



Tech Talk: (10) Electrolytic Conductivity Measurement Basics

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I. Introduction

Conductivity measurement is used extensively in industry for measuring water quality from water treatment plants and in the case of anion/cation demineralising plant, to determine when resin backwash and regeneration is initiated. Monitoring the quality of treated feed water is of great importance in contributing to the protection of steam generators (boilers) from corrosion. It is also used to monitor the quality of boiler blow down water and recycled steam condensate, where dissolved ionic solids may lead to boiler tube scaling.

Cooling water in closed circuit heat exchangers may be monitored by conductivity measurement in order to detect internal leaks, resulting in acidic material from raw cooling water contaminating the system, causing major damage.

Other applications include

- The monitoring of system cleansing fluids in the food and pharmaceutical industries to detect the effectiveness of the cleansing cycle;
- Fluid interface detection where fluids have significantly different conductivity levels;
- Monitoring of dissolved ionic solids in drinking water from water treatment facilities, as a measurement of the 'hardness' of the water delivered into the supply network;

- Monitoring of water courses in order to detect sewage or other contamination.

II. Physics

Electrolytic conductivity is an indicative measurement of the total concentration of ions present in an electrolyte. Ions are present when material such as dissolved salt solids is present. Thus, the measurement is based on the ability of an electrolyte to conduct electricity, as the conductivity of a solution is generally proportional to its ion concentration.

Conductivity versus ion concentration curves for electrolytes may be obtained from published sources or from laboratory measurements. It should be noted that over large conductivity ranges, the conductivity will increase with concentration, but may reach a peak and then decrease.

The concentration of ions in a solution is affected by its temperature. Ionisation of an electrolyte increases as its temperature rises and errors potentially in the range of 1.5%–5.5%/°C must be catered for within the measuring instrument (analyser). Hence, conductivity cells must incorporate a temperature sensor and the measuring instruments incorporate a temperature compensating algorithm. Although some instruments incorporate a standard algorithm, others allow user programming to allow the compensation to be matched as closely as is practical to the fluid's characteristics, so as to minimise measurement error.

III. Units of Measurement

Conductivity or specific conductance (C) is the reciprocal of resistivity (R), that is, $C = 1/R$. The SI unit of conductivity is Siemens/meter (S/m). When used to measure the conductivity of an electrolytic solution, a smaller measure is required, hence the common use of the derived unit $\mu\text{S/cm}$.

In North America, the unit mho/cm has historically been used to measure conductivity, where the unit 'mho' = Ω^{-1} . Table 1 shows the 'one-to-one' relationship between units.

IV. Conductivity Measuring Cells

A conductivity cell is designed for insertion into a pipeline in such a manner that the cell is continuously wetted. Conductivity cells in general use fall into two types:

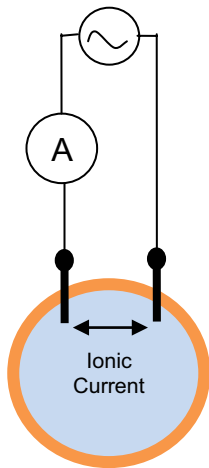
1. Contact electrode cells, which employ two electrodes made from a metal such as stainless steel, or for

Table 1. One-to-one relationship between units of measurement

Measurement	Units
Resistance	Ω (ohm)
Resistivity	$\Omega\text{ m}$
Conductance	Siemens, mho
Conductivity	Siemens/m, mho/m

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Figure 1. Contact conductivity cell circuit



corrosive applications a suitable corrosion-resistant metal.

An alternating voltage is applied to the electrodes causing the ions in the fluid to be 'excited' and conduct an alternating 'ionic' current (Figure 1). The measuring instrument uses ohms law ($\text{Resistance} = \text{Voltage}/\text{Current}$) to determine the resistance of the electrolytic path and hence its reciprocal, conductance.

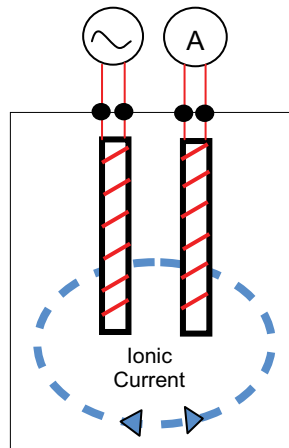
The geometry of the conductivity cell, principally the surface area and distance apart of the electrodes, affects the measurement, although extraneous current paths may also have an influence. A test rig is used to compare the cell's conductance (μS) with a fluid of known conductivity ($\mu\text{S}/\text{cm}$). The resulting ratio is known as the 'cell constant'. Using a number of cell constants, conductivity measurement over the range of 0.01–50,000 $\mu\text{S}/\text{cm}$ can be achieved.¹

A variation on the contact measuring method is the four-electrode cell. An alternating voltage is applied to the outer electrodes and conductance measured by the voltage appearing at the inner electrodes. This method increases the useable range of the sensor.

2. Inductive electrode cells

With this method, two metal toroids are wire wound and encapsulated in a

Figure 2. Toroidal conductivity cell circuit



corrosion-resistant plastic housing (Figure 2). Acting like an electrical voltage transformer, an alternating voltage is applied to the sender coil and a current induced into the receiver coil via the excited electrolytic ions. The resulting ionic current is proportional to the electrolyte's conductance.

The cell constant is a function of the size and mounting dimensions of the toroids and their number of wire turns. This method finds applications where the electrolytic solution is corrosive, contains a high suspended solid level or may foul the conductivity cell. It is particularly suitable for very high conductivity measurement but is limited to fluids having a conductivity $>15 \mu\text{S}/\text{cm}$.¹

V. Conductivity Cell Mounting

The cell must be mounted in a way that the electrodes are always immersed in the flowing fluid. Mounting in a vertical pipe with an upward flow is a preferred method. If mounted in a metal pipe, the proximity of the pipe wall will affect the measurement, hence the normal use of plastic piping such as medium density polyethylene (MDPE).

VI. Analytical Instruments

A wide variety of conductivity readout/transmitting instruments is available. Some can be used to display not only

conductivity but also the fluid ion concentration, resistivity, salinity and total dissolved solids (TDS). Typically, the relationship between the ion concentration and the conductivity for the fluid of interest is programmed into the instrument, as is linear and non-linear temperature correction.

VII. Calibration

Frequent calibration is advised and will depend to a large extent on the fouling properties of the measured fluid.

The conductivity analyser (cell and receiving instrument) may be calibrated against a standard solution of known conductivity or alternatively against a previously calibrated cell and analyser. Usually, the system is calibrated near to the midpoint of the operating range.

1. Calibration using a standard solution

A standard solution of potassium chloride is normally used. Such solutions readily absorb atmospheric carbon dioxide, forming carbonic acid, which potentially can increase the conductivity by up to $1.5 \mu\text{S}/\text{cm}$. Hence, the solution used should always be from a newly opened container. The cell should be thoroughly washed in part of the standard solution prior to calibration. It is then placed in the solution and the analyser reading adjusted to match the known conductivity. To eliminate temperature-related errors, the analyser temperature compensation can be disabled and the system calibrated using the known conductivity of the standard solution at the measurement temperature.¹

2. Calibration against a reference cell and analyser

Where the process piping configuration permits, a facility to temporarily insert a previously (laboratory) calibrated cell and analyser in series with the permanent system offers a convenient method of calibration. Turning off the temperature compensation in both analysers during the calibration process

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eliminates temperature compensation errors.

3. Alternative calibration of inductive electrode cells²

As an alternative to using a standard calibration solution, a toroidal conductivity cell may be removed from the process, cleaned and dried. An insulated wire is then passed

several times through the cell and connected to a decade resistance box. Using the analyser manufacturers' cell data and formulae provided, the analyser can thus be calibrated by adjusting the loop resistance.

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References

1. Data sheet: Theory and application of conductivity. Emerson Process Management, January 2010.
2. Invensys. *Toroidal flow-through conductivity sensors*. MI 611-202, October 2014, http://resource.invensys.com/instrumentation/documentation/eib/mi/mi_611-202.pdf

Bibliography

Conductivity (Electrolytic) – Wikipedia