MSL Technical Guide 19

Measuring Atmospheric Pressure with a Barometer

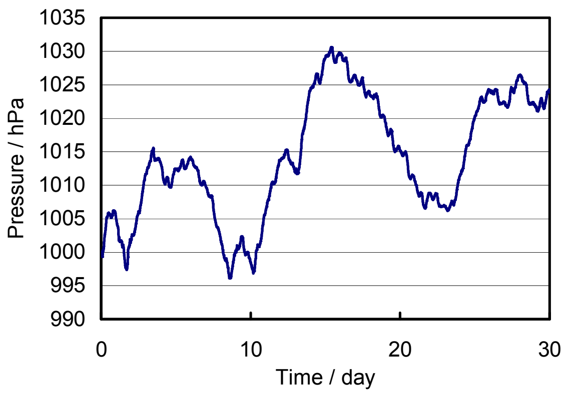
Summary

This technical guide explains how to use a digital barometer to measure atmospheric pressure in a laboratory or industrial setting. It starts with a brief discussion of the atmosphere and then talks about barometers, their stability and calibration requirements, along with how to work out the uncertainty of an air pressure measurement.

Introduction

A barometer measures the air pressure of the Earth's atmosphere. The atmospheric pressure is generated by the Earth's gravity acting on the mass of air in the atmosphere. The forces involved are surprisingly large, a surface pressure of 100 kPa means the force at the base of a column of the atmosphere, cross-section area 1 m^2, is equivalent to a mass of 10,000 kg. The atmospheric pressure depends on the local environmental conditions such as air temperature, altitude, and weather pattern.

A typical atmospheric pressure measurement, made in New Zealand at sea level, will be in the range 970 hPa to 1040 hPa. The graph below shows the air pressure recorded over a month.



A barometric pressure measurement is an example of an absolute pressure measurement. This means a barometer would read zero when measuring a vacuum (zero pressure absolute). Most pressure instruments, such as a car tyre gauge, measure gauge pressures, so read zero when open to the atmosphere.

Barometric pressure measurements are used in a wide variety of situations such as weather forecasting, air density calculation, measuring changes in altitude and in a range of thermodynamic calculations such as gas turbine efficiency.

Barometric Pressure Units

The pascal (Pa) is the metric (SI) unit of pressure and is defined as a force of 1 newton acting over an area of 1 square metre so 1 Pa = 1 N/m^2 [1]. One pascal is a small pressure so measurements are usually reported in kPa (1000 Pa) or MPa (1000 kPa).

Barometric pressure measurements are often reported in hectopascal (hPa). Hecto means times 100 so 1 hPa = 100 Pa. The prefix hecto is used in barometry as the numerical value of the pressure in hPa is the same as that measured in millibar (mbar), 1 mbar = 1 hPa = 100 Pa. Many historical meteorological records of atmospheric pressure were recorded in mbar.

There are many other barometric pressure units, some of which are shown in the table below, along with their symbol and relationship to the pascal.

Name	Symbol	Relation to SI
pascal (SI unit)	Pa	N m^{-2} = kg m^{-1} s^{-2}
hectopascal	hPa	1 hPa = 100 Pa
bar	bar	1 bar = 100 000 Pa
millibar	mbar	1 mbar = 100 Pa
torr	torr	1 torr ~ 133.322 Pa
millimetre of mercury (conventional)	mmHg	1 mmHg ~ 133.322 Pa
pounds per square inch	psi	1 psi ~ 6894.757 Pa

Pressure units for liquid manometers, like millimetre of mercury or inch of water, were commonly used. This type of unit should not now be used, as it is obsolete and can cause confusion. The problem is that "manometric" pressure units can have more than one definition.

Types of Barometer

Barometers come in many different types, ranging from mercury filled glass instruments, mechanical aneroid instruments, to resonant sensors made using silicon fabrication technology. We will briefly discuss digital barometers and end this section with a warning about why mercury-in-glass barometers should not be used.

Digital Barometers

All digital barometers have a pressure transducer that converts the force generated by the pressure into an electrical signal. The most common type of transducer is a thin metal diaphragm with the atmospheric pressure on one side and a vacuum on the other. The changing atmospheric pressure deflects the diaphragm. This deflection is measured either directly or as a change in diaphragm tension.

Currently the best performing barometers are based on silicon or quartz resonant sensors whose frequency depends on the applied pressure.

Mercury Barometers

MSL does not offer a calibration service for mercury barometers. Mercury is hazardous to human health and is a difficult fluid to handle and keep clean. Mercury-in-glass barometers are difficult to use and the readings always require significant correction. We strongly recommend replacing mercury-in-glass instruments with digital barometers. Mercury barometers must be disposed of carefully through an approved waste disposal company.

Barometer Selection

Factors to consider, when selecting a barometer, include the required measurement uncertainty, stability (drift rate), ease and frequency of calibration and features such as a computer interface.

Measurement Uncertainty

Most digital barometers will easily achieve measurement uncertainties of < 1 hPa. This will be adequate for most applications; for example weather monitoring and forecasting need to resolve pressure changes of less than 1 hPa while air density calculations require uncertainties of 10 hPa or less [2]. Here at MSL we can provide barometer calibrations with expanded uncertainties as low as 0.02 hPa, providing the barometer is capable of performing at this level.

Barometer Stability

Barometer stability is the drift in measured pressure with time. Stabilities of < 0.1 hPa per year are achievable although this will depend on the barometer. Some barometers that we have calibrated over several years, show drift rates as low as 0.02 hPa/yr. Select a barometer with an annual drift rate that is less than your required measurement uncertainty.

Cost of Calibration

Barometer recalibration intervals range between six months and two years depending on the instrument, the required uncertainty and the conditions of use. Barometers with a lower drift rate generally have a longer recalibration interval so have a smaller operating cost.

Choose a barometer with a pressure port, i.e. a tube allowing a pressure tight connection. Instruments without a pressure port need to be placed in a chamber, which complicates the calibration and increases the cost.

Computer Interface

Choose a barometer with a computer or instrument interface, such as USB, LAN, RS232, etc. An interface allows the atmospheric pressure to be read automatically and logged by computer. This is particularly useful when measuring changing air pressures.

Atmospheric Pressure Measurement

An atmospheric pressure measurement can be as simple as just recording the reading on the instrument display, as long as the following conditions are met. The barometer used for the reading should be correctly installed and have a calibration certificate from an accredited calibration laboratory. Performance checks are needed to ensure the barometer is working correctly between calibrations.

Barometer Installation

Follow the manufacturer's recommendations but also take into account how the instrument was calibrated. Factors to consider include:

- Instrument orientation. Some barometers are sensitive to tilt and are normally oriented upright and level. Ensure that the barometer is calibrated in the orientation in which it is used.
- Measurement conditions. Drafts and flow of air across the pressure port can cause small measurement errors. Temperature sensitivity may be a factor for barometers mounted out-of –doors.
- Head correction. Remember that the barometric pressure changes with altitude, it decreases by ~1.2 hPa for a 10 m increase in attitude (near sea level). Liquid trapped in the pressure port or tubing will also cause errors, a 10 mm height of water will produce an error of ~1 hPa.

You may need to apply the calibration corrections to the barometer reading although often these corrections are small enough that they can be ignored. The corrections in a MSL calibration report are simply added to the displayed reading. For example if the barometer is displaying a pressure reading of 980.25 hPa and the calibration report correction at 980 hPa is –0.1 hPa then the corrected pressure reading is

$$p = 980.25 + (-0.1) = 980.15 \text{ hPa} .$$

Measurement Uncertainty

Calculating the uncertainty of an air pressure measurement is straightforward. There are only two or three uncertainty terms that need to be considered, most of which are known before any measurement is made. The first two terms arise from the barometer performance; they are the calibration uncertainty and hysteresis. The third term is the measurement repeatability that arises from the barometer performance and from the stability of the pressure being measured. See MSL Technical Guide 13 for more discussion of pressure gauge uncertainty [1].

Calibration Uncertainty

The calibration uncertainty is taken directly from the barometer calibration report. A typical MSL calibration report uncertainty statement gives the expanded uncertainty of the corrections U_{cal} at a 95 % confidence level, refer GUM [3]. We can convert from expanded to standard uncertainty by dividing by the coverage factor k. For example, if $U_{\text{cal}} = 0.06$ hPa and $k = 2.2$ then

$$u_{\text{cal}} = \frac{U_{\text{cal}}}{k} = \frac{0.06}{2.2} = 0.027 \text{ hPa} .$$

Here the uppercase symbol U refers to expanded uncertainty while u refers to the standard uncertainty.

Hysteresis

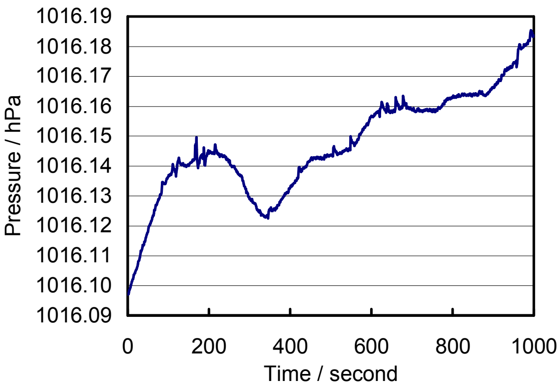
The hysteresis uncertainty component can be estimated from the difference between the calibration report rising and falling pressure corrections, at the same nominal pressure. The hysteresis is normally negligibly small for digital barometers.

If it is necessary to calculate the hysteresis uncertainty first find the largest difference, d_{max}, between the rising and falling pressure corrections (at the same nominal pressure). This is normally at a midpoint calibration pressure. Then estimate the standard uncertainty component using $u_{hys} = d_{max}/(2\sqrt{3})$ (here we have treated the hysteresis uncertainty as a rectangular distribution with a half width of $d_{max}/2$ [3]).

For example, if d_{max} = 0.15 hPa then $u_{hys} = 0.15/(2\sqrt{3}) = 0.04$ hPa.

Repeatability

The repeatability uncertainty component is an estimate of how well successive pressure measurements agree. If the measured pressure is stable then this term is just the repeatability of the barometer. If the measured pressure is unstable then there will be an uncertainty component associated with the pressure fluctuations.



In practice, the short-term fluctuations in the atmospheric pressure are small. The graph above is the measured atmospheric pressure in a laboratory recorded over 15 minutes. It shows a variation of about 0.1 hPa due to the weather pattern and some short-term fluctuations of ~ 0.01 hPa due to drafts caused by the opening and closing of doors etc.

The repeatability uncertainty component can be assessed by calculating the standard deviation of successive pressure readings. This calculation should be done to test each new measurement setup. The resulting uncertainty component will normally be small and close to the resolution uncertainty.

On the next column is a spreadsheet example of a repeatability uncertainty calculation. Ten pressure readings were recorded, at 1 second intervals, with a barometer that has a resolution of 0.05 hPa. The pressure is fluctuating in the range 1015.0 hPa to 1015.3 hPa. The bottom two rows of the table show the calculated average pressure and standard deviation. The third column shows the worksheet functions used (for data in rows 2 to 11 of column C of the spreadsheet).

Time / s	Reading / hPa	Spreadsheet Function
1	1015.25	
2	1015.10	
3	1015.25	
4	1015.25	
5	1015.30	
6	1015.30	
7	1015.05	
8	1015.20	
9	1015.30	
10	1015.05	
Average:	1015.21	=AVERAGE(C2:C11)
Standard deviation:	0.10	=STDEV(C2:C11)

The standard uncertainty due to the repeatability u_{rep} is just the standard deviation; for the example above. $u_{rep} = 0.10$ hPa.

Resolution

If $u_{rep} = 0$ hPa, meaning all ten measurements where the same, then you need to replace u_{rep} with a term for the gauge resolution uncertainty u_{res}. For example if the resolution of the barometer is 0.05 hPa then

$$u_{res} = \frac{0.05}{2\sqrt{3}} = 0.014 \text{ hPa.}$$

Finally, we can obtain the uncertainty in the measured pressure by combining all the terms together using the equation

$$u_c = \sqrt{\left(u_{cal}^2 + u_{hys}^2 + u_{rep}^2\right)}$$

(if $u_{rep} = 0$ then substitute u_{res}).This equation means you square all the terms, add them together, and take the square root of the sum.

The expanded uncertainty for the pressure reading is then calculated using $U_c = ku_c \approx 2.2u_c$. Here we have made the approximation of setting $k = 2.2$. The actual coverage factor can be calculated but is unlikely to differ from 2.2 by more than 10 percent.

The result for our worked example is

$$u_c = (0.027^2 + 0.04^2 + 0.1^2)^{0.5} = 0.11 \approx 0.10 \text{ hPa .}$$

Compare this with the barometer resolution of 0.05 hPa. The expanded uncertainty is given by

$$U_c = 2.2 \times 0.11 = 0.24 \approx 0.25 \text{ hPa.}$$

For a single barometer reading we would report a reading of 1015.20 hPa with an expanded uncertainty of 0.25 hPa.

References

[1] MSL Technical Guide13: “Pressure Gauge Calibration”, http://msl.irl.cri.nz.

[2] MSL Technical Guide 7: “Calibrating Standard Weights”, http://msl.irl.cri.nz.

[3] Guide to the Expression of Uncertainty in Measurement, ISO, 1995.

Further Information

If you want to know more, about barometers then contact MSL via the MSL website: http://msl.irl.cri.nz. MSL offers a range of one-day measurement workshops covering practical aspects of electrical, density, mass, pressure and temperature measurement and measurement uncertainty, see the website for more details.

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