

Frequently asked Questions about Conductivity

FAQ – Conductivity

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METTLER TOLEDO



Frequently asked Questions about Conductivity – a comprehensive Competence Booklet

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1 Theory

1.1 What is the basic principle of contacting conductivity measurements?

Conductivity is the ability of a solution to pass an electric current. The amount of current flowing is roughly proportional to the number of ions present in the conducting solution. Despite the fact that the measuring of conductivity is non-specific, the technique is used heavily in analytical chemistry, especially in the characterization of water purity and to measure the efficiency of water treatment systems. A conductivity measurement is also used to determine the concentration of chemicals because it gives a well-defined, though not always linear, conductance-concentration plot over a wide concentration range. It is a rapid and inexpensive way of determining the ionic strength of a solution. In Figure 1, two plates of a given material are placed in a solution. The geometry is given by the length, L , of the liquid column between the plates and the cross sectional area, A , of the liquid column. If an AC voltage, U , is connected across the two plates (electrodes) placed in a solution containing ions, the ions will move between the electrodes and an electric current, I , will start to flow.

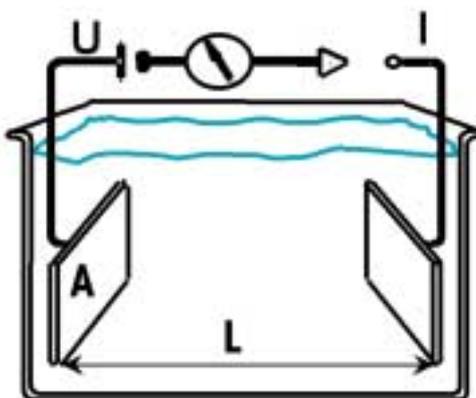


Figure 1

Conductivity is denoted by the Greek symbol κ (kappa) and has the unit Siemens per centimeter (S/cm).

$$1 \text{ S/cm} = 1,000 \text{ mS/cm} = 1,000,000 \text{ }\mu\text{S/cm}.$$

In some applications the unit S/m is used instead of S/cm:

$$1 \text{ S/cm} = 100 \text{ S/m}$$

$$\kappa = \frac{1}{\rho} = G \cdot \frac{L}{A}$$

where:

- κ = Specific Conductivity [S/cm]
- G = Conductance [S]
- L = Distance between electrodes [cm]
- A = Area of electrode [cm²]
- ρ = Specific resistance

For ultrapure water applications the reciprocal value of conductivity (called resistivity) is common. Resistivity is expressed as Ohm cm.

$$1 \text{ }\mu\text{S/cm equals to } 1 \text{ M}\Omega\text{cm}$$

1.2 What is the meaning of the term «cell constant»?

Conductivity is measured using a conductivity cell. The measured conductivity depends on both the dimensions of, and the distance between, the electrodes. Assuming that the mechanical properties of the cell will not change over the entire temperature range, the term L/A will remain constant. This term can be replaced by c , the cell constant expressed in cm^{-1} .

$$c = \frac{L}{A} \quad \text{or} \quad \kappa = G \cdot c$$

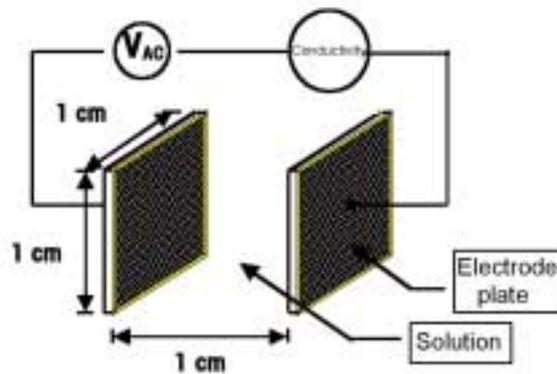


Figure 2

In a cell using 1 cm squares of platinum, 1 cm apart, the cell constant is 1.0 cm^{-1} and the conductance (G) reading in μS is numerically equal to the conductivity reading in $\mu\text{S}/\text{cm}$. For low conductivity solutions, the electrodes can be placed closer together (reducing L) to give cell constants of 0.1 cm^{-1} or 0.01 cm^{-1} . This raises the conductance between the plates and makes it easier for the electronic circuitry to obtain a result. Similarly, for high conductivity solutions, L can be increased to give a cell constant of 10.0 or more. The principle of the cell constant leads to considerable complications for comparative measurements. To avoid this problem, the concept of «Specific Conductivity» has been introduced (see previous page).

Alternative sensors have been developed to overcome the problems associated with traditional cells:

4-electrode conductivity sensors (Fig. 3 - next page) consist of two current and two voltage electrodes. Polarization occurs only at the current electrodes while a voltage drop is measured between the voltage electrodes where polarization has no effect.

The advantages of such a sensor are as follows:

- no polarization
- wide measuring range with a single cell constant
- suitable sensor dimensions.

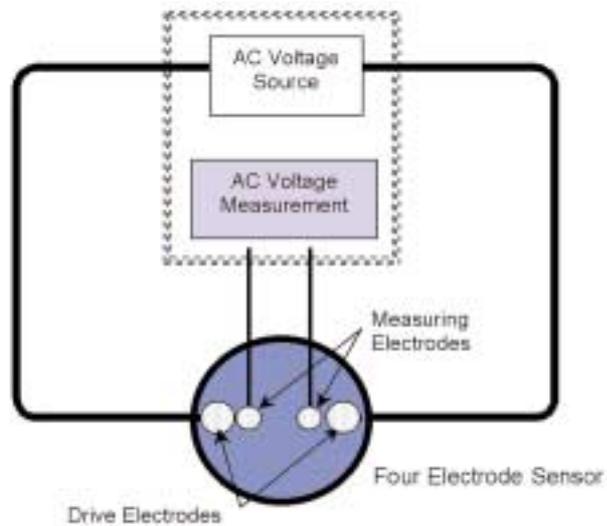


Figure 3

1.3 I have often heard that «polarization causes problems». What does this mean?

Polarization is one of the most important factors that can seriously influence the accuracy of conductivity measurements. It involves all the effects that occur at the metal liquid boundary when current flows are combined. These make the conductivity of the solution appear smaller and the cell constant appear larger. As measured towards higher conductivity values, the current has to increase in order to measure at the same voltage level. This leads to an «ion cloud» near the surface of the electrodes. This «ion cloud» is measured as an additional resistance resulting in an erroneous reading. Polarization can be prevented by:

- applying AC voltage
- selecting the correct cell constant for a particular conductivity value
- reducing the current density at the electrodes
- applying a four-electrode measuring principle.

The use of an inductive conductivity system avoids the problems related to polarization.

1.4 What is the basic principle of inductive conductivity measurements?

An inductive (electrodeless, toroidal) conductivity sensor consists of two toroidal coils encapsulated in an inert plastic (Figure 4). When immersed in electrolyte, the solution forms a conductive loop shared by both toroids. One toroid radiates an electric field in this loop and the other detects a small induced electric current. Practically speaking, the two toroids form a transformer whose coils are interconnected by the resistance of the electrolyte. The radiated field is typically 20 kHz, and the induced current, which is proportional to the conductivity, is amplified, rectified and displayed.

A more technical explanation is given below and explains the physics of what is happening and why magnetic shielding is needed between the coils:

Inductive (electrodeless, toroidal) conductivity sensors consist of two high-grade toroids (coils) which are incorporated concentrically and adjacent to one another in a non-conductive body. The primary coil is excited with a sinusoidal alternating voltage creating a changing magnetic field (Fig. 4). This changing magnetic field causes the ions in the solution to move through the center of the toroid. This ion motion is equivalent to an AC current flowing through the center of the toroid. The AC current produces an AC current in the sensing coil that is proportional to the conductivity of the solution. Ideally the signal in the sensing coil should be due to the ion motion only and not due to the changing magnetic field created by the primary coil. For this reason good magnetic shielding is needed between the coils.

An inductive sensor has the following advantages:

- no polarization
- insensitive to contamination, fouling or film formation on the sensor surface
- total galvanic separation of the measuring components from the process media.

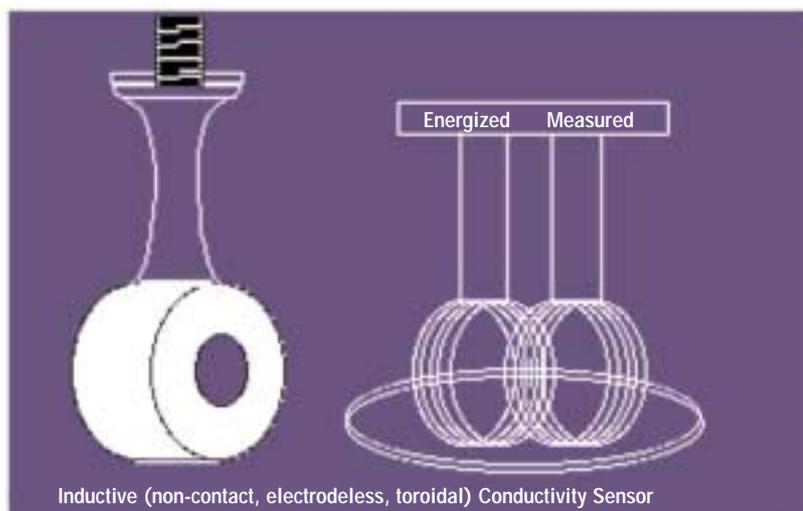


Figure 4

1.5 What is the influence of particles or air bubbles on the measurement?

The influence strongly depends on the type of sensor. 2-electrode sensors show spikes if air bubbles stay only for moments or unstable signals if many air bubbles are present. If there is an accumulation of dirt over time, the geometry of the cell changes and therefore the cell constant changes, which then results in incorrect readings, observed as a drift. Under normal conditions, the sensor can be cleaned with dilute acid (e.g. 1% hydrochloric acid for titanium electrodes or <1% nitric acid for stainless steel electrodes) or a detergent (depending on the nature of the dirt) and will then show the same cell constant as before. The sensor should be cleaned with soapy water, then the acid if needed, then with soapy water again (to remove the acid) and finally rinsed with deionized water to remove all the soap. By installing the sensor in the correct way, these kinds of problems can often be avoided. The correct way in this case is to install the sensor directly into the flow stream (direct the flow onto the tip of the sensor and out through the small holes). The best way to achieve this is an installation in a pipe bend.

4-electrode sensors with small electrode surfaces are more sensitive to air bubbles and dirt. If one of the electrodes is covered, or if air bubbles are trapped on the electrode surface, a significant error will result. Proper installation (the flow should be directed towards the sensor end) may avoid problems. It is also important to be aware that a certain clearance around the sensor tip is required for proper function of the sensor.

Inductive sensors are more or less insensitive to air bubbles and accumulation of dirt or film formation on the outer surface, assuming this does not significantly change the size of the hole in the sensor. However, sample solution must flow through the center bore of the sensor for a proper function.

1.6 How does concentration relate to conductivity?

Conductivity is widely used as a measure of electrolyte concentration. In binary solutions (one electrolyte and water), conductivity is directly proportional to concentration. Each electrolyte possesses a unique conductivity curve. Strong electrolytes (e.g. hydrochloric acid) dissociate fully in water, giving higher conductivity values than weak electrolytes, like acetic acid.

For most electrolytes, the conductivity curve reaches a maximum value, and then reverses its slope. Conductivity can be measured on the increasing or the decreasing part of the curve. Conductivity can't be used to measure concentration in the region where the curve changes, since two different concentration values have the same conductivity.

2 Temperature Compensation (TC)

2.1 Do conductivity readings depend on the temperature of the sample? If so, how can results be compared with each other?

The conductivity value of a liquid solution increases as the temperature rises as a result of higher ion mobility. This results in conductivity values that change due to temperature changes, which is not liked by customers. It is, therefore, common to compensate the temperature to a specific temperature. The most common reference temperature used today is 25 °C. The change per °C is expressed by the temperature coefficient α . Once this coefficient is determined for a specific solution, the conductivity value can be calculated at any temperature:

$$\kappa = \kappa_0 [1 + \alpha_0(T_t - T_0)]$$

where:

- κ_t = Conductivity at T_t
- κ_0 = Conductivity at T_0
- α_0 = Temperature coefficient at T_0
- T_t = Measured temperature
- T_0 = Reference temperature

For many salt solutions, the value of the temperature coefficient remains constant over a wide temperature and concentration range. If this value is determined once, it can be entered into the instrument and used for all measurements. The transmitter refers to this option as a linear compensation. The value of the temperature coefficient averages around 2 (ranging from approx. 1.5 to 2.5 for most solutions).

In ultra-pure water the change in conductivity caused by increased temperatures is much greater than in high conductivity solutions. Over a temperature range from 0 °C to 100 °C the temperature coefficient changes from 7.3%/°C at 0 °C to 2.3%/°C at 100 °C. It is obvious that the dependency is not linear. Most transmitters of today's technology are able to handle a compensation of ultra-pure water very accurately by using a polynomial function.

2.2 Are there specific algorithm alternatives to NaCl?

Yes, TDS (total dissolved solids) and salinity. Other salts of interest would be KCl, acids and NaOH.

TDS converts a conductivity reading in mS/cm or μ S/cm to a reading in ppm or ppb, assuming that the measured conductivity results only from the equivalent amount of sodium chloride or potassium chloride. Mettler-Toledo transmitters always refer to sodium chloride. A TDS reading of 10 ppm is equivalent to 10 milligram NaCl per liter.

Salinity is based on some scientific research done on seawater and is expressed as ‰ by weight. It is a useful way to display conductivity if seawater is the solution to be measured.

3 Calibration

3.1 How are both sensors and transmitters calibrated?

2-electrode sensors of the InPro 7000-VP Series are calibrated at the factory. Each sensor (slave) is calibrated individually against internal standards (master sensors) in an ultra-pure water loop (18.2 M Ω cm) at 25 °C. During this procedure, the cell constant is determined very precisely and documented in the quality certificate that is supplied with the sensor. Prior to this, the temperature sensor is also always calibrated in this water loop and the new temperature multiplier is also reported.

The master sensors/transmitter are calibrated against ASTM solutions and NIST standards.

4-electrode sensors of the InPro 7100-VP Series are tested and calibrated in a solution approximately 10 mS/cm and verified at 100 mS/cm. The determined cell constants (conductivity and temperature) are printed on the sensor label and the test results are documented in the quality certificate.

2-electrode sensors of the InPro 7010 Series. The cell constant is determined in a standard solution and printed on the sensor label. No certificate is supplied with the sensors.

Inductive sensors. The approximate cell factor is determined by the geometry of the sensor. Sensors are not individually tested to this cell factor. A re-calibration can be done at the customer site if necessary. No certificate is supplied with the sensor.

3.2 What is the best way to calibrate a conductivity system used for really low conductivity (ultrapure/pure water) measurements?

Mettler-Toledo does not recommend the use of standard solutions below approximately 100 μ S/cm, as they are critical to handle (especially under harsh industrial conditions). The best way to calibrate sensors used in low conductivity applications is to do a comparison to a transfer standard sensor/system. This can be done either at the customer site if the customer is willing to buy a master sensor, or by returning the sensor to the factory where it will be re-calibrated and re-certified (chargeable service).

3.3 What is the linearity or the linear measuring range of the sensors?

2-electrode sensors (InPro 7000-VP Series) are calibrated in 18.2 M Ω -cm water at 25 °C.

The linear measuring range of each sensor depends on:

- electrode material,
- exact cell constant
- electrode surface area
- transmitter electronics used with the sensor (different transmitters use different frequencies and voltages to drive the sensors).

4-electrode sensors (InPro 7100-VP Series) are calibrated at approx. 10 mS/cm at 25 °C.

The measuring range depends on:

- electrode material
- exact cell constant
- electrode surface area
- transmitter used with the sensor.

In the «SpecBook» you will find a graph that shows the individual measuring ranges for each sensor/transmitter combination.

3.4 When do we have to recalibrate the sensor with calibration solution and when is it better to use the predetermined cell constant?

The preferred way to calibrate sensors for use in pure and ultrapure water is to do a comparison with a standard sensor (transfer standard) in ultrapure water. Cell constants can be checked using ASTM Solution D as described in D1125.

4-electrode sensors and inductive sensors can easily be calibrated by using a standard solution i.e. 0.1 M potassium chloride (12.88 mS/cm at 25 °C). Some precautions are necessary as these sensors are stray-field sensors and the area surrounding the sensor is important for the cell constant. If a calibration is done in a large glass beaker, the determined cell constant may differ greatly from the cell constant once the sensor is installed in a small diameter stainless steel pipe.

The frequency of calibration varies from customer to customer and from application to application. In the pharmaceutical industry (water preparation) we recommend doing a calibration once a year. In the process industry, a calibration might become necessary every week and some customers don't calibrate at all.

All described methods are for sensors only. For conductivity measurements, the transmitter and the effects of cable resistance, can/need to be calibrated by using high precision resistors.

Sensors of the InPro 7000-VP Series are calibrated very precisely and Mettler-Toledo does not recommend any re-calibration at all prior to the first use.

4 Contacting Sensors

4.1 Can I connect a METTLER TOLEDO 2-electrode or 4-electrode sensor to a transmitter from the competition? And the other way round?

In most cases our 2- and 4-electrode sensors can be connected to transmitters from the competition. However, as we don't know the frequency and the voltage used in those transmitters, specified ranges may change and cannot be guaranteed anymore by Mettler-Toledo.

Inductive sensors and the respective transmitter form a system. It is unlikely that our sensor works with a transmitter from the competition (except Foxboro). With lab meters it is more a problem of the connector. You should further make sure that the transmitter/meter supports Pt1000 RTD's.

4.2 What distance from objects needs to be kept for correct measurements? 2e, 4e, inductive? Is a calibration inline a solution to resolve the problem?

2-electrode sensors are very insensitive to objects nearby as the outer electrode protects the electrical field between the electrodes. However a distance of 10 mm should be kept clear at the end of the sensor.

The design of our 4-electrode sensors is different. The electrical field lines stray into the area around the tip of the sensor. Any object that disturbs the field-lines will cause a measuring error as the cell constant changes. Experiments have shown that a minimum distance of 30 mm should be enough.

Inductive sensors also create an electrical field inside the sensor and around the sensor. A minimum of 25 mm is required to use the sensor without determination of a new cell factor. The minimum distance depends also on the material of the object. A PVC pipe will cause a different error than a stainless steel pipe.

4.3 When is a 4-electrode sensor (compared to inductive) recommended?

This strictly depends on the requirements of the application and the customer. From a maintenance point of view, electrodeless conductivity sensors are the preferred choice. Electrodeless conductivity sensors resist the effects of fouling and are generally more robust and chemically resistant, but are not recommended for applications below 50 $\mu\text{S}/\text{cm}$. A 4-electrode sensor has a smaller measuring range, lower temperature specifications, is more sensitive to fouling than a toroidal sensor and is not recommended for heavily polluted solutions. It may cause problems with the chemical resistance as metal and plastic are always in contact with the medium. On the other hand it is simpler and more cost-effective to install through a socket, does not cause flow restrictions, can be used in smaller pipes and can be sold at a lower price. 4-electrode sensors have the major advantage that they do not cause flow restrictions when installed in a 25 mm weld-in socket. For all clean solutions (no physical dirt) in the medium conductivity solutions, the 4-electrode sensor is still a good alternative to an inductive sensor.

5 Electrodeless Sensors

5.1 What is the measuring error for our inductive sensors?

As we do not really calibrate the sensors after the manufacturing, the maximum accuracy will be in the order of 5 %. These sensors, however, are influenced by the way they are installed. A re-calibration of the installed sensor may reduce the measuring error to approx. 3% over a wide measuring range. Making measurements only at a particular point and a proper calibration at the same point will improve the accuracy to 1 – 2%. In many applications this kind of accuracy is not required by the customer (wastewater, phase separation, CIP etc.)

5.2 Why does a transmitter only work with a specific type of inductive sensor?

The sensor characteristics (coil material, shielding, number of windings around the coils) requires a specific current input and delivers a specific current output. The transmitter needs to be able to respond to the signal and to display the corresponding conductivity values.

Beside the cell factor, there is another value stored in the transmitter in order to produce the correct reading. If the sensor characteristics changes (e.g. a competitive sensor), the transmitter might not be able to read the signal correctly.

5.3 How does the bore size and the coil size impact the useful measuring range?

Often sensors with a large bore size are used for low conductivity samples (1 $\mu\text{S}/\text{cm}$) but are limited on the higher side to max. 500 mS/cm .

5.4 What distance from a wall should be kept when installing an inductive sensor in the pipe?

We recommend at least a 3" pipe (DN80). The minimum distance from the wall should be approximately 20 mm from the outer side of the sensor. If the distance is 20 mm or more, the cell factor can be multiplied by one (remains the same). If the distance is smaller than 20 mm the cell factor will change. If the pipe is conducting (ss) the real cell factor will be smaller than the original one, if the pipe is made of non-conducting material, the cell factor will become larger.

5.5 Once the sensor is installed, how can the customer know what the position is, since there isn't any outside mark?

In fact there is an outside mark. There are two little notches on the back end of the sensor (where the cable sleeve goes into the PEEK body). These notches are aligned with the flow direction through the sensor.

5.6 Is it possible to use a competitor's sensor with our transmitter or our sensor with competitor's transmitter?

The transmitter and sensor comprise a system and are designed to give best performance. Basically it is not possible to use any other combination and receive good performance. However, some sensors behave very much the same. Foxboro and Rosemount sensors will probably give a good performance if interchanged. Also the combination with Yokogawa and E&H will give a reasonable performance.

5.7 Is it possible to get other adapters and fittings to install an inductive sensor in the process?

Our policy is to support customers the best possible way. Please understand that sometimes, this support is time consuming and that we have to judge between the time used to work for you and the expected sales support. We therefore may reject your requests from time to time.

5.8 Is an inductive sensor affected by polarization?

No. There is no polarization with inductive sensors. Also coatings on the sensor surface have little or no influences on the measurement (the bore should not be clogged or changed significantly in size).

5.9 Do electrodeless conductivity sensors have a cell factor?

The term «cell constant» is associated with contacting conductivity type sensors. This is because the definition of the cell constant incorporates two conducting plates (electrodes) separated by a fixed distance.

An electrodeless sensor, even though its geometry does not conform to the strict definitions of the cell constant due to the encasing, does have a measurable, repeatable cell factor. An electrodeless cell factor is measured empirically using standard solutions of known conductivity. This cell factor must be known to the transmitter and therefore needs to be typed in. As we offer only one type of electrodeless sensor (InPro 7200 Series), the cell factor is approximately the same for all sensors and a default value is already incorporated in the transmitter Condi 7100.

5.10 What installation requirements are needed for an electrodeless conductivity sensor?

The key installation requirements for an electrodeless sensor are:

1. Ensure that the flow is not so high as to cause cavitation (air bubble formation).
Cavitation does not occur below 10 ft/sec flow rate (3 m/sec.)
2. Keep the electrodeless sensor at least one diameter from the pipe or tank walls.
3. Keep the electrodeless sensor head assembly fully wetted by the process. Avoid partially filled pipes.
4. As with any analytical sensor, install in a location that offers a sample that is representative of the process.
Avoid installations where mixing and reacting are still occurring.

5.11 Which is better, a vertical or a horizontal mounting?

The measurement principle of an electrodeless sensor allows it to function in any mounting attitude. It operates equally as well in a vertical orientation as horizontal. It will even operate vertically with cable end down. However, installation in a vertical pipe (sensor horizontal) with flow moving from the bottom to the top of the pipe will guarantee a fully wetted sensor. Therefore, this is the preferred orientation.

5.12 How often must an electrodeless conductivity sensor be cleaned?

Frequency of cleaning depends on the application. Sensors used in clean streams may only need cleaning once every several months (some customers never clean the sensors). Sensors in contact with high consistency streams (paper mill causticizer, aluminum mill digester, etc.) may require cleaning as often as once per week or more.

If the sensor doughnut becomes coated with a measurable level of solid materials, or if the sensor bore becomes plugged, the measurement value will be compromised. This is because the gross coatings significantly change the cell factor of the sensor as its geometry has been altered.

Experience with each specific application will dictate the frequency of cleaning. For a new installation, it is recommended to check calibration after a week or two. If the calibration has not shifted, then the inspection cycle can be lengthened.

6 Transmitters

6.1 What are the variables that drive a transmitter to work with a sensor in a specific measuring range (voltage, current, frequency)?

The voltage and the frequency are the main variables. Sophisticated transmitters have several internal ranges. The voltage and the frequency can be varied in each of the ranges allowing the transmitter to measure from ultrapure water up to very high conductivity values.

The transmitter circuitry sets the voltage and current used in the circuit to measure conductivity. The voltage across the sensor electrodes varies automatically with the solution conductivity. The frequency of the square wave applied to 2-electrode sensors is automatically changed by the transmitter as the measured conductivity changes. The frequency is changed in order to eliminate polarization effects.

6.2 What is the advantage for a customer to use a 2-wire versus a 4-wire transmitter

A 2-wire transmitter is used mostly for safety and cost reasons. A plant is equipped with an internal 24 VDC power supply, which can even be touched without doing any harm to personnel. Most of the Ex-proofed transmitters are 2-wire instruments as it is much easier to fulfill the Ex requirements with such an instrument compared to a transmitter that is mains powered. A 2-wire instrument is also easier to install (less wiring).

7 Cables

7.1 How is the compensation of the cable lengths done in our instruments? Up to what conductivity this feature is relevant.

Mettler-Toledo Process Analytics specifies the following maximum cable lengths:

- InPro7000 Series: 60 m
- InPro7100 Series: 15 m/60 m (depends on transmitter)
- InPro7200 Series: 30 m
- InPro7010 Series: 60 m (not specified)

Longer cables may be used, depending on the exact value that needs to be measured and the requirements for accuracy. If the signal degrades, a loss of accuracy results. Longer cables need to be evaluated each time.

7.2 What is the relation between cable lengths and loss of signal/precision (inductive sensor)?

Within the specified measuring range and the maximum cable lengths customers should not note a difference. If the cable is longer than the maximum specified length, customers will see an error.

8 Flow

8.1 Is there an ideal flow rate for conductivity measurements?

No. Conductivity measurements do **NOT** depend on the flow rate. They work in a beaker, in a tank or in a flow stream equally well.

However, especially in high purity water, one must be concerned about contaminating the water by the absorption of CO₂ from air into the water stream. This happens by passage through fittings and diffusion through tubing. The addition of CO₂ causes the formation of carbonic acid, which is weakly dissociated. You may tighten the fittings, but there is often little you can do about the diffusion. Some ways to reduce or eliminate the impact of the diffusion of CO₂ through the pipe are to increase the flow rate, increase the pipe-wall thickness, or use a different pipe with a lower diffusion coefficient, like SS. All of these have the impact of diluting the CO₂.

A key point: Conductivity measurements are **NOT** dependent on the flow rate. But the conductivity (or quality) of the water can be affected by the flow rate. The instrumentation is just responding to the quality of the water.

Conductivity can be measured accurately from static situations to fairly high flow rates. Flow can be critical depending on the application. With ultra-pure water, contaminants from the piping, tanks, etc. are constantly dissolving in the water and thus high flow keeps them from building up in the water. Also CO₂ will get into the water through joints and through the pipes and tank walls and it will change the conductivity. Again, a high flow rate removes the diffused CO₂ before it can build up to a significant level.

8.2 What is the optimum flow rate in measurements below 10 µS/cm?

It depends on the system. You want enough flow to keep the contamination level from dissolved impurities and CO₂ at an acceptable level.

Any flow rate that the «quality» of the solution is not effected. Sometimes, especially in some industries, this is believed to be a velocity of >0.3m/s, but this is **NOT** right. The exact number will depend on the type of tubing, the conductivity, and the degree of precision required.

Some general guidelines: For flowing samples in a plastic pipe, if the conductivity is <0.1 µS/cm, you could be at risk. When >1 µS/cm, not a problem. Between 0.1 and 1, there is less of a chance of a problem, depending on the accuracy you need.

For static samples, then you are at risk if the conductivity is <10 µS/cm. >100 µS/cm, there is no problem, between 10 and 100 µS/cm, maybe. Do not use <50 µS standard solution to calibrate.

8.3 Flow dependency of 2-e, 4-e and inductive sensors?

2- and 4-electrode conductivity measurements are typically not flow dependent. At extremely high flow rates the measurement would be affected by turbulence but we have never seen this in any practical application.

9 Applications

9.1 What applications for conductivity are typical for individual industries?

Biotech/Pharma:

Water preparation (USP 25, Thornton), chemical concentrations in fine chemicals, downstream processes, phase separation, CIP/SIP cleaning, waste water treatment.

Chemical industry:

Water preparation (ion-exchanger, filtration, distillation), chemical concentration measurements (acids, alkalis, salts), waste water treatment

Pulp & Paper:

mostly concentration measurements (NaOH)

Food & Beverages:

Make-up water, washing solutions, CIP/SIP. Some foodstuff requires conductivity measurements for salting/desalting processes.

9.2 What conductivity ranges are common for each application?

- Water Preparation: 0.05 to 10 $\mu\text{S}/\text{cm}$
- Chemical concentration: 1 $\mu\text{S}/\text{cm}$ to 2000 mS/cm
- CIP/SIP: 1 $\mu\text{S}/\text{cm}$ to 200 mS/cm
- Waste water: 10 $\mu\text{S}/\text{cm}$ to 200 mS/cm

9.3 Are there any standard chemical/processes that conductivity sensors are typically exposed to in various industries?

Dilution of acids is very common. Standard solutions are sulfuric acid, hydrochloric acid, phosphoric acid and nitric acids. Also citric acid and acetic acid are very common. CIP/SIP are using standard solutions: 5% NaOH, 1 – 2% phosphoric acid.

In pulp & paper there are two main processes to produce pulp – one is using mostly NaOH while the second one is based on sulfuric acid.

9.4 What are the preferred materials for each industry: sensor and bushing (food, pulp/paper, bio/pharmaceutical)?

There is no standard answer to this question as it strongly depends on the specific application. In the chemical process industry we see a wide range of chemicals. It is important that the sensor material can withstand the conditions. PEEK is a very good material, but often not sufficient as it is not suitable in high concentration sulfuric acids, fuming sulfuric acid, oleum, high concentration nitric acid, and hydrofluoric acid. Sensors coated with PTFE or PFA are sometimes required. For oleum, glass sensors are also common.

In the pharmaceutical and food industry it is important to use only FDA positive listed material. Virgin PEEK is among the most preferred, but PP is also acceptable from a material point of view. As electrode material stainless steel is preferred in the pharmaceutical industry.

However, at least in Europe, we see more and more a requirement for higher quality steels than 316L.

9.5 Are there preferred/industry standards for sensor fittings?

Chemical industry. Flanges of different sizes and materials. Very common are DIN 50/PN 15 or DIN 100/PN 16. In the US and UK markets, ANSI flanges are common and Japan also has its own stand for flanges. Bushings are less common but sometimes also acceptable.

In the pharma industry Tri-Clamp is very common (US, Asia and partly in Europe). As Tri-Clamp is not considered as very hygienic, more and more other fittings can be found (also in the food/and beverage industry) such as SMS (France), DIN 11851 & 11864 (Germany), Neumo, Tuchenhagen Varivent and APV.

As we have a strong history with our sockets, these can be found in the biotech and chemical industry as well.

9.6 In which applications are inductive sensors used?

In all applications above a few 100 $\mu\text{S}/\text{cm}$ where a 4-electrode sensor will not work because of its specifications, increased maintenance, or material compatibility.

More specifically, in the pulp industry, in the chemical process industry and in wastewater applications. In CIP applications the suitability is small as the standard sensor is not sterilizable and the sterilizable one is very expensive. Also glass-filled PEEK is not the preferred choice of customers.

9.7 What is the time frame for sensor replacement in the chemical industry?

That depends on the nature of the solution. Iron oxide manufacturers have to clean the sensors every two weeks and calibrate them every 4 weeks. In some pulp applications, the sensor does not last for more than 1-2 years and in oleum or hydrofluoric acid it is even hard to find a suitable sensor at all. In most applications however, the sensor last for at least several years.

9.8 What chemicals are used for cleaning in chemical processes?

Acidic, caustic, detergents, soap. It really depends on the nature of contaminants.

9.9 What types of solutions can I measure with a METTLER TOLEDO conductivity sensor?

METTLER TOLEDO conductivity sensors (systems) are used in all process industries, including chemical, food & beverage, metals & mining, textiles, pulp & paper and pharmaceuticals. The sensors are used wherever water is heated, cooled, purified, or combined with acids, bases, and salts to produce solutions used in the process. Applications range from demineralization processes to the determination of chemical concentration. Typical applications include: water purification, water for injection, rinse water, cooling tower water, acid concentration control, caustic concentration control, leak detection at heat exchangers, phase and media separations, CIP control.

Conductivity measurements are used over a wide range of electrolyte concentration. From ultra-pure water, which contains only traces of contamination, to water containing percent levels of acids, bases, and salts, the dynamic range of process conductivity measurements spans seven decades of concentration.

9.10 What are some of the often-encountered applications for concentration measurements?

Although many standard curves are provided in our conductivity equipment, also non-standard applications are frequently encountered. A few of these would be high concentration nitric acid (HNO_3), high concentration hydrochloric acid (HCl), and possibly the most commonly encountered would be the dilution of high concentration sodium hydroxide (NaOH) from approximately 50% to some lower concentration (5 - 20%).

9.11 What is the difference between electrodeless conductivity sensors and contacting conductivity sensors?

A contacting conductivity sensor uses metal or graphite electrodes in direct contact with the fluid being measured. The electrodes are excited by a high frequency AC signal, the resistance is then being measured across the two electrodes.

An electrodeless sensor uses a pair of transformer-wound toroids, which are encased in a chemically and electrically inert housing. One toroid is energized by the analyzer, creating an induced current in the liquid. The second toroid senses the field created by the first toroid. As the conductivity varies, the size of the sensed signal varies proportionally.

Contacting sensors offer lower detection limits than electrodeless sensors, but electrodeless sensors require much less maintenance.

10 Services

10.1 What types of services are available?

Beside single item calibration for sensors, calibrators and transmitters (only products manufactured by Mettler-Toledo Thornton), we are working on implementing procedures for ordering system calibration (Mettler-Toledo Thornton manufactured products only).

10.2 Are there any 3.1B certificates for sensors available?

For sensors (InPro7000-VP Series and InPro7100-VP Series) we supply a heat certificate as well as a confirmation that all parts are made from the same steel. In most cases this documentation is sufficient for our customers.

10.3 Surface roughness certificates for sensors?

We already supply a certificate for RA for InPro7001-VP and InPro7002-VP.

11 Ex-Approval / Certificates

11.1 Is it possible to install a 2e, 4e or inductive sensor in an Ex-zone? What is required to achieve ATEX approval or FM class 1 div 1 approval?

In general yes, if they are Ex-certified. In the past, 2- and 4-electrode sensors were considered as passive elements and specific certificates or approvals were not required. For inductive sensors using a different technique it was always required. With new guidelines described in the ATEX, we are no longer able to declare 2- and 4-electrode sensors as passive elements and we have to address this properly.

11.2 Do we have ex certificates for our sensors?

We do have an Ex certificate for all of our inductive sensors and will apply for ATEX in 2003.

11.3 How important is Ex-approval? Is it more important for one industry than another?

In some industries it is almost mandatory. In those industries organic chemicals (solvents) are common and therefore the requirements for electrical equipment to avoid any spark are high. Amongst those industries are some chemical but also pharmaceutical plants and definitely the petrochemical industry. Sometimes specific areas require ex-proofed equipment, sometime the whole plant (incl. wastewater treatment) is declared as Ex.

11.4 Are all o-rings and wetted body materials FDA positive listed?

All o-rings of the InPro 7000-VP and InPro 7100-VP Series are made of FDA positive listed materials and we are able to supply the required certificate if requested. Those products are manufacture by Thornton and they purchase o-rings from us. O-rings on inductive sensors and those of the InPro 7010 Series are not supplied with certificates.

12 List of additional information available on request

Available Application Notes

Order No	Description
52 000 627	«Conductivity in HPW»
52 001 798	«CIP - concentration control in the makeup system»
52 001 799	«CIP - return line»
52 001 800	«Phase separation»
52 001 801	«Black liquor spill reclamation»
52 001 802	«Measurement of conductivity in pulp & paper-digester»
52 001 803	«Lye peeling»
52 001 804	«Steam generation - boiler blow down»
52 001 805	«Rinse control»
52 001 806	«Chemical concentration control»
52 001 807	«Leak detection in heat exchangers»
52 001 808	«Brown stock washing»

13 Glossary

	Description
316 L	Stainless steel, AISI 316L (USA Standard) similar to 1.4404 and 1.4435 (DIN norm).
3-A standard	Sanitary standards. Criteria for cleanability of dairy and food processing equipment (voluntarily based, USA founded).
Accuracy	The quality or state of correctness, i.e. freedom from mistake or error. In technical terms, the closeness of a measured value to the known «true» value, e.g. in measurement, the degree of conformity to some recognized standard.
Anion	A negatively charged ion.
Anion Exchange Resin	An ion exchange material that removes anions from solution by exchanging them with hydroxyl ions.
ASTM	The American Society of Testing and Materials
ATEX	ATEX («Atmosphères Explosibles») is the common name of the directive 94/9/EC. The objective of directive 94/9/EC is to ensure free movement for the products to which it applies in the EU territory. After 30 June 2003 products may be placed on the market in the EU territory, freely moved and operated as designed and intended in the expected environment only if they comply with directive 94/9/EC (and other relevant legislation). The directive 94/9/EC provides for the first time Essential Health and Safety Requirements for non-electrical equipment intended for use in potentially explosive atmospheres and equipment intended for use in environments which are potentially explosive due to dust hazards and protective systems and for devices intended for use outside explosive atmospheres which are required for or contribute to the safe functioning of equipment or protective systems with respect to risks of explosion.
°C	Abbreviation for degree Celsius (Centigrade). Conversion to °F (Fahrenheit): multiply °C by 9 / 5 and add 32 = °F. [0 °C = 32 °F], [1 °C] = [1.8 °F].
Calibration	A comparison between an item of measuring equipment or test equipment and a standard or a similar item of higher accuracy, for the purpose of detection, correlation, and the documentation of the instrument or item of equipment being compared or tested.
Cation	A positively charged ion.
CE	The letters «CE» are an abbreviation of a French phrase «Conformité Européenne». The marking CE on a product indicates that the manufacturer has conformed with all the obligations required by the legislation of the European Union (EU) regarding health, safety and environmental protection, and allows free circulation of the products within the EU market place. The legislative requirements also apply to the European Free Trade Area (EFTA).
Cell constant	$c = d / A$ (theoretical) d: distance between electrodes A: electrode surface. This defines the volume (of solution) between the electrodes of a conductivity cell. Solutions with a high conductivity require a sensor with a cell constant greater than 1.0.
CIP Process	Cleaning in Place : A process in which cleaning and disinfecting solutions are circulated in a loop without having to dismantle the equipment for treatment. Such circulatory cleaning systems are often automatic, controlled by special programs.
Competition	Makes life more difficult.
Concentration	The actual amount of a substance in a given volume of solution.
Conductance	Conductance $G [S] = 1 / R [Ohm]$
Contacting Conductivity Sensor	Sensor electrodes are directly in contact with measuring media.
Conductivity value	The reciprocal of resistivity, it is a measure of the ability (e.g. of a solution) to conduct an electric current. Since ionized impurities increase the conductivity of water, it is also an accurate measure of ionic purity. To measure it, current is passed between two electrodes a fixed distance apart. Conductivity is normally expressed as microsiemens/cm, identical to micromhos/cm. The conductivity value is a measure for the concentration of all ions in a liquid. The instrument reading of a sample will change with temperature. Conductivity x S/cm = $G [S] * c [1/cm]$
CSA	Canadian Standards Association : norming institute for Canada.
Demineralization	Term sometimes used interchangeably with deionization. It refers to the removal of minerals and mineral salts using ion exchange.
Dissolved Solids	Also referred to as Total Dissolved Solids (TDS), it is the amount of non-volatile matter dissolved in a water sample, and is usually expressed in parts-per million (ppm) by weight.
Distillation	The process of separating water from impurities by heating until it changes into vapor and then cooling the vapor to condense it into purified water.

	Description
EHEDG	European Hygienic Equipment Design Group. A consortium made up of equipment manufacturers, food industries, research authorities and public health bodies, founded in 1989 with the aim of promoting hygiene during the processing and packing of food products. Guidelines have been drawn up on subjects surrounding hygienic design criteria, and these are widely accepted. Company product certification and hygienic tests to EHEDG «Standards» are available.
Electrolyte	A substance which ionizes in an aqueous solution. Weak electrolytes are only slightly dissociated into ions in solution (acetic acid), and strong electrolytes are highly dissociated (HCl, NaCl). Strong electrolytes are good conductors of electricity, and conductance measurements are well correlated with electrolyte strength.
Ex (-Proof)	Explosion protected device
°F	Unit of temperature. Abbreviation for degree Fahrenheit. Conversion to °C (Celsius): Subtract 32 from °F and multiply by 5 / 9 = °C. [212 °F = 100 °C], [1 °F] = [0.5556 °C].
FDA	U.S. Food and Drug Administration. Plant parts in contact with liquid products require compliance with the FDA regulations.
Filtration	Removal of suspended matter by passing it through a porous matrix that prevents particles from getting through, usually by entrapment on or in the filter matrix.
FM	Factory Mutual
Fouling	When gelatinous coatings, colloidal masses or dense bacterial growth form a compacted crust on membrane or filter surfaces which blocks further flow.
Four-electrode cell	Conductivity cell with 4 (2 current and 2 voltage) electrodes; suitable for measuring high conductivity.
HART Communication	«Highway Addressable Remote Transducer». It allows two-way digital communication by superimposing digital signals on the loop current of smart field instruments. It is compatible with existing 4 to 20 mA systems.
Hastelloy®	Hastelloy® is the registered Trade Mark of Haynes International.
Ion	An atom or group of atoms with an electrical charge that is positive (cation) or negative (anion) as a result of having lost or gained electrons.
Ion Exchange	Also called deionization. A process in which harmless ions attached to the resin beads are exchanged for undesirable ions in solution. Typically, hydrogen ions are exchanged for any cations and hydroxyl ions for any anions. The hydrogen and hydroxyl ions combine to form pure water.
IP XY	IP means Interelement Protection. The two following numbers identify the protection grade: 1 st number: contact protection and protection against intrusion of a foreign body. 2 nd number: protection against intrusion of water.
MegΩ-cm	A measure of ionic purity in water. Resistivity (the reciprocal of conductivity) is a measure of specific resistance to electrical flow. The fewer dissolved ions in water the higher its resistivity. One megΩ-cm is equivalent to one million ohms of resistance measured between two electrodes one centimeter apart. The theoretical maximum ionic purity for water is 18.3 megohm-cm at 25 °C.
µS / cm	Unit of specific conductance of water. Abbreviation of micro Siemens/cm.
MNPT	A definition of a NPT thread, (M = male).
NIST	National Institute of Standards and Technology USA).
NPT	Abbreviation for National Pipe Thread
Ohm [Ω]	The practical unit of electrical resistance in a circuit, where a potential difference of one volt produces a current of one ampere.
Ohm•cm	Unit of specific resistance of water.
Osmosis	The diffusion of a solvent through a semipermeable membrane.
PEEK	PolyEther-EtherKetone. PEEK, a unique semi-crystalline, high temperature engineering thermoplastic, is an excellent material for a wide spectrum of applications where thermal, chemical and combustion properties are critical to performance.
Percent rejection	In reverse osmosis or ultrafiltration, the ratio of impurities removed to total impurities in the incoming feedwater. For example, RO membranes typically remove (reject) 90% of the dissolved inorganic contaminants in water.

	Description
ppb	Unit of concentration. Abbreviation for parts per billion (10 ⁻⁹), (e.g. 1 ppb = 1 microgram per liter).
ppm	Unit of concentration. Abbreviation for parts per million (10 ⁻⁶), (e.g. 1 part per million = 1 milligram per liter). The most common measure of dissolved ionized impurities in water.
Profibus	A digital communication system to integrate decentrally installed field units into a process control system via cable. It is regarded as one of the most viable system to replace 4 – 20 mA technology in the future.
Pt 100/Pt 1000	The principle of operation is to measure the resistance of a platinum element. The most common type (Pt100) has a resistance of 100 ohms at 0 °C and 138.4 ohms at 100 °C. There are also Pt1000 sensors that have a resistance of 25 ohms and 1000 ohms respectively at 0 °C. The relationship between temperature and resistance is approximately linear over a small temperature range: for example, if you assume that it is linear over the 0 to 100 °C range, the error at 50 °C is 0.4 °C. For precision measurement, it is necessary to linearize the resistance to give an accurate temperature. The most recent definition of the relationship between resistance and temperature is International Temperature Standard 90 (ITS-90).
Quality certificate	Certifies that a product system or parts thereof meet a desired level of quality within agreed tolerances and that traceability is guaranteed within the complete production process.
Ra	Average roughness (of surfaces).
Reference temperature	With temperature compensation enabled, the measured value is calculated for the reference temperature (usually 20 or 25 °C) using the temperature coefficient.
Reject	In reverse osmosis and ultrafiltration, those impurities not able to permeate the membrane are said to be rejected (removed). They are flushed away in the reject (waste) stream.
Resistivity	A measure of specific resistance to the flow of electricity. In water, it is an accurate measure of ionic purity. See «Megohm-cm». This is the reciprocal of the conductivity value and is measured in Ohms. It is generally limited to the measurement of ultrapure water with a very low conductivity.
Reverse Osmosis	The reversal of osmosis to purify water. In osmosis, water diffuses through a semipermeable membrane from a less concentrated solution to a more concentrated solution. The flow of water can be reversed with an opposing pressure that exceeds osmotic pressure. With Reverse Osmosis, water is forced out of a concentrated solution, leaving the solute (impurities) behind.
RTD	Abbreviation for remote temperature detection, a feature of many types of sensor/electrode to allow (automatic) temperature compensation of the actual parameter measurement by the transmitter. RTD is effected by a temperature sensor (Pt 100/Pt 1000) incorporated in the tip of the sensor/ electrode as near as possible to the active parameter measurement point in the sample medium.
S	Siemens, unit of measurement for conductivity.
S/cm	Unit of specific conductance of water. Abbreviation for Siemens per centimeter. 1 Siemens/cm = 1mho/cm
Salinity	The concentration of soluble mineral (mainly salts of the alkali metals or of magnesium) in water.
Specific Conductance	The reciprocal of specific resistance, usually expressed in microsiemens/cm, identical to micromhos/cm.
Specific Resistance	Resistance of a one-centimeter cube of water to the passage of electricity under standard conditions, expressed in ohms-cm. It is a measure of the Total Ionized Solids concentration.
Sterilization	Destruction or removal of all viable organisms by heating up the media to a determined temperature for a determined period of time.
TDS	Abbreviation for total dissolved solids.
Temperature coefficient	When temperature compensation is enabled, the temperature coefficient is used to convert the measured value to the respective value at the reference temperature.
Temperature compensation	Serves to convert the measured value to a reference temperature. Correction of the temperature dependency of the diaphragm diffusion.
Two-electrode cell	Conductivity cell with 2 (voltage) electrodes; suitable for measuring low conductivity.
Validation	The evaluating of processes, products or analytical methods to ensure compliance with product or method requirements.

	Description
Ultrapure water	Water with a specific resistance higher than 1 megohm-cm. In the laboratory, it usually refers to ASTM D1193 Type 1 reagent grade water. Anything in laboratory water that is not H ₂ O is an impurity. Although chemically pure water is not attainable, ultrapure water systems are now capable of reducing impurities down to the limits of detection.
USP	United States Pharmacopeia. Recommendations for purified water standards.

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Subject to technical changes.
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