Calibration methods

Why calibrate a thermometer?

Directives or standards such as ISO 9000 or ISO 17025 require organisations to provide accurate temperature measurements traceable to national or international standards. It is an important part of quality assurance in industry - for example in manufacturing to guarantee the quality of a product- and also to ensure effective testing or calibration laboratories.

Definition of terms

According to the International Vocabulary of Basic and General Terms in Metrology (ISO VIM, 2nd ed, 1993),

> *traceability* is:
>
> the property of the result of a measurement or the value of a standard whereby it can be related to stated references, usually national or international standards, through an unbroken chain of comparisons all having stated uncertainties.
> (You may also wish to see a practical discussion at the NIST website.)
>
> *calibration* is:
>
> the sets of operations which establish, under specified conditions, the relationship between values indicated by a measuring instrument and the corresponding known value of a measurand. The result of a calibration permits the estimation of the uncertainty of indication of the measuring instrument.

In the specific area of thermometry, a calibration is a comparison between a thermometer to be calibrated and a "standard" related to a national standard. What results froma calibration is is a correction to apply to the reading of the calibrated thermometer and its associated uncertainty.

Standards used

Fixed points

Thermometers are calibrated at fixed temperatures specified in the International Temperature Scale of 1990 (ITS-90). Interpolation equations depending on the temperature range are determined for the thermometer.

Standard thermometers

Standard thermometers are Platinum Resistance thermometers (PRTs) or thermocouples of type S, R or D, ideally calibrated at fixed points.

Thermometer to be calibrated

A thermometer consists of three components

- a detector
- a connecting chain
- a readout instrument (or temperature indicator)

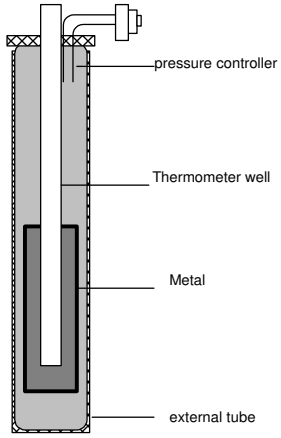
There are two ways to calibrate a thermometer, according to its type: either calibrate the thermometer as a whole or calibrate only the detector. For example, in the case of the liquid-in-glass thermometer, the three components cannot be separated, so the calibration must be of the thermometer as a whole. Contrarily, in the case of a thermoelectric or resistance thermometer, the sensing element could be separated from the connecting wires and the readout instrument and so these thermometers can be calibrated either as a whole system or separately. However, it is generally best to calibrate the thermometer as a whole system since that is how it will be used in practice.

Fixed points method

This absolute method is used for the realisation of the International temperature scale, ITS-90.

The thermometer is calibrated by measurements at a series of temperature fixed points: e.g. freezing/melting points, triple points, vapour pressure points.

This method consists in setting up a thermometer in a fixed-point cell that provides an isothermal environment.

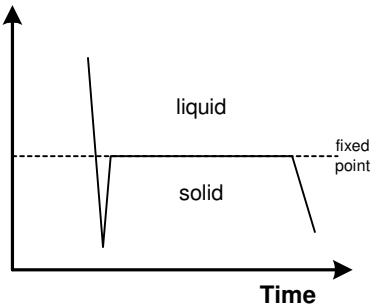


example of fixed-point cell

The fixed point cell is a flask almost completely filled with pure material and protected by a shell. The cell is placed in an apparatus that must provide good temperature control and sufficient cell immersion to generate a uniform temperature in the measurement zone.

The apparatus must provide for fixed-point cooling as well as controlled heat. It may be a furnace - generally, a vertical tube furnace with suitable insulation - or a liquid bath.

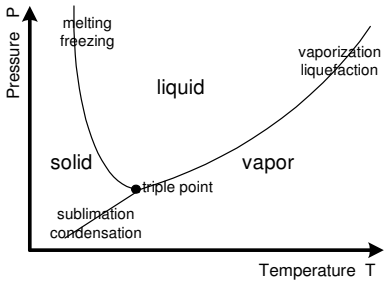
A number of fixed points are chosen. They should be as few as possible, consistent with the need to establish a good interpolating formula. This method gives a highly accurate calibration and is used only for highest quality thermometry. But it is difficult to undertake because of the complexity of the equipment and the many precautions that must be taken to realise the fixed points successfully.



Freezing temperature plateau obtained from a typical cell

Fixed points are realised using numerous pure substances. However, many do not ensure the required stability and reproducibility and others require a complex procedure and special laboratory facilities.

Usually the greatest difficulty in realising a fixed-point temperature arises from the impurities that can be found in the fixed-point material. In practice, the freezing point of a metal corresponding to a liquid-to-solid transition are easier to realise and are not very sensitive to ambient pressure.



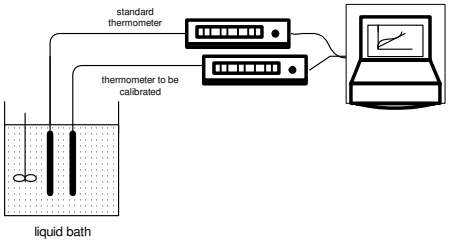
Pressure-Temperature diagram of water

The triple point of water is the most important defining thermometric fixed point used in the calibration of thermometers to the International Temperature Scale of 1990 (ITS-90).

It is also one of the most accurately realisable of the defining fixed points. It provides a useful checkpoint of the stability of a thermometer by verifying if a shift has occurred.

The apparatus used is a glass flask nearly filled with very pure water and placed in an ice-and-water bath that maintains the cell at or near the freezing point of water.

Comparison method



The thermometer is calibrated by comparison with a reference or standard thermometer in a thermally stabilised bath or furnace.

In the comparison method:

- the standard used depends on the temperature range of interest, the quality of the probe being calibrated and the required accuracy. It can be a primary, a reference or a working standard.

- the facility used can be a liquid bath, a block calibrator or a furnace, depending on the calibration temperature range.

- for accurate calibration the entire sensor must be at a steady, uniform temperature during the calibration.

The calibration environment to choose depends on the temperature range, as follows:

- for low temperature calibration (typically below 90K) a vacuum-jacketed copper block

- above 90°C and up to 300°C a controlled stirred liquid bath is the most common means of calibration. Freon or alcohol may be used from –90°C, water at room temperature, oil to 300°C

- for temperatures up to 600°C a salt bath may be used

- for higher temperatures furnaces are more appropriate. Many designs exist. Some have low thermal mass and rapid response, others have large thermal mass and slow response

To minimise or reduce temperature gradients within a bath or furnace, a metal equalising block may be inserted, with thermowells to receive both the standard and the thermometer(s) to be calibrated. This method allows a wide range of temperatures to be covered, point by point or continuously, in a short time, and to calibrate simultaneously a great number of thermometers. Nevertheless, the comparison method is less accurate than the fixed point method because of the lesser accuracy and stability of the reference standard and enclosure.

Calibration of the temperature indicator

In the case where a sensor has been calibrated separately, i.e. without the temperature detector, to ensure traceable measurement the temperature detector must also be calibrated. Electrical simulations do this by means of a temperature simulator. It consists of replacing the sensor by an electrical device in order to calibrate the temperature indicator. Using reference tables, the electrical output of the temperature sensor at the required calibration point is determined and the output of the electrical source is set to this level. The electrical signal is applied to the temperature indicator and the reading from the indicator is compared with the simulated temperature. Then, the error of indication of the temperature indicator is determined. This procedure is applicable for electrical thermometers as thermocouples or resistance thermometers.

Conclusion

Accurate temperature measurements are possible if you take care to ensure the following:

- use a suitable (fit for purpose) calibrated thermometer (both detector and instrumentation).

- the quality of a thermometer (whether standard or not) varies with time and use according to the conditions of use, such as mechanical constraints during manufacturing, chemical pollution, thermal cycles at low or high temperature. Then it is necessary to undertake regular checks or calibrations and an eventual replacement of the thermometer. The periodicity of the checks and/or calibration depends on the stability of the thermometer, its conditions of use and the required accuracy for its application. For example, thermocouples are less stable than resistance thermometers and need calibration more frequently to account for drift over time

- it is desirable to calibrate the thermometer system, i.e. detector and connected readout instrument, together rather than the probe itself; and to do so in conditions that are close to the measurement situation.

Where next?

For a list of laboratories or NMIs performing thermometer calibrations see Measurement services.

For suppliers of temperature calibration equipment see Services, where you can search by setting the flags Calibration and Temperaure, for example.

Further information about temperature calibration can be found in good practice guides or standards, see Literature.

References

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- *Improving the accuracy of temperature measurement,* A Tong, Sensor Review, vol 21, n°3 2001
- *Traceability of measuring and test equipment to national standards*, EAL-G12, November 1995