

The Effect of Temperature on Conductivity Measurement

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Abstract

The conductivity of all solutions changes as the solutions' temperature changes. It is a fundamental, practical requirement in the field of conductivity measurement that test measurements taken at different temperatures can be compared. This comparison can be facilitated by the use of Temperature Compensation, which provides an estimate of the samples' conductivity at a common reference temperature. This paper describes the principle of Temperature Compensation and provides details of the different types of Temperature Compensation that are available to the analyst so that the most appropriate type can be selected for the analyst's measurement application.

1 Introduction

An increase in a solution's temperature will cause a decrease in its viscosity and an increase in the mobility of the ions in solution. An increase in temperature may also cause an increase in the number of ions in solution due to dissociation of molecules. As the conductivity of a solution is dependent on these factors then an increase in the solution's temperature will lead to an increase in its conductivity.

The Temperature Coefficient of Variation is the rate at which a solution's conductivity increases with an increase of temperature and is expressed as the percentage increase in conductivity for a temperature change of 1°C. The Temperature Coefficient of Variation will be different for each solvent / solute mixture - examples are outlined in Table 1.

As can be seen from Table 1, temperature has a significant effect on the measured conductivity. For ultrapure water, a variation in temperature of 0.1°C will cause a change in conductivity of

0.55%. This example shows that accurate temperature measurement and control is of paramount importance for accurate conductivity measurement.

2 Temperature Compensation

In many applications, including field or process measurement, temperature control may prove impractical; but comparison of results is still required. This is achieved by using temperature compensation to calculate the samples' conductivity values at a common reference temperature.

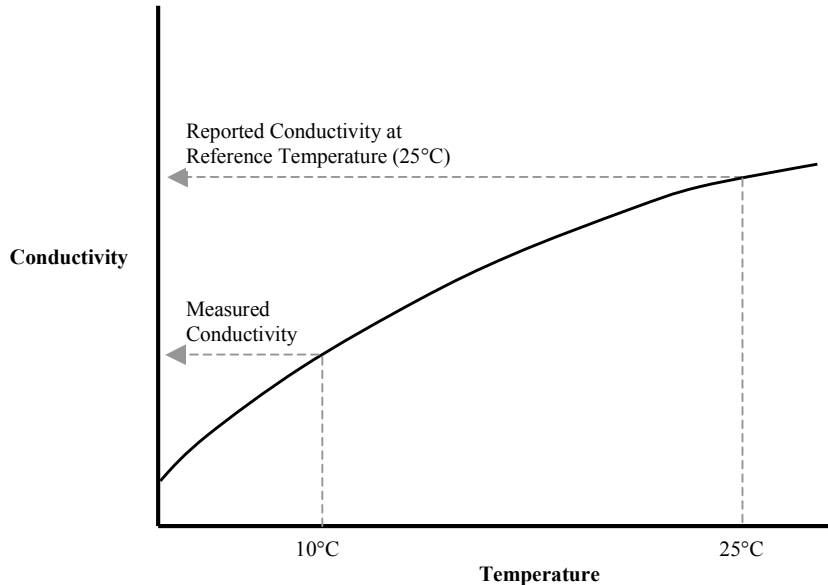
To allow the analyst to compare conductivity measurements, results should be referenced to a specified temperature. Most conductivity measurements are referenced to 25°C, but some guidelines reference results to other temperatures – examples are given in Table 2.

Solution	Temperature Coefficient of Variation %/ °C at 25 °C
Ultrapure Water	5.5
NaOH 5%	2.01
NaOH 30%	4.50
HCl 5%	1.58
HCl 30%	1.52
KCl 5%	2.01
KCl 20%	1.68
Fresh water	~ 2.0

Table 1: Temperature Coefficient of Variation for Common Solutions ^(1,2)

Standard Procedure	Reference Temperature
United States Pharmacopoeia ⁽³⁾	25°C
ISO 7888-1985 ⁽⁴⁾	25°C
European Pharmacopoeia ⁽⁵⁾	25°C
ASTM D 1125 – 95 ⁽⁶⁾	25°C
U.K. Water Quality Supply Regulations ⁽⁷⁾	20°C

Table 2: Reference Temperature Cited in Commonly used Procedures



Graph 1: Temperature Compensation

Temperature compensation requires an algorithm to be applied to the measured conductivity reading and measured temperature to produce a compensated reading at a reference temperature. Graph 1 shows how a reading taken at 10°C is used to generate a temperature compensated conductivity value at 25°C by applying the algorithm represented by the curve.

2.1 Linear Temperature Compensation

For linear temperature compensation, it is assumed that the temperature coefficient of variation has the same value for all measurement temperatures. This assumption is not true; but for many measurements this does not result in a substantial contribution to the combined uncertainty of measurement of the reported result.

The temperature coefficient of variation at 25°C, $\alpha_{0,25}$, is calculated as shown in Equation 1, with its value being expressed as a percentage change in conductivity value per 1°C change in temperature.

$$\alpha_{0,25} = \frac{K_{\theta} - K_{25}}{K_{25} (\theta - 25)} \times 100$$

Equation 1

Where θ and 25°C are temperatures at which conductivities K_{θ} and K_{25} respectively are measured.

When the measurement is not carried out at 25°C, $\alpha_{0,25}$ can be used to calculate the solution's compensated conductivity at 25°C, as shown by Equation 2.

$$\kappa_{25} = \frac{\kappa_{\theta}}{1 + (\alpha_{\theta,25}/100)(\theta - 25)}$$

Equation 2

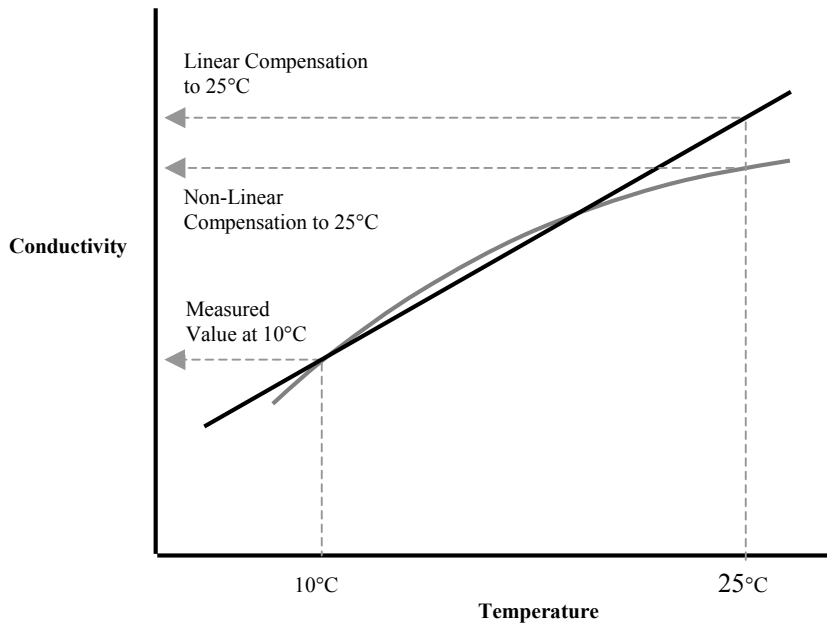
2.2 Non-Linear Temperature Compensation

As previously mentioned the relationship between temperature and conductivity does not follow a linear relationship. When the assumption of a linear relationship is not adequate, a polynomial may be applied to improve the accuracy of the calculated result.

Non-linear temperature compensation data for a variety of solutions is widely available, e.g. ISO 7888-1985⁽⁴⁾ provides data for natural waters having κ_{25} of 60 to 1000 $\mu\text{S}/\text{cm}$ over the temperature range 0 to 35°C. The standard

warns that the data is not applicable to potassium chloride calibration solutions – a different temperature compensation algorithm must be applied during calibration.

Graph 2 demonstrates how linear and non-linear temperature compensation are used to provide temperature compensated readings at 25°C from a measured value at 10°C. The graph demonstrates that the two forms of temperature compensation will result in different reported conductivity values at the reference temperature of 25°C. It should not be assumed that non-linear temperature compensation will lead to lower measurement errors than linear compensation - this will only be the case if the non-linear temperature compensation is a good fit for the sample's conductivity variation with temperature.



Graph 2: Representation of Linear Compensation & Non-Linear Compensation

Whatever form of compensation is used, the reading will not be as accurate as taking a reading of the sample's conductivity at the reference temperature.

2.3 Manual Temperature Compensation

Manual Temperature Compensation involves taking a series of conductivity measurements on a sample at various temperatures. A linear or polynomial best fit is then applied to the data to produce an equation for the temperature compensation of results. The temperature compensated conductivity result is manually calculated using the derived equation and the measured conductivity and temperature.

2.4 Automatic Temperature Compensation (ATC)

ATC utilises a microprocessor within the instrument to determine a temperature compensated conductivity result. The ATC options available will depend upon the specification of the conductivity instrument:

- Basic conductivity instruments may only offer linear compensation with the temperature coefficient fixed at 2%/°C. This value is chosen because it is a reasonable approximation of the temperature coefficient of commonly encountered dilute salts. However, many solutions have a markedly different temperature coefficient and measurements of these solutions with basic instruments will result in significant errors in the reported conductivity value.
- Intermediate conductivity instruments may offer linear compensation with a user-definable temperature coefficient. These instruments may only allow the user to vary the temperature coefficient in relatively large increments, e.g. 0.5%/°C increments.

- Advanced instruments may offer both linear and non-linear temperature compensation functions as well as an uncompensated mode. These instruments will allow the analyst to input a temperature coefficient (normally 0.00 to 10.00 %/°C) and a reference temperature (normally 20 or 25°C). It is important to note that some procedures, such as USP 26 <645>⁽³⁾ require that no temperature compensation can be applied to the measured value.

The non-linear temperature compensation will carry out temperature compensation using pre-programmed data in the instrument. Non-linear ATC data is available for a variety of solutions including

- Natural Waters according to ISO 7888⁽⁴⁾
- Ultrapure water with traces of ammonia
- Ultrapure water with traces of HCl
- Ultrapure water with traces of NaCl
- Ultrapure water with traces of NaOH

In addition to temperature compensation for sample measurements, conductivity instruments may also be pre-programmed to allow temperature compensation to be utilised during calibration. In this instance, the appropriate compensation will be applied during the calibration process for common conductivity calibration standards such as potassium chloride based 147, 1413 & 12,880 µS/cm at 25°C. Many conductivity meters also allow calibration with a user-defined conductivity standard. Standards selected for this purpose should be provided with full characterization of their conductivity's variation with temperature so that this can be accounted for during the calibration process.

3 Conclusion

Measurement temperature has a significant influence on conductivity readings; but appropriate temperature compensation is a powerful tool to allow meaningful comparison of readings taken at different temperatures. The analyst must ensure that the type of temperature compensation utilized is appropriate for both the type of sample being analyzed and the required test accuracy. This is an essential factor for determining the suitability of a conductivity instrument for measurement applications.

A conductivity measurement taken with the sample at the reference temperature will always be more accurate than a temperature compensated reading taken away from the reference temperature – this point is essential for critical applications requiring high accuracy of measurements.

Further information on the implications of temperature effects on conductivity measurements is given in further Reagecon practical conductivity measurement publications^(8,9).

4 References

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* These papers form part of a comprehensive series of papers that the authors have written covering all of the practical requirements for accurate conductivity measurement. These papers and the authors' book, "A Practical Guide to Accurate Conductivity Measurement" are available via Reagecon's website - www.reagecon.com.

Biographical Notes:

John J Barron is Managing and Technical Director of Reagecon Diagnostics Limited. The company, which was founded in 1986, is the largest producer worldwide of Conductivity Standards and is also a major producer of other chemical standards. Mr. Barron is an expert in several areas of analytical chemistry, including electro-chemical analysis, good laboratory practice (GLP) and chemical metrology. He has written and lectured extensively and is credited with several technical discoveries including stable low level conductivity standards.

Colin Ashton has worked in the Reagecon group since 1994 and is currently Head of the Chemical Metrology Department. A graduate of the University of Southampton, he has developed particular expertise in the development, stabilisation, manufacture and validation of cation, anion and electro-chemical standards. He has particular scientific interest in all aspects of on line chemical analysis and has lectured and published on several areas of this field.

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