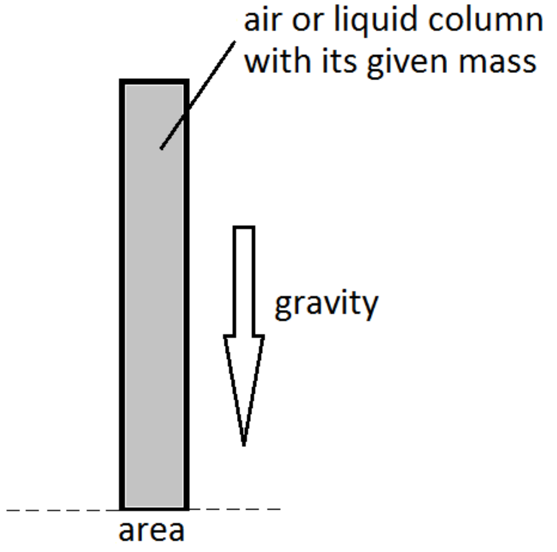
- The numerical value of the pressure is big so in the meteorological science a special unit has been introduced: the hectopascal. One hectopascal is one hundred Pascal.

$$1\ hPa = 100\ Pa$$

$$(1\ hPa = 1\ mbar)$$

Concepts and definitions

- Following the definition of WMO-No. 8
  - A liquid (or gas) **column standing on a surface**.
  - Thus a **liquid at rest exerts** a pressure solely due to its **gravity.**



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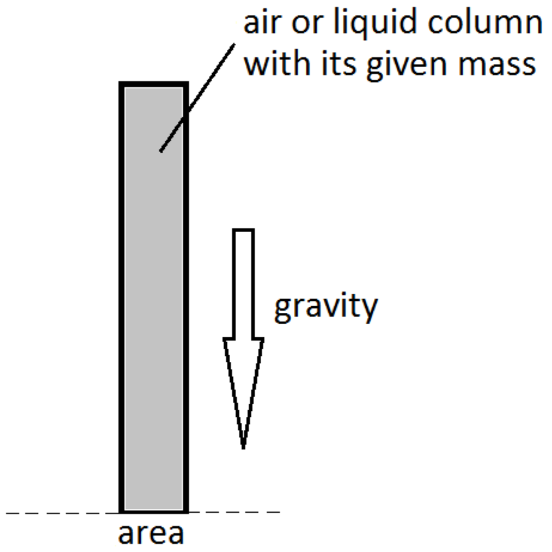
Concepts and definitions

- Let's assume an **incompressible fluid**. How do you calculate the gravity pressure?



$$P = \frac{F}{A} = \frac{F_G}{A} = \frac{m * g}{A} = \frac{\rho * V * g}{A} = \frac{\rho * A * h * g}{A} = g * \rho * h$$

$P:$ *Pressure in Pascal* $= 1\ \frac{N}{m^2}$

$A:$ *area in* m^2

$m:$ *mass in kg* $= \rho * V$

$g:$ *earth's standard gravity* $= 9.80665\ \frac{m}{s^2}$

$\rho:$ *air density in* $\frac{kg}{m^3}$

$h:$ *height of the column in m*

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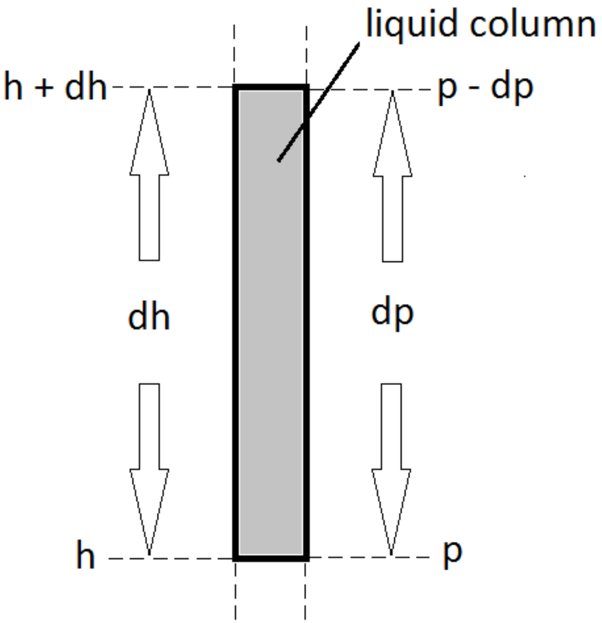
Concepts and definitions

- If the equation of the gravity pressure of this fluid is **differentiated and then integrated**, the gravity pressure of the fluid is easy to calculate because its density can be regarded as approximately constant.

- We can now calculate the so-called **hydrostatic pressure**:



$$dp = g * \rho * dh$$

$$\int_{p_0}^{p} dp = g * \rho * \int_{h_0}^{h} dh$$

$$p - p_0 = g * \rho * (h - h_0)$$

$$p = p_0 + g * \rho * (h - h_0)$$

Concepts and definitions

- Let us now calculate the pressure when immersing **10 m deep in water**:

$$p = p_0 + g \, * \, \rho \, * (h - h_0)$$

$$p = 101325 \, Pa + 9.80665 \, \frac{m}{s^2} * 1000 \frac{kg}{m^3} * 10 \, m = 101325 \, Pa + 98066.5 \, Pa$$

$$p = 1993.915 \, hPa \sim 2000 \, mbar \sim 2 \, bar.$$

- Assuming that the density is constant, the pressure increases by ~1 bar per 10 m immersion depth.

Concepts and definitions

- As the air pressure **decreases** with altitude, its change is negative. The following equation is called the basic static equation in meteorology.

$$-dp = g * \rho * dh$$

- It can be calculated that in the **lowest atmospheric layers** the air pressure decreases at **0 °C** by **1** $\boldsymbol{hPa}$ (P = 1013.25 hPa) with a height difference of approximately $\boldsymbol{\sim 8\ m}$.

- This simple rule of thumb shows that a height difference of only $\mathbf{8\ cm}$ between calibration object and reference would mean an error of $\boldsymbol{1\ Pa}$.

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Calibration of Pressure Instruments
End of Part 1

Thank you.

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