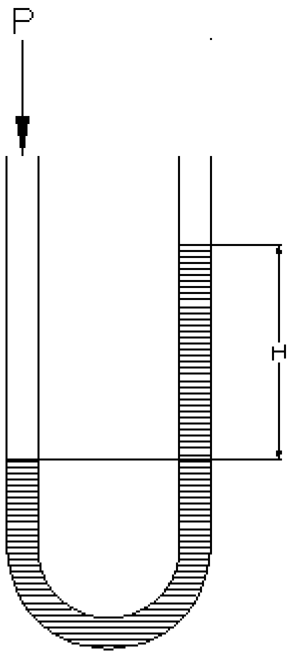
PRESSURE SOLUTIONS

# P101: Pressure Measurement

Pressure is defined as force per unit area. Its SI unit is Newtons per square meter $N/m^2$ which has been given the special name of Pascal.

The earliest method of pressure measurement was a liquid column. The simplest visualisation is a U-Tube.




The pressure is applied to one leg, and the other leg is open to atmosphere. This makes it a gauge measurement. The pressure is balanced by difference in the height of the liquid.

If the cross section of the pipe is A, and the density of the liquid is ρ, then the force balance is PxA on the one side and H x ρ x A on the other side. The A cancels out, and we are left with P = H x ρ which is the fundamental head equation.

If the vented leg is now sealed and evacuated, we can measure absolute pressure, including the pressure of the atmosphere.

If pressure is applied to both legs, we can measure the difference between two pressures.

The problem with the liquid tube is that it is bulky, fragile, and limited to lowish pressures. A 100 kPa pressure requires a column of water 10m high. Making the liquid mercury, which is the densest available liquid, reduces this to 750 mm.

Apparently, when the first railway system started, the boiler pressure was indicated by a mercury column. The problem arose when new boilers came available using higher pressures for greater power and efficiency. The new indicators didn't fit the tunnels! Thus there arose an urgent need to find a more compact means of measuring pressure.

In 1849, two inventors came up with two different mechanisms to solve this problem. M. Bourdon invented the Bourdon tube. Herr Schaffer invented the Schaffer diaphragm.

These are described in P103.

Like all things, these two mechanisms have their strengths and weaknesses.

The bourdon tube is cheap to make and is suitable for pressures from about 60 kPa upwards. Below this, the tubes become so flimsy they are easily damaged. The response is fairly linear. The inlet to the bourdon tube is restricted. Only a few materials are suitable for manufacturing bourdon tubes, including copper alloys, steel (including stainless) and some nickel alloys like Monel.

The bourdon tube is thus suitable for most clean, non-corrosive, medium to high pressure applications, and thus has become the elements of choice for most pressure gauges.

The Schaffer diaphragm is less easy to make, and less linear. It is best suited for low pressures, and at much over 2 500 kPa, the diaphragm starts getting bulky. It can measure down to about 4 kPa. It can have the full face exposed to the medium, making it difficult to block. It can be easily supported, making it suitable for quite high overpressure. It can be protected with foil discs of various corrosion resistant materials. It is sensitive to pulsation.

The Schaffer diaphragm is thus ideal for dirty corrosive fluids, and low liquid pressures.

Her Schaffer went into partnership with Herr Budenberg to develop his invention, and that grew into the current Budenberg Gauge Co.

When made into the form of a capsule or bellows for very low pressure measurement, we can measure down to around 250 Pa. The effects of any liquid entrapped in the capsule become significant, making this design suitable for dry gas applications only.

There is another type of diaphragm which is seen in pressure switches and some differential pressure gauges. This is the spring-opposed piston. This uses the overpressure capability of the diaphragm to provide a mechanism which can measure fairly low pressures while withstanding very high pressures. Examples include the  Orange Research DP gauges, and the Delta Sovereign and Compact switches

When it comes to electrical pressure measurement, the corrugated diaphragm has been complemented by the flat or mainly flat diaphragm, but the fact remains that virtually all electronic pressure devices use some form of diaphragm in their sensor. Sometimes the diaphragm itself senses pressure, e.g. through piezoelectricity where the pressure creates and electrical signal. In other cases the displacement of the diaphragm cause by the pressure is measured. Mechanisms include strain gauge, LVDT and capacitive. The required displacement is very much less for an electrical sensor, so diaphragms are much smaller.

There are five properties of fluids which impinge on sensor selection: these are cleanliness, viscosity, corrosiveness, pressure and temperature.

Pressure sensors mostly work on some type of force balance, usually where the applied pressure is balance by the reaction from the elastic deformation of the sensor. The elastic modulus of the sensor material will vary with temperature, so apart from any destructive effects, extremes of temperature will cause errors. 60ºC is usually considered the upper limit for mechanical gauges. Low temperatures may cause the pressure medium to freeze, or cause embrittlement of components.

Sensors can be protected from extreme temperatures by mounting remotely from the tapping point. A short length of pipe will drop the temperatures drastically. A rule of thumb is 20ºC drop per 150mm of line.

Pressure will to a certain extent dictate the type of sensor used.

Corrosiveness will dictate which materials are acceptable. If the sensor cannot be made from a corrosion resistant material, or protected in the case of a diaphragm, consider a chemical seal (see P104.)

Cleanliness and viscosity will determine whether the pressure port can be restrictive, as with a bourdon tube. This is discussed further in P201 (Selecting a pressure gauge).