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# 1. Introduction

Yokogawa's Technical Information Conductivity Analyzer Guide provides a convenient source of information on basic conductivity theory; measurement methods; applications; and product features necessary for the proper equipment selection.

Conductivity is one of the key measurement parameters used by industries for monitoring and control of various kinds of water usage, such as boiler feed water and water for injection (WFI). Conductivity is also the most stable and cost effective parameter available when the measurement of percent concentration of a specific chemical is required.

## 2. Conductivity

Conductivity is the parameter used to measure a solution's ability to conduct an electric current. The term "Conductivity" is derived from Ohm's Law which is defined as:  $E = I \cdot R$ , where  $E$  is voltage applied between the two "plates" (shown in Figure 2.1), and an electrical current  $I$  will flow which is dependent on the resistance  $R$  of the conductor. Therefore, conductivity is defined as the reciprocal of resistance of a solution between two electrodes and it can be expressed as:  $G = I / R$ .

The basic unit of conductivity is the siemen (S), formerly called the mho. Since the cell geometry determines the conductivity value it can be used to measure, standardized measurements are expressed in specific conductivity units to compensate for variations in the electrode dimensions. Specific conductivity is calculated by multiplying the measured conductivity ( $G$ ) by the electrode's cell constant. The cell constant is determined by the formula  $L/A$ ; where  $L$  is the length of the column of liquid between the electrodes and  $A$  is the area of the electrodes:  $C = G \times (L/A)$

Conductivity measurements cover a wide range of solution conductivity from pure water at less than  $1 \times 10^{-7}$  S/cm to values greater than 1 S/cm for concentrated solutions. Conductivity is a measure of the purity of water or the concentration of ionized chemicals in water. However, it is a nonspecific measurement, unable to distinguish between different types of ions, giving instead a reading that is proportional to the combined effect of all the ions present.

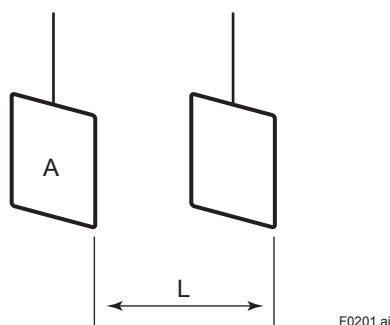


Figure 2.1 Measurement Principle

### 2.1 Conductivity versus Percent Concentration

Conductivity is a common measurement used to determine the percent concentration of a chemical (electrolyte). The conductivity of a chemical increases as the percent concentration increases (see Figure 2.2) while the amount of dissolution (percent values) are small. However, when the concentration of the electrolyte increases a point will be reached where the degree of disassociation (ease of ionization) decreases, and the increase in conductivity tends to level off or begin to decrease. The graphs in Figure 2.3 show the relationships between the percent concentration value and the conductivity value of common chemicals used in industry.

The relationship is indeed very complex where there can be more than one percent concentration value having the same conductivity value. Note the graphs for sulfuric acid ( $H_2SO_4$ ), and sodium chloride (NaCl). This is an important point to note when planning to control the concentration of solutions with a conductivity analyzer.

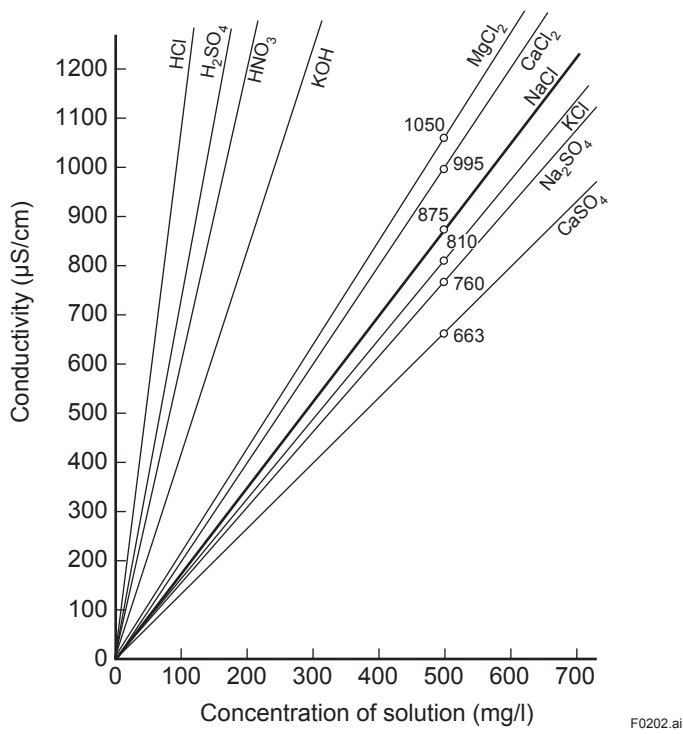


Figure 2.2 Relationship between Concentration of Solutions and Conductivity (at 18°C)

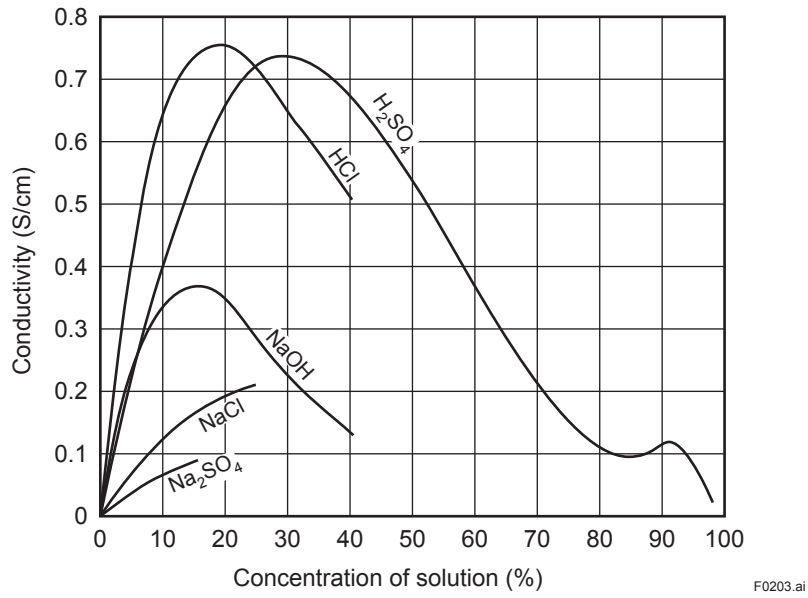


Figure 2.3 Relationship between Concentration of Solutions and Conductivity (at 18°C)

## 2.2 Temperature Coefficient

The conductivity of a chemical or solution is significantly affected by changes in temperature. Most fluids will increase in conductivity as the temperature increases. For example, ionic solutions increasing about 2% for each 1°C increase in temperature. So, it is impossible to obtain the true value of a liquid by measuring only the conductivity. The temperature of the liquid must also be measured.

Industrial equipment adjusts the conductivity value based on a Temperature Compensator and displays a value that is corrected, or normalized to 25°C. The instrument automatically adjusts the reading as if the sample was at 25°C, no matter what the actual temperature is.

The following formulas help to show the relationship of temperature to conductivity measurements and how the rate of change is different for different electrolytes.

When the liquid temperature changes from  $t_1$  to  $t_2$ , and the conductivity changes from  $K_1$  to  $K_2$ , the temperature coefficient  $\alpha$  of that liquid is represented by the equation (2.1).

$$\alpha = \frac{1}{K_1} \cdot \frac{K_2 - K_1}{t_2 - t_1} \quad \text{----- (2.1)}$$

In some instances, the value of conductivity in a certain temperature range includes a secondary coefficient  $\beta$  which can be calculated by equation (2.2).

$$K_t = K_{ts} \{1 + \alpha (t - t_s) + \beta (t - t_s)^2\} \quad \text{----- (2.2)}$$

Where;  $t_s$  : Reference temperature  
 $K_{ts}$  : Conductivity at reference temperature  
 $K_t$  : Conductivity at temperature  $t^\circ\text{C}$

$$K_t = K_{ts} \{1 + \alpha (t - t_s) + \beta (t - t_s)^2\} \quad (2.2)$$

Where

$t_s$ : Reference temperature  
 $K_{ts}$ : Conductivity at reference temperature  
 $K_t$ : Conductivity at temperature  $t^\circ\text{C}$

Temperature coefficients will vary depending on the type and percent concentration of the solution. Table 2.1 shows temperature coefficients of typical solutions at a temperature range of about 0 to 30°C.

**Table 2.1 Temperature Coefficients of Electrolyte Solutions**

Dissolved substance	$\alpha$	$\beta$
NaCl	$226 \times 10^{-4}$	$84 \times 10^{-6}$
KCl	$217 \times 10^{-4}$	$67 \times 10^{-6}$
NaNO <sub>3</sub>	$220 \times 10^{-4}$	$75 \times 10^{-6}$
CaCO <sub>3</sub>	$229 \times 10^{-4}$	—
Na <sub>2</sub> CO	$233 \times 10^{-4}$	$97 \times 10^{-6}$
Na <sub>2</sub> CO <sub>3</sub>	$261 \times 10^{-4}$	$151 \times 10^{-6}$
MgSO <sub>4</sub>	$238 \times 10^{-4}$	$95 \times 10^{-6}$
MgCl <sub>2</sub>	$254 \times 10^{-4}$	—
CuSO <sub>4</sub>	$232 \times 10^{-4}$	—
HCl	$164 \times 10^{-4}$	$-15 \times 10^{-6}$
H <sub>2</sub> SO <sub>4</sub>	$165 \times 10^{-4}$	$-16 \times 10^{-6}$
H <sub>3</sub> PO <sub>4</sub>	$169 \times 10^{-4}$	$-1 \times 10^{-6}$
HNO <sub>3</sub>	$163 \times 10^{-4}$	$-16 \times 10^{-6}$
KOH	$190 \times 10^{-4}$	$32 \times 10^{-6}$

Diluted NaCl solution. This temperature coefficient is based on the IEC table (IEC 60746-3) (see Table 2.2).

If the temperature coefficient of the actual measurement solution is significantly different from that of the diluted NaCl solution, you will need to calculate and program the proper coefficient manually in order to have an accurate conductivity or percent concentration measurement.

**Table 2.2 NaCl Compensation Compliant with IEC 60746-3 (at Reference Temperature of 25°C)**

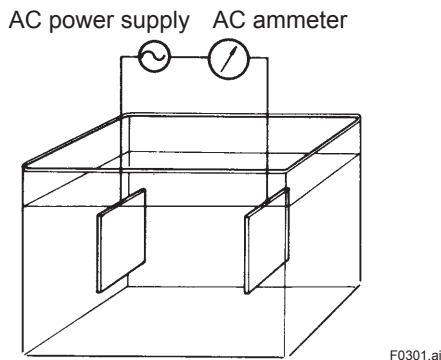
T (°C)	K <sub>t</sub>	$\alpha$	T (°C)	K <sub>t</sub>	$\alpha$
0	0.54	1.8	100	2.68	2.2
10	0.72	1.9	110	2.90	2.2
20	0.90	2.0	120	3.12	2.2
25	1.0		130	3.34	2.2
30	1.10	2.0	140	3.56	2.2
40	1.31	2.0	150	3.79	2.2
50	1.53	2.1	160	4.03	2.2
60	1.76	2.2	170	4.23	2.2
70	1.99	2.2	180	4.42	2.2
80	2.22	2.2	190	4.61	2.2
90	2.45	2.2	200	4.78	2.2

$\alpha$ : Temperature compensation coefficient (%/°C)  
T: Solution temperature (°C)  
K<sub>t</sub>: Conductivity value at temperature T

## 3. Conductivity - Measurement Methods

The two most common methods used to measure conductivity are: (1) Contacting; and (2) Inductive, also known as Toroidal. The measuring elements (plates or electrodes) of Contacting sensors, as the name implies, come in direct contact with the process. The inductive method uses electromagnet coils that are encased in a chemically resistant plastic to keep them from direct contact with the process. So they are suitable for measurement of highly-concentrated acid and alkali solutions or heavily polluted waste water.

### 3.1 Contacting Electrode Method



**Figure 3.1 Principle of Contacting Conductivity Measurement**

When two metal plates are placed in a solution as electrodes as shown in Figure 3.1, and an AC voltage is applied across these plates, the electric current that flows between the plates is proportional to the resistance (or conductivity) of the solution they are in. The equation is:

$$I = \frac{E}{R_C} \text{ ..... (1)}$$

Where  $R_C$  represents an electrical resistance of solution between the electrodes. The following equation represents the relationship between  $R_C$  and the conductivity  $K$  of the solution.

$$R_C = J \cdot \frac{1}{K} \text{ ..... (2)}$$

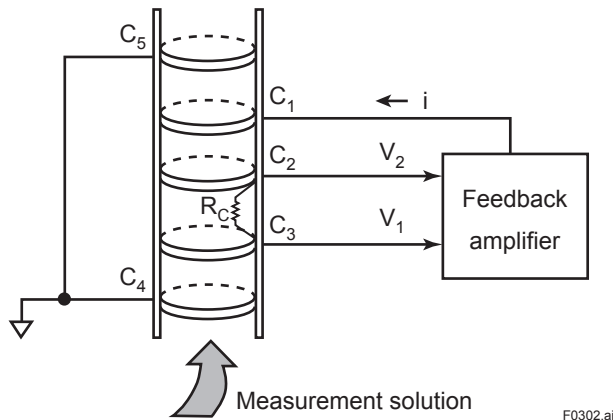
Where  $J$  is a constant that is determined by the distance shape of the electrodes and the distance between them. This is called the cell constant. Take a look at the following equations.

$$I = \frac{E}{J} \cdot K \text{ or } K = \frac{J}{E} \cdot I$$

$E$  and  $J$  are fixed values, so conductivity  $K$  can be obtained by measuring current  $I$ .

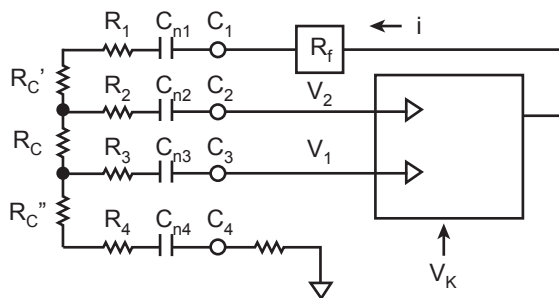
If the measurement solution is highly conductive, or contains contaminating components, polarization of the sensor elements will occur and a correct measurement cannot be obtained. In such cases, it is recommended to use a four-electrode sensor to reduce the influence of contamination and polarization. Using an Inductive sensor is another option.

Figure 3.2 shows the principle of the four-electrode measurement.



**Figure 3.2 Principle of Four-Electrode Measurement**

The four-electrode design reduces the effect of polarization and fouling of the electrode. An AC alternating current is applied only to the outer pair of rings C4 and C5. The voltage is measured on the inner rings without polarization effects because no current flows in the measuring circuit. This type of probe is superior to two electrode contacting sensors in function for most solutions and covers nearly the whole conductivity range with one or two cell constants.



- $C_{nx}$  : Capacity between electrodes ( $C_1$  to  $C_4$ ) and solution
- $R_n$  : Resistance to fouling
- $R_C$  : Cell resistance =  $\frac{K}{J}$
- $K$  : Cell constant ( $\text{cm}^{-1}$ )
- $J$  : Conductivity ( $\text{S/cm}$ )
- $V_K$  : Reference voltage

**Figure 3.3 Equivalent Circuit Schematic**

If the electric current flowing between the measurement electrodes is greater than the geometry of the electrodes can accept, polarization occurs at the electrodes causing the measurement to be incorrect. In the case of a four-electrode sensor, the current does not flow through the actual measurement electrodes C2 and C3, so polarization does not occur. In addition, the square-wave feedback amplifier makes sure the voltage potential  $|V_2| - |V_1|$  between the electrodes is kept constant, so that high conductivity values can be measured. See Figure 3.3.

$$V_1 = (R_C'' + R_4) i$$

$$V_2 = (R_C + R_C'' + R_4) i$$

$$|V_2| - |V_1| = R_C \cdot i = V_K$$

Therefore,

$$i = \frac{V_K}{R_C}$$

Accordingly, the method is immune to the influence of resistance  $R_n$  to fouling.



## 3.2 Inductive Method

Unlike contacting sensors (2 or 4-electrode), the inductive method, measures conductivity without any contact between the electrodes and the process fluid. The measurement is based on inductive coupling of 2 ring transformers (toroids) by the liquid being measured. The transformers are incased in a chemically resistant plastic to protect them from the process. Figure 3.4 shows the structure of the sensor.

Figure 3.5 is a diagram showing the principle of operation. The analyzer supplies a reference voltage at a high frequency to the drive coil ( $T_1$ ) and a strong electromagnetic field is generated in the toroid. The liquid passes through the hole in the toroid and can be considered as a "one turn" secondary winding ( $C_2$ ). The magnetic field induces a voltage in this liquid winding that is proportional to the conductivity of the solution. In turn, the resultant voltage is induced in the Receiver coil ( $T_2$ ) and this output voltage is proportional to the specific conductivity of the solution.

Inductive sensors are well suited for measuring high-conductivity solutions as they are not susceptible to polarization like contacting sensors, and have excellent corrosion resistance, as there are no metal parts in contact with the solution. They are simpler to maintain and therefore suitable for measurement of strong acidic ( $H_2SO_4$ ) or caustic (NaOH) solutions.

However, inductive sensors are not as accurate below  $50\mu S$  and are not suited for measuring low-conductivity water solutions such as pure water.

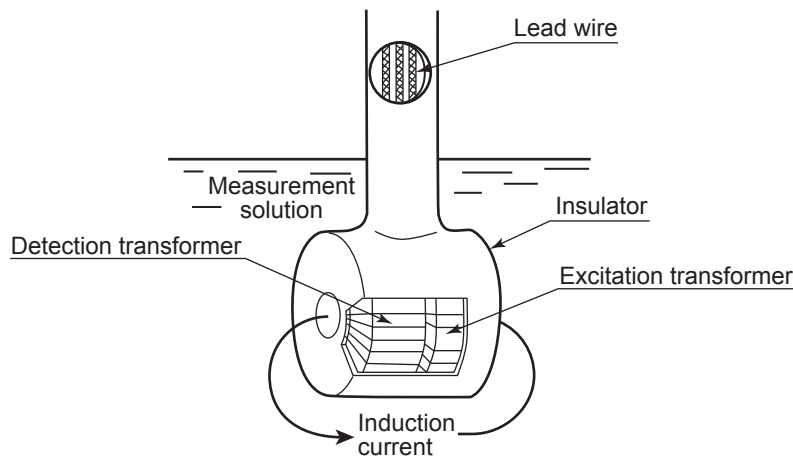


Figure 3.4 Structure Diagram (Cross-section view with outer wall removed)

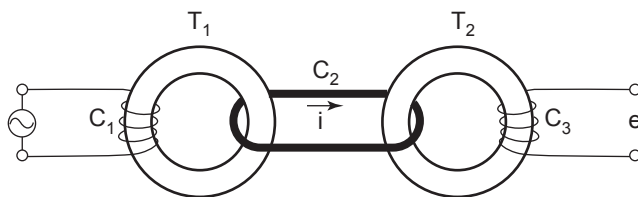


Figure 3.5 Principle Diagram

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## 4. Calibration

There is no global organization (or standard) that defines or certifies standard calibration solutions and procedures for the calibration of conductivity process loops. The most common calibration method is to use locally obtainable conductivity calibration solutions as the standard for adjusting the conductivity analyzer – sensor loop.

### 4.1 Calibration of Electrode Contacting Sensor

Yokogawa's contacting conductivity sensors are factory calibrated using standard calibration solutions before they are shipped.

Periodic re-calibration of conductivity sensors is not usually required unless the sensors become worn, corroded, or coated by the process. These affects can cause the cell constant to change resulting in an inaccurate measurement. There are two basic calibration methods used.

- (1) Calibration can be performed by adjusting the analyzer/transmitter to a known conductivity solution at a known temperature. Specific calibration procedures are described in the operation manuals for the SC450G converter and SC202G/SC202S/SC202SJ transmitters. Conductivity solutions are commercially available in liquid and powder form. The powder form is usually prepared in the plant laboratory assuring it is fresh and accurate. In Section 4.3 are two reference Tables, one using NaCl (Table 4.1) and one using KCl (Table 4.2) that show the conductivity values of several concentrations of these salt solutions.
- (2) Calibration can also be performed by adjusting the process loop to the values measured with an independent conductivity analyzer used at the laboratory. In this case, the Lab analyzer should have traceable periodic calibrations to assure its accuracy. Also, the calibration of the process loop using the laboratory loop must be done at the same temperature to eliminate any possible error due to the instruments temperature compensation circuitry.

### 4.2 Calibration of Inductive Sensor

Calibration of inductive conductivity sensors are only required upon initial installation or when the installation location is changed as the sensor is unaffected by corrosion or coating like contacting sensor are.

The cell factor of an inductive conductivity sensor is affected by the proximity of the sensor to the wall of the pipe or tank in which it is installed. Therefore, it is necessary to perform a calibration if the location of the sensor is changed. It is best to perform the calibration with the sensor actually installed so that the proximity to the process wall can be taken into account. The specific procedure is described in the operation manuals of the ISC450G inductive converter and ISC202G/ISC202S/ISC202SJ inductive transmitters.

### 4.3 Typical Calibration Solutions

Tables 4.1 and 4.2 show the typical values of sodium chloride (NaCl) and potassium chloride (KCl) solutions.

**Table 4.1 Conductivity Values of NaCl Solution at Temperature of 25°C (IEC 60746-3)**

<b>%</b>	<b>mg/kg</b>	<b>Conductivity</b>
0.001	10	21.4 $\mu$ S/cm
0.003	30	64.0 $\mu$ S/cm
0.005	50	106 $\mu$ S/cm
0.01	100	210 $\mu$ S/cm
0.03	300	617 $\mu$ S/cm
0.05	500	1.03 mS/cm
0.1	1000	1.99 mS/cm
0.3	3000	5.69 mS/cm
0.5	5000	9.48 mS/cm
1	10000	17.6 mS/cm
3	30000	48.6 mS/cm
5	50000	81.0 mS/cm
10	100000	140 mS/cm

**Table 4.2 Conductivity of KCl Solution at Temperature of 25°C**

<b>mol/l</b>	<b>mg/kg</b>	<b>Conductivity</b>
0.001	74.66	0.1469 mS/cm
0.002	149.32	0.2916 mS/cm
0.005	373.29	0.7182 mS/cm
0.01	745.263	1.4083 mS/cm
0.1	7419.13	12.852 mS/cm
1.0	71135.2	111.31 mS/cm

Reference: International Recommendation No. 56, International Organization of Legal Metrology (OIML)

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## 5. Conductivity Sensor

Yokogawa offers a wide variety of contacting and inductive conductivity sensors designed to meet the varied requirements of industrial process applications.

### 5.1 Measurement Methods and Applications

- **Two-Electrode Method**

This contacting conductivity sensor and is most suitable for low-conductivity applications for pure and ultra-pure water such as demineralizers and boiler water in Power Plants.

- **Four-Electrode Method**

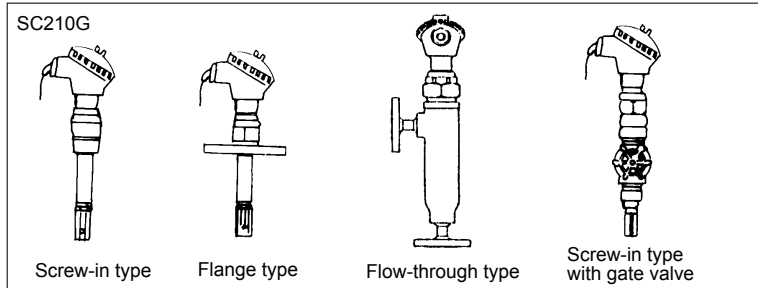
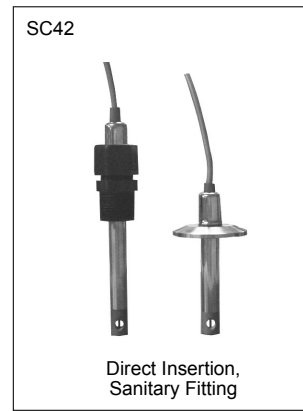
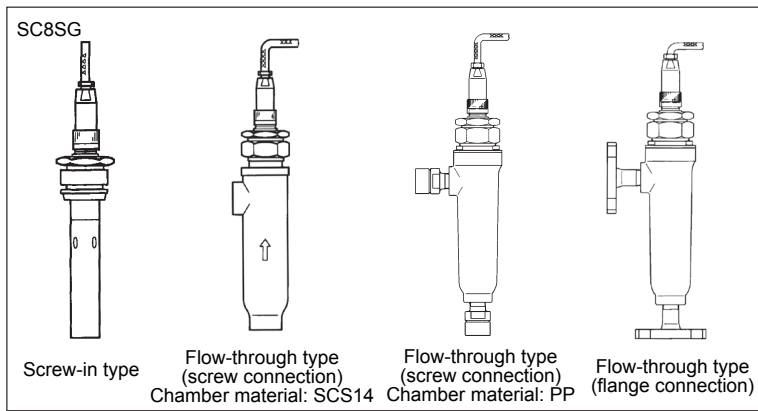
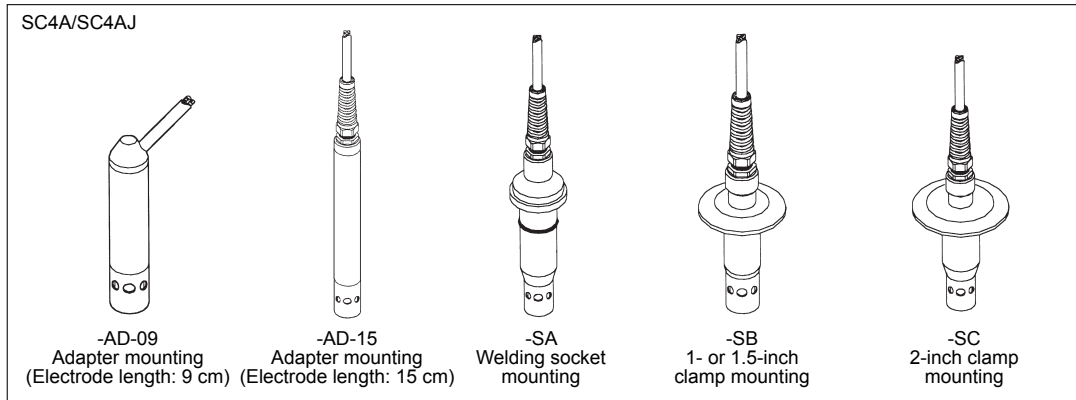
This contacting conductivity sensor can be used for moderate to high-conductivity applications where polarization may be a problem.

- **Inductive Method**

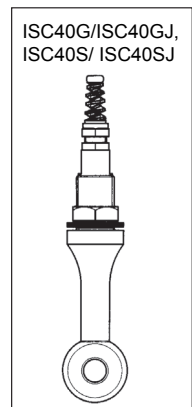
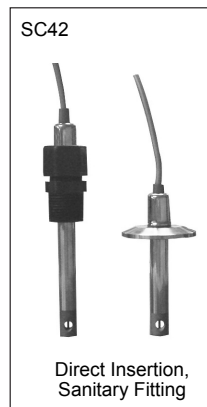
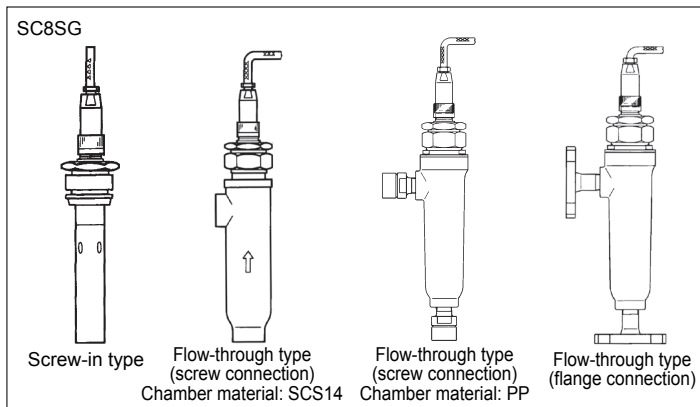
The Inductive sensor is not affected by polarization problems and is suitable for all applications with a conductivity value greater than 50 $\mu$ S.

## 5.2 Conductivity Sensors and Selection Criteria

### Two-Electrode Method



### Four-Electrode Method

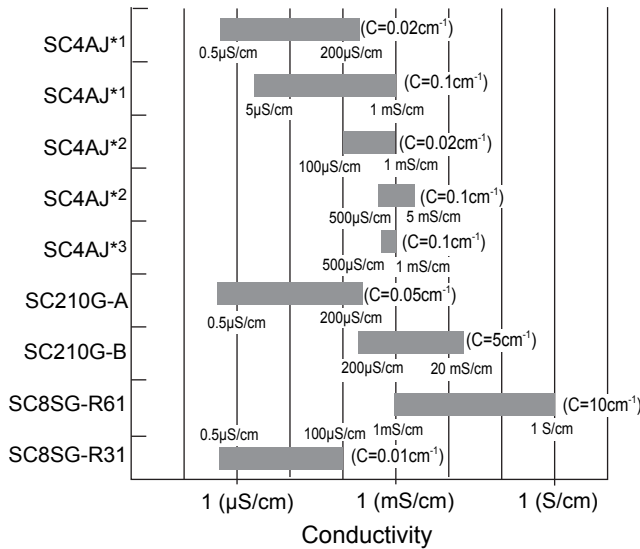


### Conductive Method

Table 5.1 List of Types of Sensors and Combination with Converter/Transmitter

Measurement method	Sensor model	Cell constant	Combined converter/transmitter model
Two-electrode method	SC4A/SC4AJ- □ - □□-□□ -002	0.02 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ, SC100
	SC4A/SC4AJ- □ - □□-□□ -010	0.1 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ, SC100
	SC10XB	0.05 cm <sup>-1</sup>	SC100
	SC8SG-R31-T	0.01 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ
	SC8SG-R61-T	10 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ
	SC210G-A	0.05 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ
	SC210G-B	5 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ
	SC42-SP34	0.01 cm <sup>-1</sup>	SC450G, SC202G, SC202S
	SC42-SP24, -SP26, -TC26	0.1 cm <sup>-1</sup>	SC450G, SC202G, SC202S
	SC42-EP14, -EP15, -SP16	1.0 cm <sup>-1</sup>	SC450G, SC202G, SC202S
	SC42-EP04, -FP04, TP04	10.0 cm <sup>-1</sup>	SC450G, SC202G, SC202S
	SX42-SX34	0.01 cm <sup>-1</sup>	SC450G, SC202G, SC202S
SX42-SX24	0.1 cm <sup>-1</sup>	SC450G, SC202G, SC202S	
Four-electrode method	SC8SG-R61-F	10 cm <sup>-1</sup>	SC450G, SC202G, SC202S/SC202SJ
	SC42-EP18	1.0 cm <sup>-1</sup>	SC450G, SC202G, SC202S
	SC42-EP08, -FP08, -TP08	10.0 cm <sup>-1</sup>	SC450G, SC202G, SC202S
Conductive method	ISC40G/ISC40GJ		ISC450G, ISC202G
	ISC40S/ISC40SJ		ISC202S/ISC202SJ (*)

(\*) The ISC402J is combined with the ISC202SJ.



NOTE:  
The bar graph at the left shows the range of the upper range limit of each sensor. For example, in the case of SC8SG-R61, the measuring range is from 0-1 mS/cm to 0-1 S/cm. In measurement in high conductivity range, polluted solution may affect measured values of any sensors. C represents cell constant.

Note that when used in combination with the SC100 converter, the SC4AJ sensor has different measuring range depending on the material and so forth.

\*1 : In case of the combination with the SC450G, SC202G, or SC202SJ

\*2 : In case of the combination with the SC100 (Titanium)

\*3 : In case of the combination with the SC100 (SUS)

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Figure 5.1 Range ability of conductivity sensors

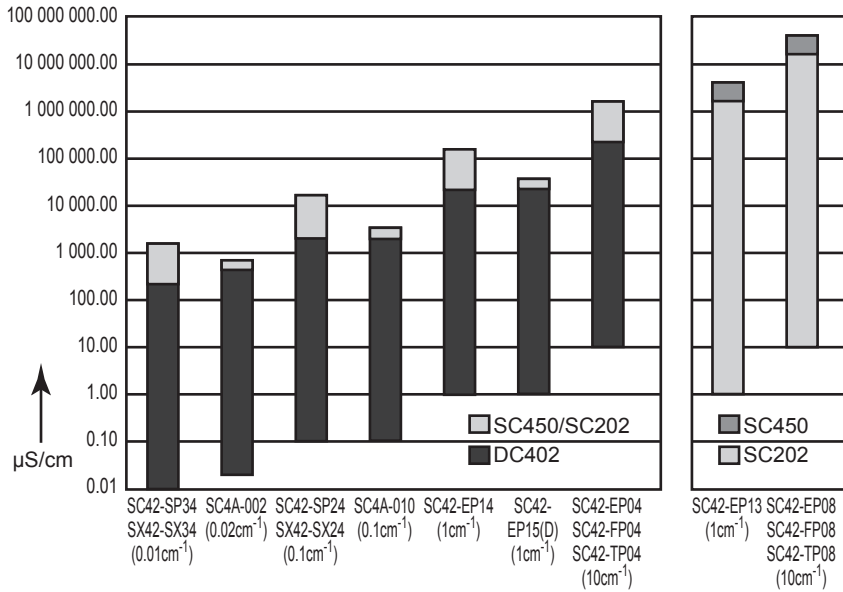


Figure 5.2 Range ability of conductivity sensors (For excluding Japan)

## 5.3 Sensor Installation Issues

### 5.3.1 Contacting Sensor Installations

Air bubbles in the process will interfere with the continuity between the sensor electrodes causing a noisy and erroneous measurement. Care should be taken to eliminate these air bubbles by proper installation of the sensor or additional measures such as providing an overflow tank, as shown in Figure 5.3.

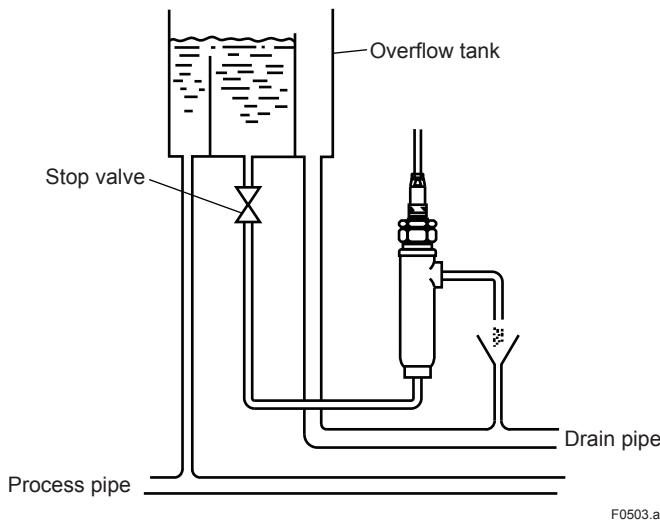


Figure 5.3 Example of Piping for the Case where Many Air Bubbles are Contained in Measurement Solution

### 5.3.2 Inductive Sensor Installation

An inductive conductivity sensor is donut-shaped sensor and function best when installed with the donut at a right angle to the direction of the process flow (see Figure 5.4).

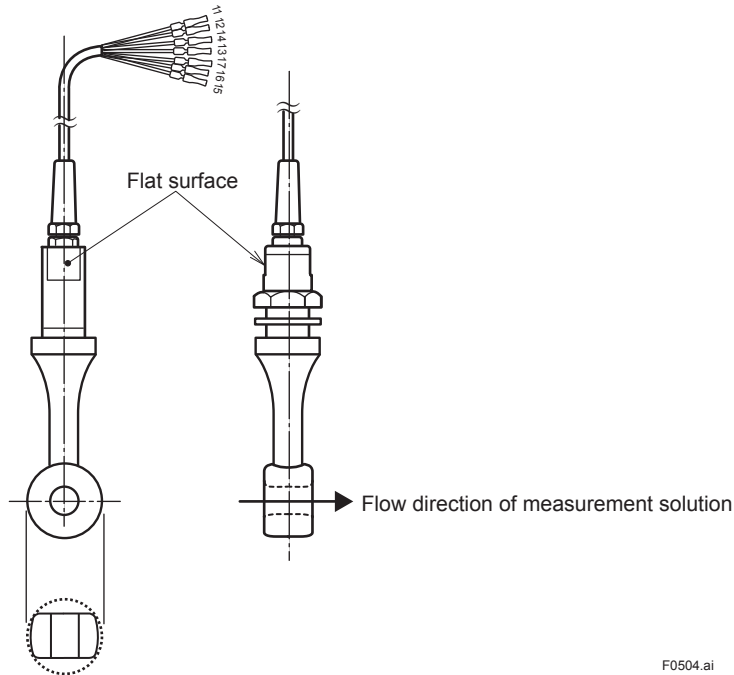


Figure 5.4 Installation Direction of Sensor

F0504.ai

The distance (d) between the sensor and the pipe wall shall be at least 30 mm (see Figure 5.5). If this requirement cannot be met for the distance (d), see “Adjusting Cell Constant” below.

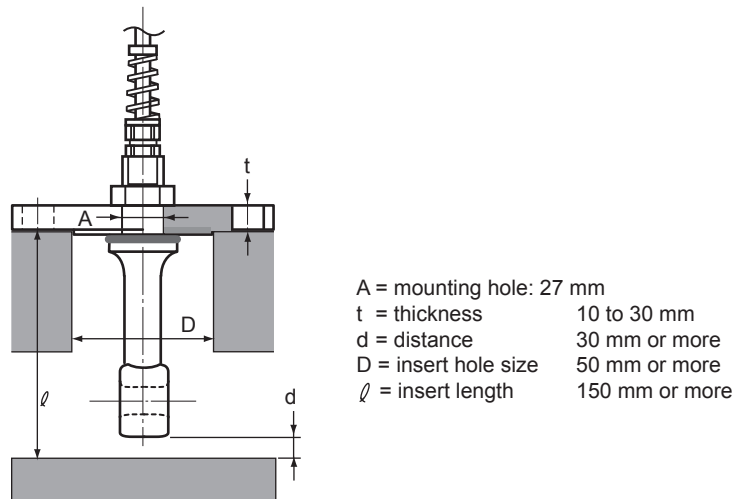


Figure 5.5 Flange Mounting Example

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## ■ Adjusting Cell Factor

Inductive sensors do not have a cell constant in the same sense as a contacting sensor does. Instead, it is manufactured with a nominal cell factor of  $1.88 \text{ cm}^{-1}$ . This factor is affected by the material of the process pipe or tank and how close the “donut” is mounted to the wall of the pipe or tank. If a distance of 30 mm is possible, then the cell factor is unaffected. If this distance cannot be met, an on-line calibration must be performed allowing the inductive conductivity converter (or transmitter) to calculate a new cell factor based on the installation conditions. This new factor is used to perform conductivity measurement.

If on-line calibration is not possible, input a cell factor in the converter (or transmitter) in accordance with the instructions described below.

- If the sensor is to be installed in the standard stainless steel holder (ISC40FF-S), the cell factor will be about 7% less. Input a value that is 7% less than the value indicated on the label of the sensor cable.
- If the sensor is to be installed in the standard polypropylene holder (ISC40FF-P), the cell factor is about 1% greater. Input a value that is 1% greater than the value indicated on the label of the sensor cable.
- If the sensor is to be installed in a pipe (conductive or non-conductive), mount it in the direction as shown in Figure 5.6 and use the graph to determine the cell factor to be programmed in the converter (transmitter).

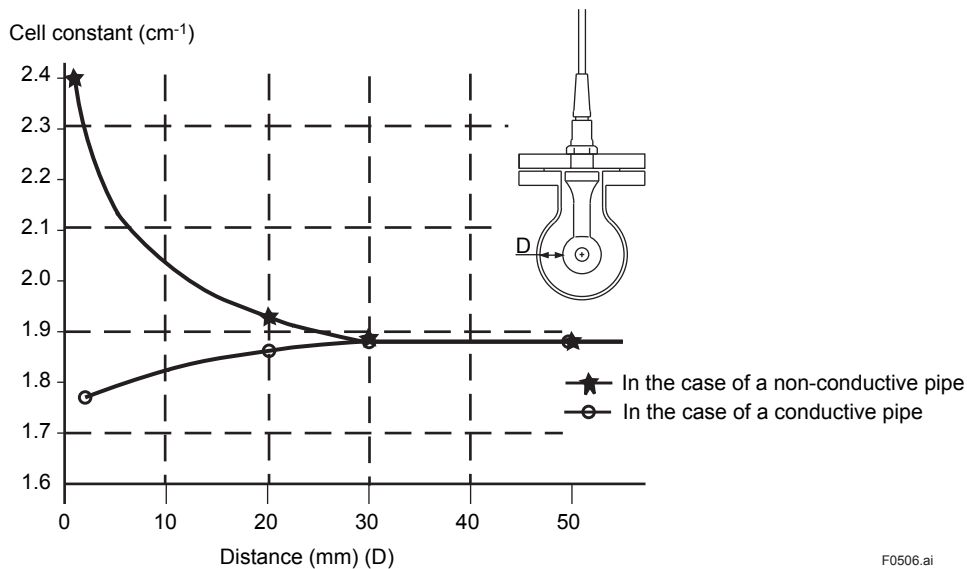


Figure 5.6 Cell Constant when Installing on Pipe (reference value)

F0506.ai

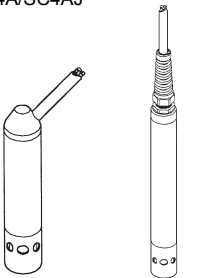
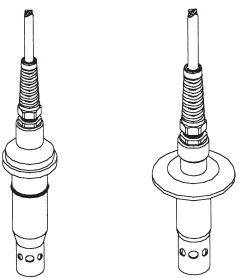
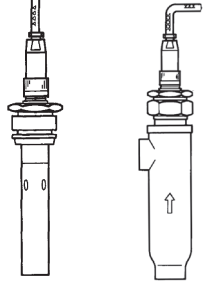

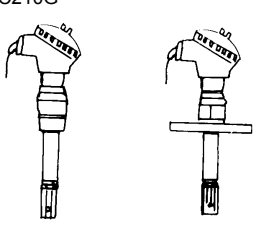
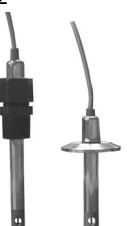

# 6. System Configuration of Contacting Conductivity Analyzers

There are two standard contacting conductivity instruments versions used for process control.

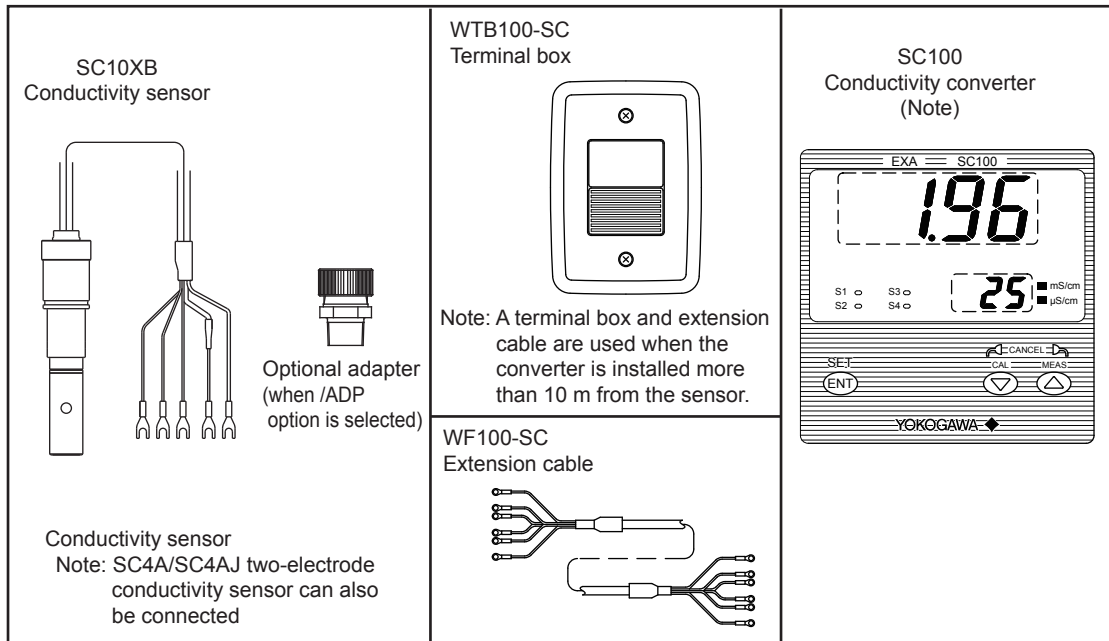
- (1) “Four-wire” (mains powered, 90-264 VAC) conductivity converter system with 4-20mA outputs and dry alarm contacts. This version comes in both ½ DIN and ¼ DIN configurations for wall, pipe and panel mounting.
- (2) “Two-wire” (24 VDC, loop powered) conductivity field transmitter suitable for general purpose, Class 1, Div 2 or Class 1 Div 1 areas. Comes in 4-20mA, HART, Foundation Fieldbus or Profibus versions.

## 6.1 Four-Wire Contacting Conductivity Analyzer System

### System Configuration

Conductivity sensors						Conductivity converter	
<p>SC4A/SC4AJ</p>  <p>Adapter mounting      Adapter mounting</p>  <p>Welding socket mounting      Welding clamp mounting</p>					<p>SC8SG</p>  <p>Screw-in type      Flow-through type</p>		<p>SC450G</p> 
<p>SC210G</p>  <p>Screw-in type      Flange type</p>		<p>SC42</p>  <p>Direct Insertion, Sanitary Fitting</p>		<p>SX42</p>  <p>Screw-in type, Flange type</p>			

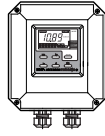
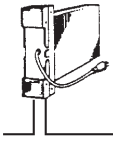

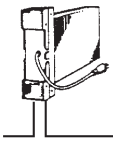
**System Configuration (Panel type)**



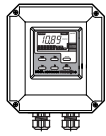
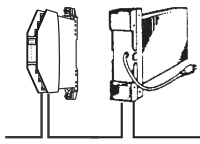
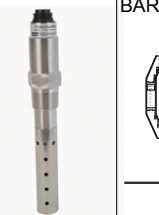
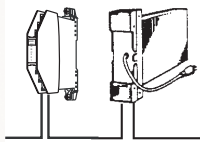
Note: The SC100 has been terminated.

# 6.2 Two-Wire Contacting Conductivity Analyzer System

## System Configuration (Non-explosion-proof type)

Conductivity sensors						Conductivity transmitter	Distributor
SC4A/SC4AJ		SC8SG		SC202G			 <p>Dedicated distributor PH201G</p> <p>Analog output 1 to 5 V DC Failure contact output Maintenance contact output</p>
Adapter mounting	Adapter mounting	Welding socket mounting	Welding clamp mounting	Screw-in type	Flow-through type		
SC210G		SC42		SX42			 <p>General type distributors SDBT, SDBS, etc.</p> <p>Analog output 1 to 5 V DC</p>
Screw-in type	Flange type	Flow-through type	Screw-in type with gate valve	Direct Insertion, Sanitary Fitting	Screw-in type, Flange type		

## System Configuration (Explosion-proof type)

Conductivity sensors						Conductivity transmitter	Distributor
SC4A/SC4AJ		SC8SG		SC202S/SC202SJ			 <p>Safety barrier Dedicated distributor PH201G BARD800</p> <p>Analog output 1 to 5 V DC Failure contact output Maintenance contact output</p>
Adapter mounting	Adapter mounting	Welding socket mounting	Welding clamp mounting	Screw-in type	Flow-through type		
SC210G		SC42		SX42			 <p>Safety barrier General type distributor SDBT BARD800</p> <p>Analog output 1 to 5 V DC</p>
Screw-in type	Flange type	Flow-through type	Screw-in type with gate valve	Direct Insertion, Sanitary Fitting	Screw-in type, Flange type		

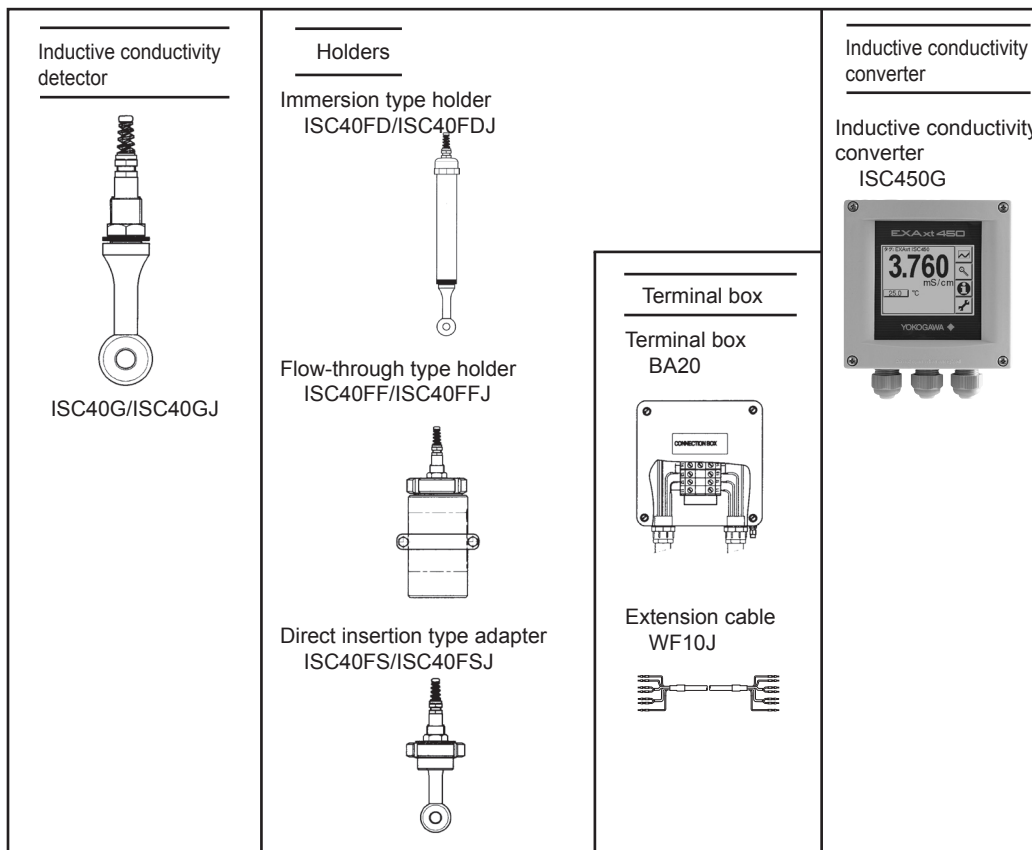
## 7. System Configuration of Inductive Conductivity Analyzers

There are two inductive conductivity analyzer systems for process control as follows.

- (1) “Four-wire inductive conductivity transmitter system” for general conductivity measurement system
- (2) “Two-wire inductive conductivity transmitter system” for conductivity measurement system requiring large-scale instrumentation and explosion-proof protection

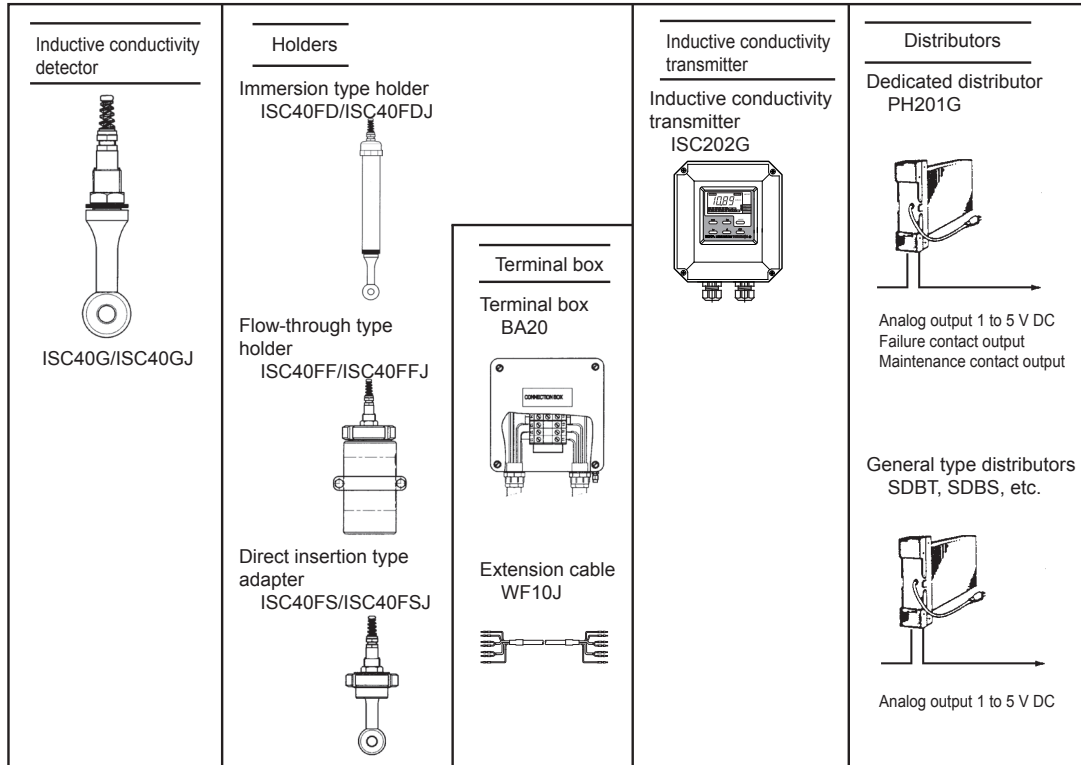
### 7.1 Four-Wire Inductive Conductivity Analyzer System

#### System Configuration

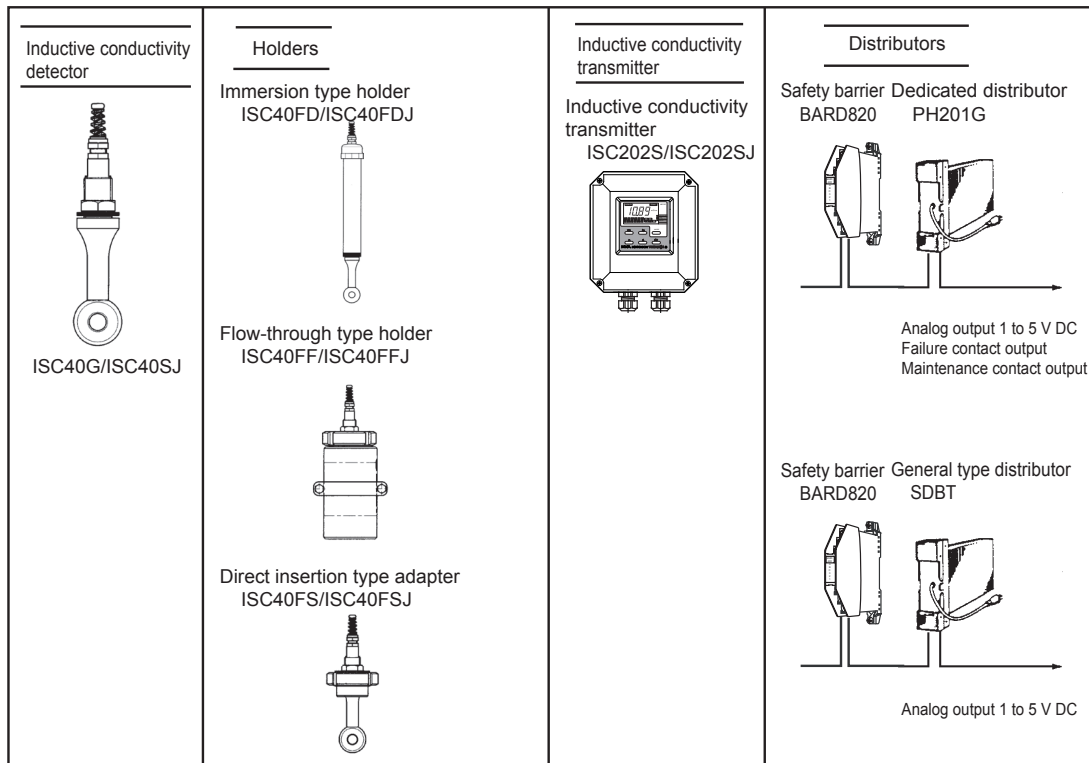


## 7.2 Two-Wire Inductive Conductivity Analyzer System

### System Configuration (Non-explosive-proof type)



### System Configuration (Explosion-proof type)



# 8. Functions and Features of EXAxt 450 (SC450G/ISC450G)

## 8.1 Human Machine Interface (HMI)

- An easy-to-view, easy-to-read large screen with backlight is employed.
- High-resolution graphics display. The trending graphics show data for up to two weeks.
- A touch panel method makes it easy to read information and configure settings.
- An interactive operation window eliminates the need of an operation manual.

### (1) Main screen

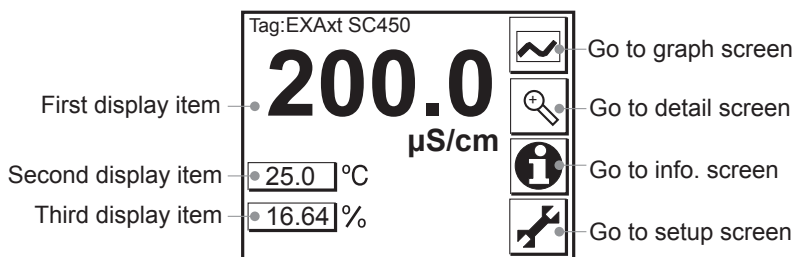


Figure 8.1 Main Screen

#### • Main Screen


First display item: Displays measured values (conductivity, temperature, or concentration) in large characters. User selectable

Second display item: Displays measured values (conductivity, temperature, or concentration) in small characters. User selectable

Third display item: Displays measured values (electrical conductivity, temperature, or concentration) in small characters. User selectable

Unit, tag number (user configurable), etc.

### (2) Trend Screen

Pressing the  button in the main screen changes the display into a graphical mode in which the average measured value is shown on a time scale. The real-time value is also digitally displayed in a text box.

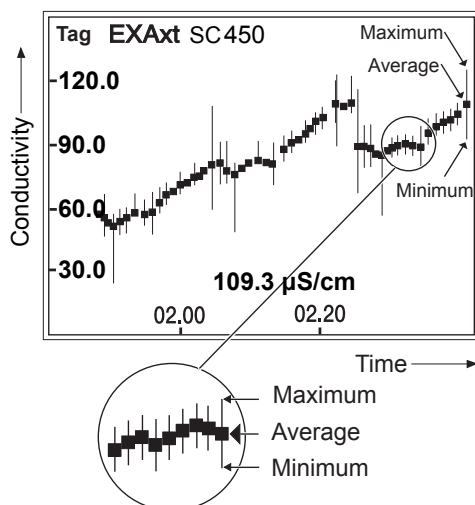


Figure 8.2 Trend Screen

#### • Trend screen display

Time scale (X-axis) (user selectable, 15 minutes to 2 weeks)

Value scale (Y-axis) (user selectable)

Tag No. (user selectable)

Real-time value

Average, maximum, and minimum measured values per unit time (time scale/51)

### (3) Detail Screen

The detail screen provides the following five screens including a screen showing “easy-to-read graphic display of output status” or “parameters for the current measurement.”

- Graphic display of output status
- Parameters for the current measurement
- Date of last calibration, recommended calibration date, scheduled calibration date
- Device ID, firmware version, HART device revision
- Logbook

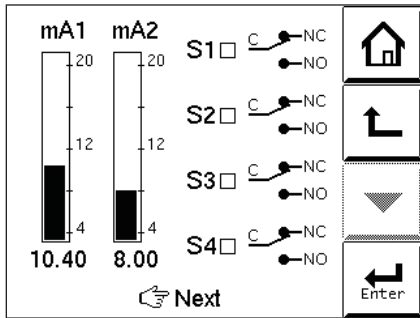


Figure 8.3 Detail Screen 1

This detail screen graphically displays the values of electric current output 1 (mA1) and 2 (mA2), and the current status of contacts 1 to 4.

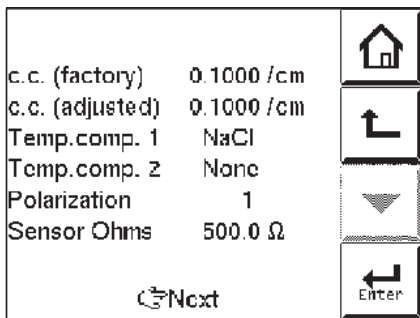


Figure 8.4 Detail Screen 2

This detail screen displays parameters for the current measurement.

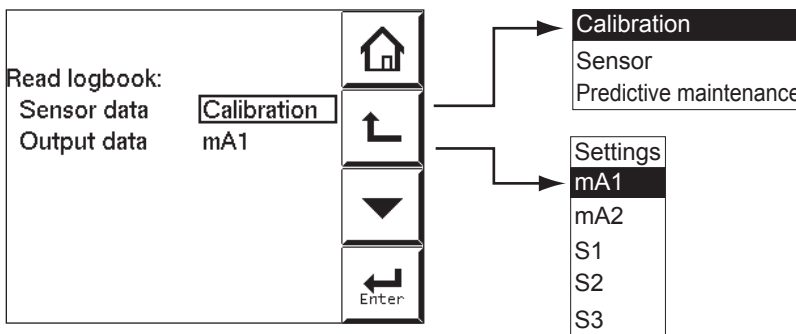






Figure 8.5 Detail Screen 3

For example, press the text box for calibration to display the pull-down menu as shown above. Scroll through the items with the ▼ key, and select the item to be displayed. Press the Enter key while the selected item is highlighted to display the logbook data.



### (4) Device Status Screen

This screen displays the diagnosis information on the converter and sensor.

The place of the  key in the main screen displays the marks  (Device information),  (Caution), or  (Error) depending on the status of the device. Press the displayed mark to see the detail information on that status.



**Information:** No error. Press this key to change to the status report screen in which “No error” is displayed.



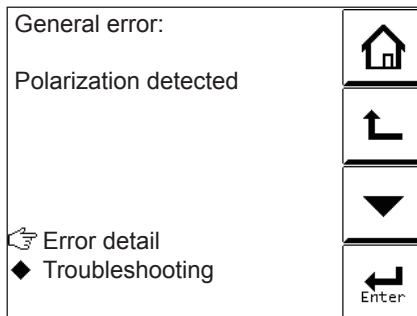
**Caution:** Display of Caution indicates maintenance is required. Press this key to change to the status report screen in which “General error” is displayed.



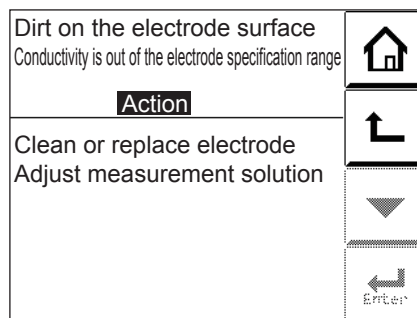
**Failure:** Indicates that a failure was found by the diagnosis function. Check the system. Press this key to change to the status report screen in which “General error” is displayed.



**Error detail:** Error detail and action to be taken  
Press “Error detail” to display the explanation and action to be taken.



**Figure 8.6 Display Example of “General Error”**



**Figure 8.7 Display Example of “Error Detail”**

## (5) Commissioning Screen

This screen is used to perform device calibration and maintenance and configure the device parameters. These operations can be protected by a password.

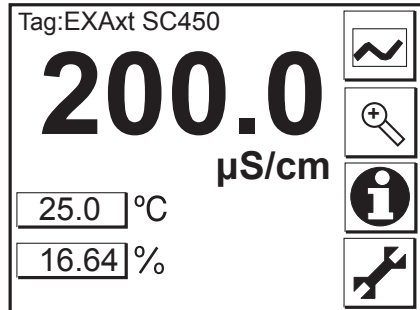



Figure 8.8 Main Screen

### Main Screen

This is a screen of the normal measurement status. Press the  key to access the screens below.

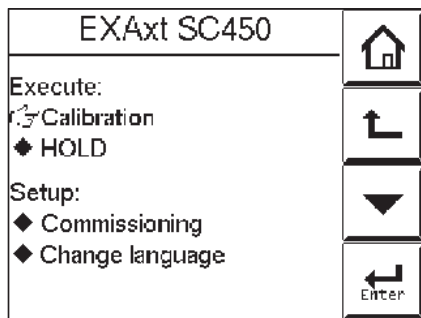


Figure 8.9 Primary Setup Screen

### Primary Setup Screen

This is a screen for performing calibration and maintenance. Execution – Calibration executes the calibration operation, and Execution – HOLD executes the hold operation. Press Commissioning to access the following screen. Access to Commissioning can be protected by a password.

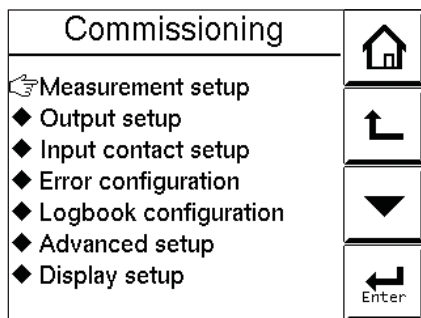


Figure 8.10 Commissioning Menu Screen

### Commissioning Menu Screen

This is a screen for setting parameters. While you are performing operation in this screen, the device is maintained in the hold status.

## 8.2 Logbook Function

The SC450G and ISC450G contain several logbooks to store history information on error messages, changed settings, and calibrations. The maintenance and replacement schedules of devices can be determined by referring to the logbooks.

Logbooks are classified as follows in order to make it easy to search for information.

- (1) Calibration logbook: Stores information on calibrations that were performed in the past. This can be used to monitor the long-term performance and lifetime of the sensor.
- (2) Sensor logbook: Stores the past parameter settings information of the sensor.
- (3) Predictive maintenance logbook: Stores the diagnosis information that is saved when the sensor diagnosis function of the SC450G is enabled. In the SC450G, data on polarization (caused by fouling) is saved once a day. Polarization indicates the degree of fouling so its information can be used for predictive maintenance schedules. Make sure that the sensor is always kept clean to ensure the best result can be obtained.
- (4) Settings logbook: Stores the past parameter settings information for analog outputs (mA1 and mA2) and contacts (S1 to S3). This can be used to track changes in the performance caused by changes in the settings.
- (5) mA1/mA2 logbook: Stores dynamic events concerning analog outputs.
- (6) S1/S2/S3 logbook: Stores dynamic events concerning the contacts.

Up to 5 events are displayed on one page (one screen) of a logbook. Up to 50 events can be stored in each logbook, and past events are displayed on up to 10 pages (depending on the item).

## 8.3 Temperature Compensation for Measurement Solution

### (1) NaCl Temperature Compensation

The temperature compensation calculation function is based on the NaCl temperature coefficient table (IEC 60746-3). This non-linear compensation method can be applied to almost all applications from (Ultra) pure water to concentrated salt solutions. Even for most diluted acid and alkaline's.

**Table 8.1 NaCl Compensation (IEC 60743-3 at a reference temperature of 25°C)**

T	Kt	$\alpha$	T	Kt	$\alpha$	T	Kt	$\alpha$
0	0.54	1.8	60	1.76	2.2	130	3.34	2.2
10	0.72	1.9	70	1.99	2.2	140	3.56	2.2
20	0.90	2.0	80	2.22	2.2	150	3.79	2.2
25	1.00	—	90	2.45	2.2	160	4.03	2.2
30	1.10	2.0	100	2.68	2.2	170	4.23	2.2
40	1.31	2.0	110	2.90	2.2	180	4.42	2.2
50	1.53	2.1	120	3.12	2.2	190	4.61	2.2
						200	4.78	2.2

If the temperature compensation based on the NaCl temperature coefficient table is not suitable for your application, the following compensation method is available.

## (2) Matrix Temperature Compensation

The SC450G and ISC450G provide a matrix temperature compensation (conductivity functions with respect to the concentration and temperature) function to enable correct temperature compensation for various applications.

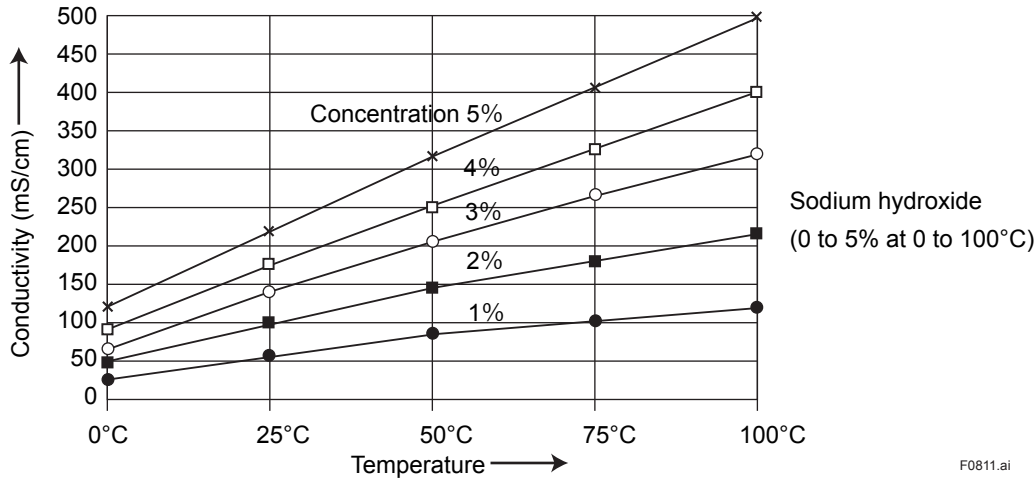


Figure 8.11 Example of Matrix Temperature Compensation

Matrix temperature compensation lets you select the matrix from 13 types of preset matrices and two types of user-configurable matrices. Select the applicable matrix by taking a look at the substances to be measured and concentration ranges.

Table 8.2 Matrices Preset in SC450G

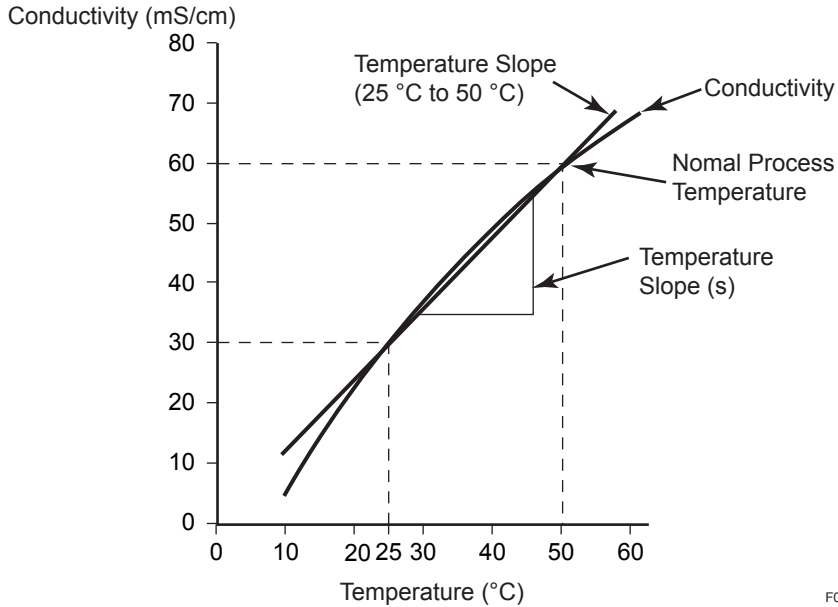
Solution name	Concentration range	Temperature range
Ammonia	0 to 50 ppb	0 to 90 °C
Ammonia	15 to 30 %	10 to 50 °C
Morpholine	0 to 500 ppb	0 to 90 °C
Sulfuric acid	0 to 27 %	0 to 100 °C
Sulfuric acid	39 to 85 %	-18 to 116 °C
Sulfuric acid	93 to 100 %	10 to 90 °C
Sodium hydroxide	0 to 15 %	0 to 100 °C
Sodium hydroxide	25 to 50 %	0 to 80 °C
Hydrochloric acid	0 to 200 ppb	0 to 100 °C
Hydrochloric acid	0 to 18 %	-10 to 65 °C
Hydrochloric acid	24 to 44 %	-20 to 65 °C
Nitric acid	0 to 25 %	0 to 80 °C
Nitric acid	35 to 80 %	-16 to 60 °C

Table 8.3 Matrices Preset in ISC450G

Solution name	Concentration range	Temperature range
Sulfuric acid	1 to 5 %	0 to 100 °C
Sulfuric acid	1 to 27 %	-1 to 99 °C
Sulfuric acid	39 to 85 %	-18 to 116 °C
Sulfuric acid	93 to 100 %	10 to 90 °C
Hydrochloric acid	1 to 5 %	0 to 60 °C
Hydrochloric acid	0 to 18 %	-10 to 65 °C
Hydrochloric acid	24 to 44 %	-20 to 65 °C
Nitric acid	1 to 5 %	0 to 80 °C
Nitric acid	0 to 25 %	0 to 80 °C
Nitric acid	35 to 85 %	-16 to 60 °C
Sodium hydroxide	1 to 5 %	0 to 100 °C
Sodium hydroxide	0 to 15 %	0 to 100 °C
Sodium hydroxide	25 to 50 %	0 to 80 °C

### (3) Linear Temperature Compensation Coefficient

When the composition of the process is not fluctuating and the NaCl compensation is not good enough the TC of the process can be determined and entered into the analyzer. By measuring the conductivity of the process at 2 different temperature (covering the process temperature) the change in conductivity per °C can be determined.



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Figure 8.12 Temperature Compensation for Conductivity Increase with Temperature

**Example**

Acid	1.0 - 1.6 %/°C
Bases	1.8 - 2.2 %/°C
Salts	2.2 - 3.0 %/°C
Fresh Water	2.0 %/°C

The temperature coefficient is calculated by the following equation and expressed in %/°C.

$$\alpha = \frac{K_t - K_{ref}}{T - T_{ref}} \times \frac{100}{K_{ref}}$$

α = Temperature compensation coefficient (%/°C)  
 T = Measured temperature (°C)  
 K<sub>t</sub> = Conductivity at measurement temperature

T<sub>ref</sub> = Reference temperature  
 K<sub>ref</sub> = Conductivity at reference temperature

## 8.4 WFI Monitoring (USP <645> Directive)

The directive for online monitoring of WFI using a conductivity analyzer was published in the USP23 standard. According to this standard, water purity is classified into three levels.

Level 1 requires monitoring by conductivity measurement. If the conductivity exceeds the limit value, a water quality test of WFI by manual analysis is required. Both compensated and uncompensated conductivity values can be read from the display, as can the solution temperature. Alarms can be set to indicate that the signal is nearing the USP <645> limit, and there is a trip alarm to indicate that the limit is exceeded. USP <645> determines a level of uncompensated conductivity for each temperature. The water must be below this level to be acceptable. This curve is preprogrammed into the transmitters and is used in the setpoint calculations for the alarms and trip.

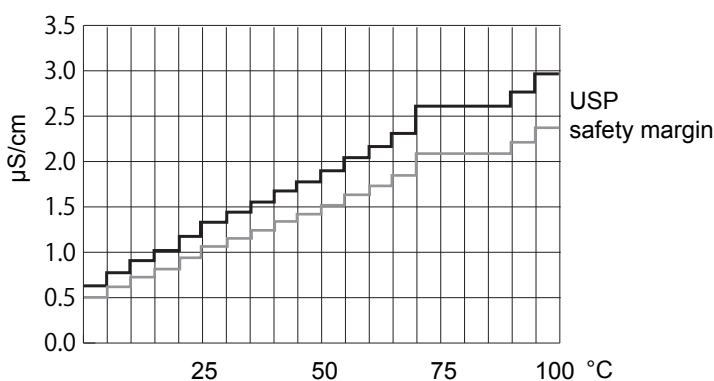


Figure 8.13 USP Safety Margin

### ● USP

USP stands for the United States Pharmacopeial Convention, which is responsible for the publication of the guidelines for the pharmaceutical industry.

It is strongly recommended to follow these guidelines in the U.S. pharmaceutical market. USP has important implications when considering the global pharmaceutical market including that of the U.S.

### ● USP <645> makes up the guidelines for conductivity measurement.

USP23 <645> (see <645> in USP23) specifies the method of controlling the water quality using conductivity measurement in place of conventional complex analysis methods.

### ● WFI

WFI stands for Water for Injection. The USP23 defines WFI as “water purified by distillation or reverse osmosis. It contains no added substances.”

## 8.5 Output Function

### (1) Current Output

The SC450G conductivity converter and ISC450G inductive conductivity converter provide two 4-to-20-mA outputs for display, recording, and control.

The following measurement parameters are available for selection (If resistivity is to be measured, concentration cannot be selected).

- Conductivity or resistivity
- Concentration
- Temperature

Furthermore, the following functions can also be selected.

- HOLD function: Holds the last measured value or arbitrary fixed value as the output signal
- Burnout function: Outputs a burn-up or burn-down signal in the event of a failure
- Programmable output function: Arbitrarily set by the user to linearize the output when using the converter as a concentration meter.

The following shows an example of a 21-point line segment that linearizes the output for a concentration curve line.

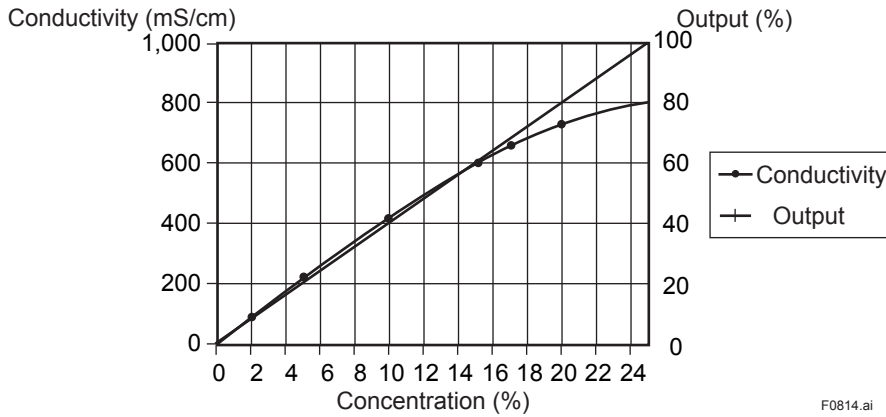


Figure 8.14 Linearizing Output (Example of 0 to 25% sulfuric acid)

Table 8.4 Example: Setting Detail of 21-Point Line Segment Output

Output (%)	4 to 20 mA	Concentration (%)	Conductivity value (mS/cm)
0	4	0	0
5	4.8	1.25	60
10	5.6	2.5	113
15	6.4	3.75	180
20	7.2	5	237
25	8	6.25	290
30	8.8	7.5	335
35	9.6	8.75	383
40	10.4	10	424
45	11.2	11.25	466
50	12	12.5	515
55	12.8	13.75	555
60	13.6	15	590
65	14.4	16.25	625
70	15.2	17.5	655
75	16	18.75	685
80	16.8	20	718
85	17.6	21.25	735
90	18.4	22.5	755
95	19.2	23.75	775
100	20.0	25	791

## (2) Contact Output

The SC450G provides four SPDT contact outputs. All the contact outputs can be set for the alarm and control functions. If the measured values for contacts S1, S2, and S3 are larger than the setpoint, a change to the excitation state occurs. These are usually used for the high/low limit alarm and control functions. Contact S4 is a failsafe contact that changes to the alarm state when a change to the non-excitation state occurs. This contact is usually used for notifying of the failure state.

### (3) Control Function

The SC450G provides a process control function. Current output and contact output make up a PID control output. When using a contact for process control, the contact output is used for duty cycle control or pulse frequency control.

- **Duty Cycle Control**

Duty cycle control is usually used to operate electromagnetic valves or continually operate liquid injection pumps. The on-off cycle can be set from 1 second to 30 minutes. The on-to-off ratio (duty cycle) is controlled by the PID control function.

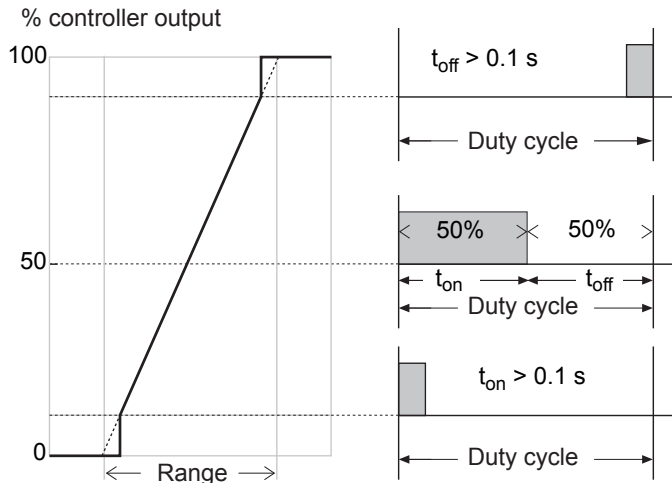


Figure 8.15 Duty Cycle Control

- **Pulse Frequency Control**

This is used when feeding chemical with a pulsating pump. One pulse represents a specified amount of reagent. The maximum number of pulses per minute can be selected from 1 to 70 pulses per minute. The pulse frequency is determined by the PID function of the analyzer.

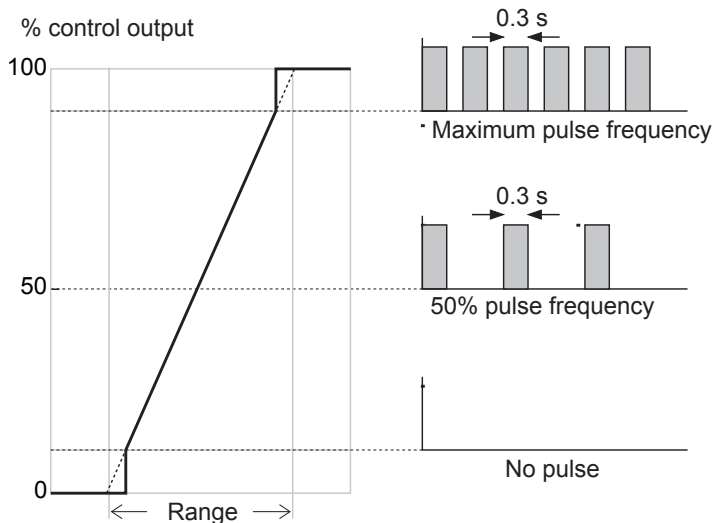


Figure 8.16 Pulse Frequency Control

“Proportional band,” “Integral time,” and “Derivative time” are set in the control menu of the device.



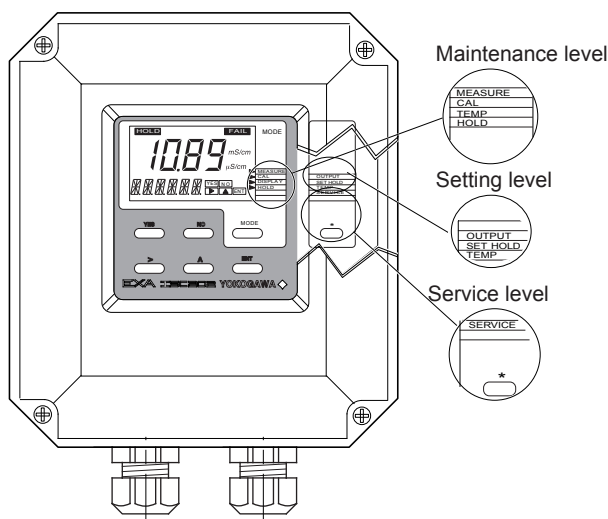
# 9. Functions and Features of EXA sc/EXA isc

## 9.1 Three-Level Operation Function

The SC202G/SC202S/SC202SJ conductivity transmitters and ISC202G/ISC202S/ISC202SJ inductive conductivity transmitters introduced a three-level operation system, which retains the simple operation of conventional analog transmitters, while making the best use of the advantages of a microprocessor.

In order to prevent operation errors, less-frequently used functions are separated from routine operations, and each operation can be performed according to the operation level to be used.

A three-digit password can be set for each of the three operation levels to prevent unauthorized access.



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Figure 9.1 Three-Level Operations

### (1) Maintenance Level

The daily maintenance function lets you perform operation by pressing the operation key without removing the front cover.

Use: Daily operation and checking

Operation: Simple interactive operation with the button in the screen while the front cover is closed.

### (2) Setting Level

A function required to set process operation parameters of the instrument is hidden inside the cover in order to prevent unnecessary changes. Removing the front cover reveals a parameter setting menu and setting level switching key (a button marked with an asterisk \*).

Use: Setting routine process operation parameters

Operation: Open the front cover, and press the setting level switching switch to start the menu

### (3) Service Level

This level can be selected by the service level, and accessed by the service code.

Use: Dedicated for setting special functions

Operation: Input the service code, and then configure the setting

Table 9.1 Overview of Operations on Each Level

Level	Display	Function
Maintenance level	CALB	Standard solution calibration or sample calibration
	DISP	Auxiliary data reading or message display setting
	HOLD	HOLD on/off switching (when enabled)
Setting level	OUTPUT	Change output range
	HOLD	Enable HOLD function
	TEMP	Select temperature compensation method
Service level	SERV	Transmitter detail setting

## 9.2 Temperature Compensation for Measurement Solution

### (1) NaCl Temperature Compensation

A non-linear temperature compensation calculation function based on the NaCl temperature coefficient table (compliant with IEC 60746-3) is set at the time of shipment for SC202G/SC202S/SC202SJ conductivity transmitters and ISC202G/ISC202S/ISC202SJ inductive conductivity transmitters. This compensation method can be used for almost all measurements, and any adjustments in the field are usually not required. If the temperature compensation based on the NaCl table is not suitable for your application, another compensation method is also available as described below.

### (2) Matrix Temperature Compensation for Conductivity Transmitters

The SC202G/SC202S/SC202SJ conductivity transmitters and ISC202G/ISC202S/ISC202SJ inductive conductivity transmitters provide a matrix temperature compensation function (based on functions of conductivity for concentration and temperature) in order to enable correct temperature compensation for various applications.

The following options are available for selection for pure water applications.

- Hydrochloric acid (HCl) compensation: 0 to 80 °C
- Ammonia compensation: 0 to 80 °C
- Morpholine compensation: 0 to 80 °C

The following options are available for selection for high-conductivity measurements.

- Hydrochloric acid (HCl) compensation: 1 to 5%, 0 to 60 °C
- Sodium hydroxide compensation: 1 to 5 %, 0 to 100 °C
- 25-point (5 x 5) user-programmable matrix

This matrix can be programmed by entering temperature values at 5 points, and the conductivity for each concentration at those temperatures.

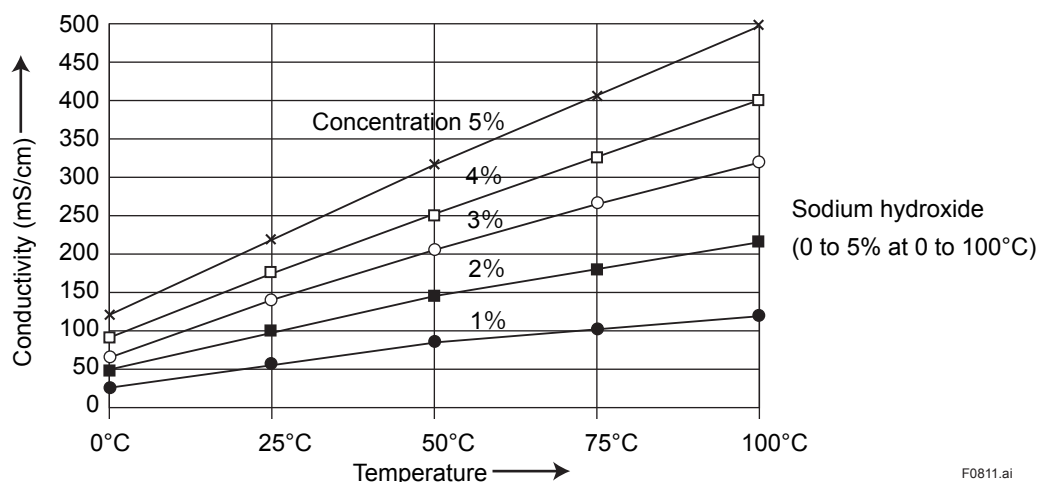


Figure 9.2 Example of Matrix Temperature Compensation

Table 9.2 Details of Matrix Data Preset in SC202G/SC202S/SC202SJ

Solution name	Temperature (°C)	Data 1	Data 2	Data 3	Data 4	Data 5
Hydrochloride acid/ pure water (Cation) Selection 1		0 ppb	4 ppb	10 ppb	20 ppb	100 ppb
	0	0.0116 $\mu$ S	0.0228 $\mu$ S	0.0472 $\mu$ S	0.0911 $\mu$ S	0.450 $\mu$ S
	10	0.0230 $\mu$ S	0.0352 $\mu$ S	0.0631 $\mu$ S	0.116 $\mu$ S	0.565 $\mu$ S
	20	0.0419 $\mu$ S	0.0550 $\mu$ S	0.0844 $\mu$ S	0.145 $\mu$ S	0.677 $\mu$ S
	30	0.0710 $\mu$ S	0.085 $\mu$ S	0.115 $\mu$ S	0.179 $\mu$ S	0.787 $\mu$ S
	40	0.1135 $\mu$ S	0.129 $\mu$ S	0.159 $\mu$ S	0.225 $\mu$ S	0.897 $\mu$ S
	50	0.173 $\mu$ S	0.190 $\mu$ S	0.220 $\mu$ S	0.286 $\mu$ S	1.008 $\mu$ S
	60	0.251 $\mu$ S	0.271 $\mu$ S	0.302 $\mu$ S	0.366 $\mu$ S	1.123 $\mu$ S
	70	0.350 $\mu$ S	0.375 $\mu$ S	0.406 $\mu$ S	0.469 $\mu$ S	1.244 $\mu$ S
80	0.471 $\mu$ S	0.502 $\mu$ S	0.533 $\mu$ S	0.595 $\mu$ S	1.373 $\mu$ S	
Ammonium/pure water Selection 2		0 ppb	2 ppb	5 ppb	10 ppb	50 ppb
	0	0.0116 $\mu$ S	0.0229 $\mu$ S	0.0502 $\mu$ S	0.0966 $\mu$ S	0.423 $\mu$ S
	10	0.0230 $\mu$ S	0.0337 $\mu$ S	0.0651 $\mu$ S	0.122 $\mu$ S	0.535 $\mu$ S
	20	0.0419 $\mu$ S	0.0512 $\mu$ S	0.0842 $\mu$ S	0.150 $\mu$ S	0.648 $\mu$ S
	30	0.0710 $\mu$ S	0.0788 $\mu$ S	0.111 $\mu$ S	0.181 $\mu$ S	0.758 $\mu$ S
	40	0.1135 $\mu$ S	0.120 $\mu$ S	0.149 $\mu$ S	0.221 $\mu$ S	0.866 $\mu$ S
	50	0.173 $\mu$ S	0.178 $\mu$ S	0.203 $\mu$ S	0.273 $\mu$ S	0.974 $\mu$ S
	60	0.251 $\mu$ S	0.256 $\mu$ S	0.278 $\mu$ S	0.344 $\mu$ S	1.090 $\mu$ S
	70	0.350 $\mu$ S	0.356 $\mu$ S	0.377 $\mu$ S	0.439 $\mu$ S	1.225 $\mu$ S
80	0.471 $\mu$ S	0.479 $\mu$ S	0.501 $\mu$ S	0.563 $\mu$ S	1.393 $\mu$ S	
Morpholine/pure water Selection 3		0 ppb	20 ppb	50 ppb	100 ppb	500 ppb
	0	0.0116 $\mu$ S	0.272 $\mu$ S	0.0565 $\mu$ S	0.0963 $\mu$ S	0.288 $\mu$ S
	10	0.0230 $\mu$ S	0.0402 $\mu$ S	0.0807 $\mu$ S	0.139 $\mu$ S	0.431 $\mu$ S
	20	0.0419 $\mu$ S	0.0584 $\mu$ S	0.108 $\mu$ S	0.185 $\mu$ S	0.592 $\mu$ S
	30	0.0710 $\mu$ S	0.0851 $\mu$ S	0.140 $\mu$ S	0.235 $\mu$ S	0.763 $\mu$ S
	40	0.1135 $\mu$ S	0.124 $\mu$ S	0.181 $\mu$ S	0.289 $\mu$ S	0.938 $\mu$ S
	50	0.173 $\mu$ S	0.181 $\mu$ S	0.234 $\mu$ S	0.351 $\mu$ S	1.12 $\mu$ S
	60	0.251 $\mu$ S	0.257 $\mu$ S	0.306 $\mu$ S	0.427 $\mu$ S	1.31 $\mu$ S
	70	0.350 $\mu$ S	0.357 $\mu$ S	0.403 $\mu$ S	0.526 $\mu$ S	1.52 $\mu$ S
80	0.471 $\mu$ S	0.481 $\mu$ S	0.528 $\mu$ S	0.654 $\mu$ S	1.77 $\mu$ S	
Hydrochloride acid Selection 4		1 %	2 %	3 %	4 %	5 %
	0	62 mS	125 mS	179 mS	229 mS	273 mS
	15	91 mS	173 mS	248 mS	317 mS	379 mS
	30	114 mS	217 mS	313 mS	401 mS	477 mS
	45	135 mS	260 mS	370 mS	474 mS	565 mS
60	159 mS	301 mS	430 mS	549 mS	666 mS	
Sodium hydroxide Selection 5		1 %	2 %	3 %	4 %	5 %
	0	31 mS	61 mS	86 mS	108 mS	127 mS
	25	53 mS	101 mS	145 mS	185 mS	223 mS
	50	76 mS	141 mS	207 mS	268 mS	319 mS
	75	97.5 mS	182 mS	264 mS	339 mS	408 mS
	100	119 mS	223 mS	318 mS	410 mS	495 mS

### (3) Matrix Temperature Compensation for Inductive Conductive Transmitters

Temperature compensation curves for several types of typical process solutions as listed below are pre-set in the ISC202G/ISC202S/ISC202SJ inductive conductivity transmitters. These can be easily set by selecting them from the service menu.

Sulfuric acid	H <sub>2</sub> SO <sub>4</sub>	0.5 to 5.0 %	0 to 100 °C
Sulfuric acid	H <sub>2</sub> SO <sub>4</sub>	2.5 to 25.0 %	0 to 100 °C
Hydrochloride acid	HCl	0.5 to 5.0 %	0 to 60 °C
Hydrochloride acid	HCl	1.0 to 20.0 %	0 to 60 °C
Nitric acid	HNO <sub>3</sub>	0.5 to 5.0 %	0 to 80 °C
Nitric acid	HNO <sub>3</sub>	2.5 to 25.0 %	0 to 80 °C
Sodium hydroxide	NaOH	0.5 to 5.0 %	0 to 100 °C
Sodium hydroxide	NaOH	0.5 to 15.0 %	0 to 100 °C

If any of the above temperature compensation curves cannot be applied to your process, a temperature compensation curve specific to your process can be created by configuring the setting for a simple matrix table of temperatures for conductivity. In this way, measurement accuracy can be fine-tuned even for special process conditions.

Table 9.3 Details of Matrix Data Preset in ISC202G/ISC202S/ISC202SJ

Solution name	Temperature (°C)	Data 1	Data 2	Data 3	Data 4	Data 5
Sulfuric acid (1) H <sub>2</sub> SO <sub>4</sub> 0.5 to 5 %		1 %	2 %	3 %	4 %	5 %
	0	33.8 mS	63.5 mS	95.0 mS	124.5 mS	154.0 mS
	25	47.0 mS	92.3 mS	135.3 mS	178.0 mS	218.0 mS
	50	57.5 mS	112.5 mS	166.0 mS	220.0 mS	270.0 mS
	75	63.7 mS	126.0 mS	188.5 mS	249.0 mS	307.0 mS
	100	68.0 mS	137.5 mS	203.0 mS	273.0 mS	336.0 mS
Sulfuric acid (2) H <sub>2</sub> SO <sub>4</sub> 2.5 to 25 %		5 %	10 %	15 %	20 %	25 %
	0	154.0 mS	292.0 mS	398.0 mS	475.0 mS	516.0 mS
	25	218.0 mS	424.0 mS	590.0 mS	718.0 mS	791.0 mS
	50	270.0 mS	524.0 mS	749.0 mS	929.0 mS	1043.0 mS
	75	307.0 mS	612.0 mS	871.0 mS	1094.0 mS	1251.0 mS
	100	336.0 mS	673.0 mS	963.0 mS	1221.0 mS	1418.0 mS
Hydrochloric acid (3) HCl 0.5 to 5 %		1 %	2 %	3 %	4 %	5 %
	0	65 mS	125 mS	179 mS	229 mS	273 mS
	15	91 mS	173 mS	248 mS	317 mS	379 mS
	30	114 mS	217 mS	313 mS	401 mS	477 mS
	45	135 mS	260 mS	370 mS	474 mS	565 mS
	60	159 mS	301 mS	430 mS	549 mS	666 mS
Hydrochloric acid (4) HCl 1 to 20 %		2 %	4 %	8 %	12 %	20 %
	0	125 mS	279 mS	387 mS	479 mS	558 mS
	15	173 mS	317 mS	527 mS	650 mS	745 mS
	30	217 mS	401 mS	660 mS	820 mS	938 mS
	45	260 mS	474 mS	793 mS	985 mS	1130 mS
	60	301 mS	549 mS	919 mS	1146 mS	1315 mS
Nitric acid (5) HNO <sub>3</sub> 0.5 to 5 %		1 %	2 %	3 %	4 %	5 %
	0	39.5 mS	76.1 mS	113.4 mS	147.2 mS	179.5 mS
	20	57.4 mS	108.5 mS	161.4 mS	210.0 mS	258.0 mS
	40	81.4 mS	148.1 mS	215.0 mS	275.0 mS	330.0 mS
	60	99.9 mS	180.8 mS	260.0 mS	331.0 mS	397.0 mS
	80	127.8 mS	217.0 mS	299.0 mS	374.0 mS	448.0 mS
Nitric acid (6) HNO <sub>3</sub> 2.5 to 25 %		5 %	10 %	15 %	20 %	25 %
	0	179.5 mS	330.0 mS	448.0 mS	523.0 mS	575.0 mS
	20	258.0 mS	462.0 mS	616.0 mS	717.0 mS	794.0 mS
	40	330.0 mS	586.0 mS	778.0 mS	902.0 mS	1004.0 mS
	60	397.0 mS	696.0 mS	929.0 mS	1079.0 mS	1206.0 mS
	80	448.0 mS	795.0 mS	1075.0 mS	1263.0 mS	1426.0 mS
Sodium hydroxide (7) NaOH 0.5 to 5 %		1 %	2 %	3 %	4 %	5 %
	0	31.0 mS	61.0 mS	86.0 mS	105.0 mS	127.0 mS
	25	53.0 mS	101.0 mS	145.0 mS	185.0 mS	223.0 mS
	50	76.0 mS	141.0 mS	207.0 mS	268.0 mS	319.0 mS
	75	97.5 mS	182.0 mS	264.0 mS	339.0 mS	408.0 mS
	100	119.0 mS	223.0 mS	318.0 mS	410.0 mS	495.0 mS
Sodium hydroxide (8) NaOH 0.5 to 15 %		1 %	3 %	6 %	10 %	15 %
	0	31.0 mS	86.0 mS	146.0 mS	195.0 mS	215.0 mS
	25	53.0 mS	145.0 mS	256.0 mS	359.0 mS	412.0 mS
	50	76.0 mS	207.0 mS	368.0 mS	528.0 mS	647.0 mS
	75	97.5 mS	264.0 mS	473.0 mS	692.0 mS	897.0 mS]
	100	119.0 mS	318.0 mS	575.0 mS	847.0 mS	1134.0 mS

#### (4) Manual Temperature Compensation

Independent temperature coefficients can be set for 2 outputs by manually entering the temperature coefficients. Either enter known temperature coefficients on the service level before starting measurement, or adjust the temperature coefficients by calibration of the actual measurement solutions. Furthermore, more accurate measurements can be performed because reference temperatures can be freely set.

## 9.3 Output Function

### (1) Current Output

The SC202G/SC202S/SC202SJ conductivity transmitters and ISC202G/ISC202S/ISC202SJ inductive conductivity transmitters provide a standard 4-to-20-mA output that can be used for recording, command, and control functions.

The following options are available for selection according to your application.

- Measured conductivity value
- Measured resistivity value

Furthermore, the following output functions can also be set.

- HOLD function: Holds the output immediately before the measurement mode or a fixed output for the period before returning to the normal measurement mode.
- Burnout function: Provides a burn-up (22 mA) or burn-down (3.9 mA) in the FAIL state.
- Programmable output function: Linearizes the output for concentration when the transmitter is used as a concentration analyzer.

The following shows an example of setting a 21-point line segment that linearizes the output for the concentration curve.

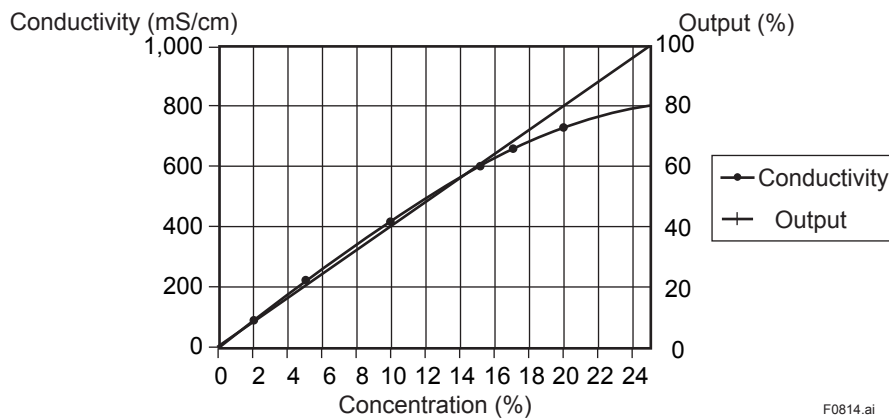


Figure 9.3 Linearizing Output (Example of 0 – 25% sulfuric acid)

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Table 9.4 Setting Details of 21-Point Line Segment in Figure 9.3

Output (%)	0 to 20 mA	4 to 20 mA	Concentration (%)	Conductivity value (mS/cm)
0	0	4	0	0
5	1	4.8	1.25	60
10	2	5.6	2.5	113
15	3	6.4	3.75	180
20	4	7.2	5	211
25	5	8	6.25	290
30	6	8.8	7.5	335
35	7	9.6	8.75	383
40	8	10.4	10	424
45	9	11.2	11.25	466
50	10	12	12.5	515
55	11	12.8	13.75	555
60	12	13.6	15	590
65	13	14.4	16.25	625
70	14	15.2	17.5	655
75	15	16	18.75	685
80	16	16.8	20	718
85	17	17.6	21.25	735
90	18	18.4	22.5	755
95	19	19.2	23.75	775
100	20	20.0	25	791

## 9.4 Failure Detection (Self-Diagnosis) Function

While measurement is performed, failures are always checked, such as electrode damage and contamination, immersion state of electrodes into the measurement solution, and cable failure. If a failure is detected, a FAIL signal is output. Furthermore, use of a 3.9-mA output or 22-mA output (burnout function) enables the transmission of a notification signal to the control and monitoring room. It is also possible to notify of the failure state by lighting up the FAIL indication on the operation panel or displaying the error code in the message display screen.

## 9.5 WIF Monitoring (USP <645> Directive)

See Section “8.4 WFI Monitoring (USP <645> Directive.”

# 10. Maintenance of the Measuring Cell

In practice, it has been seen that conductivity measuring cells seldom require attention and preventative maintenance is hardly necessary.

However, when the result of the conductivity measurement is unreliable, then two items must be considered:

- A. Is the operation of the measuring converter correct?
- B. Is the function of the conductivity measuring cell with connecting cable and/or the built-in temperature sensor correct?

The use of a Sensor Simulator (QT40) of Yokogawa makes it easier to check the measuring cell. In addition, the correctness of the cable and the temperature sensor can be determined.

A service handbook and accurate test equipment are required for a correct operating check of the measuring converter.

## 10.1 Calibration of the Measuring Cell

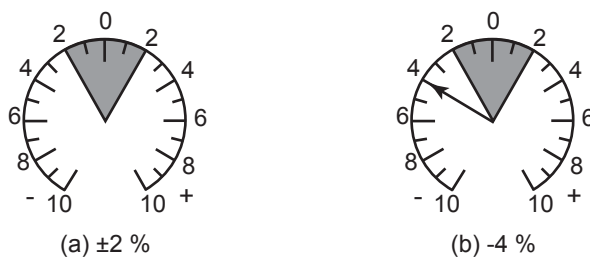
The cell constant is determined at a call resistance of 1000 Ohms. It is possible that slight variations in the cell constant may occur at other conductivity values. This possible error can be corrected by recalibrating with a solution of known conductivity value (according to DIN 53779).

### NOTES

1. The specific conductivity value of the solution of known value must be near to the value of the liquid to be measured.
2. The specific conductivity value is highly dependent on temperature. Therefore, the temperature of the cell and the liquid should be allowed to equalize and should be accurately measured with a calibrated thermometer.

If no arrow is indicated on the text plate (see Figure 10.1 (a)), then the deviation from nominal cell constant value will be within  $\pm 2\%$  and no recalibration is required.

The arrow (see Figure 10.1 (b)) indicates the deviation from nominal cell constant value ( $-4\%$ ). Individual cell calibration ensures maximum accuracy of the measurement (see instruction manual of the measuring converter).



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Figure 10.1 The deviation from the nominal value



## 10.2 Cleaning the Measuring Cell

In general conductivity/resistivity measurements do not need much periodic maintenance. If the EXA indicates an error in the measurement or in the calibration, some action may be needed. In case the sensor has become fouled an insulating layer may be formed on the surface of the electrodes and consequently, an apparent increase in cell constant may occur, giving a measuring error. This error is:

$$2 \times \frac{R_V}{R_{\text{cel}}} \times 100 \quad (\%)$$

$R_V$  : Resistance of the fouling layer

$R_{\text{cel}}$  : Cell resistance

Note: Resistance due to fouling as well as to polarization does not effect the accuracy and operation of the four-electrode conductivity measuring system. If an apparent increase in cell constant occurs, cleaning the cell will restore accurate measurement.

### ● Cleaning Methods

- (1) For normal applications hot water with domestic washing-up liquid added will be effective.
- (2) For lime, hydroxides etc. a 5 ... 10% solution of hydrochloric acid is recommended.
- (3) Organic foulings (oils, fats, etc.) can be easily removed with acetone.
- (4) For algae, bacteria or moulds, use a solution of domestic bleach (hypochlorite).

\* Never use hydrochloric acid and bleaching liquid simultaneously. The very poisonous chlorine gas will result.

### NOTES

1. Sharp objects must not be used on the surface of the electrodes. The paragraph about the decrease or prevention of polarization effects informs about a special layer (e.g. rhodium) to increase the electrode surface. The attack of this layer can give considerable increase of polarization and consequently, measuring errors.
2. The surface of the electrodes of f.i. stainless steel must not be polished. The special "ray patterned" electrode surface have an enlarge active surface to give a small current density. Polished electrodes give an increase to the polarization effect and consequently, measuring errors.

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# 11. Applications

The industrial applications of conductivity measurements are numerous and vary from a simple determination of the salinity to more complex quality measurements and control.

A number of applications are listed below, some of which are described in detail.

Water quality treatment

- Conductivity measurement of pure water.
- Check and control of demine installations like cation exchanger protection, an-ion exchanger protection, mixing-basin exchanger protection.
- Boiler feed water protection.
- Condensate protection.
- Steam quality protection.
- Boiler blow-down control.
- Air-conditioning blow-down control.
- Hardness protection (e.g. laundries).
- Surface water protection.

Concentration measurements and control

- Sulphuric acid and oleum.
- Hydrochloric acid.
- Lye concentration control for generation of ions exchanger.
- Acid concentration control for regeneration of ions exchanger.
- Phosphate in boiler water.
- Ammonium and ammonia gas.
- Nitric acid for dairy cleaning.

Gas analysis

- Carbon dioxide in water.
- Sulphuric dioxide in water.

## 11.1 The Conductivity Measurement of Pure Water

The conductivity measurement in pure water needs a separate explanation.

The precise measurement of the specific conductivity of pure water is a complex subject.

In the conductivity measurement principles mentioned before, the starting point is that the concentration of ions in the dissolved solutions are much greater than the concentrations of the available  $H^+$  and  $OH^-$  ions for the equilibrium.

In pure water the concentrations of  $H^+$  and  $OH^-$  ions may not be neglected.

The specific conductivity of pure water equates to the sum of the specific conductivity values of the salts present and the dissociated  $H^+$  and  $OH^-$  ions.

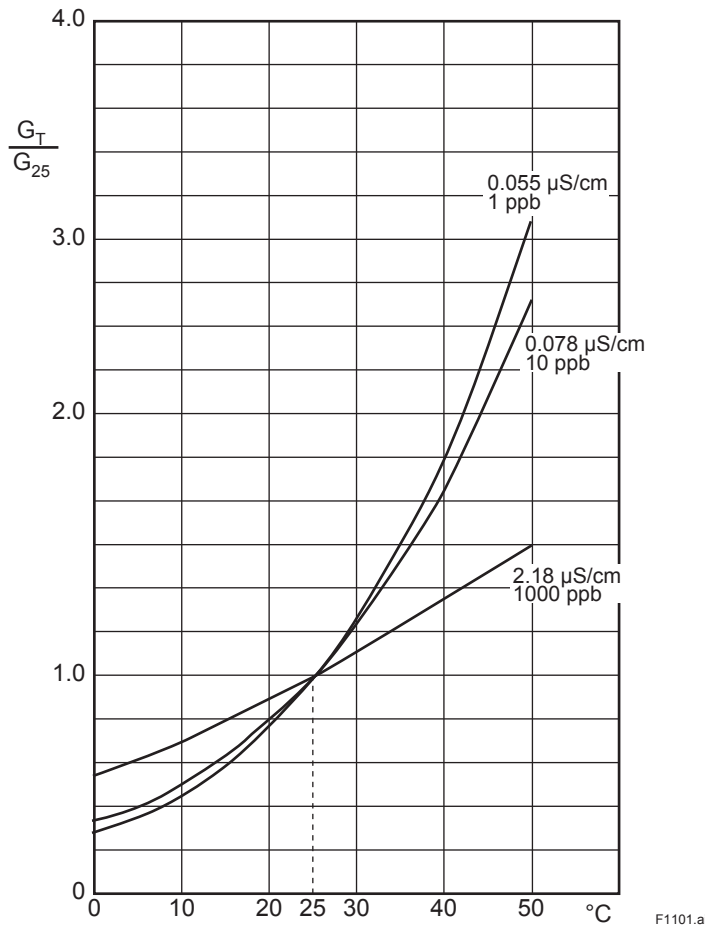
$$K = K_{\text{water}} + K_{\text{salts}}$$

The temperature influence differs for the two factors and cannot be compensated for by using one temperature coefficient based on NaCl. For pure water conductivity measurements, temperature compensation is made by utilizing two separate temperature sensors and electric circuits.

For dissolved salts a temperature coefficient of 2.16 %/°C is used.

The calculated curve for the temperature coefficient of the water equilibrium is added to the normal temperature correction requirements in an electronic circuit.

Figure 11.1 shows the temperature dependence of “pure” water at three conductivity values.



**Figure 11.1** Conductivity of pure water with pollutions of resp. 1, 10 and 100 ppb.

Yokogawa has developed a special signal converter for measurements in pure water (low concentration converter). The measuring principle of this converter is similar to the two-electrode measuring principle.

However, the temperature compensation is made with two separate temperature sensors both mounted in the conductivity cell.

If the conductivity of the water is expected to be low, the low concentration principle for conductivity measurement is recommended. Generally, the accuracy of other measuring principles will be unacceptable.

## 11.2 Boiler Blow-off Control

A common application of conductivity measurement is blow-down or make-up control.

Industrial steam is used for a number of applications. The most important of which are energy generation in power stations and heating purposes.

Since the effect of boiler installation is pre-determined by the quality of the boiler feed water, it is important to monitor its quality.

The most usual method of maintaining the quality of the boiler water is by blow-down control based on the conductivity measurement.

A small sample is drawn continuously from the boiler and passed through a sample cooler. The conductivity of this sample is monitored and when it reaches an unacceptable level, a control value in the blow-down line is opened. The decrease in boiler level initiates through a level controller, the opening of a feed water valve. The conductivity controller of the control valve ensures that it only opens sufficiently to adjust the boiler water to the maximum permissible conductivity level.

Good blow-down control ensures that at the minimum loss of energy, in the form of heat, is coupled with minimum usage of make-up water.

## 11.3 Check on Condenser Performance

In the majority of chemical industries, steam is used to heat the process liquids.

The problem with this method is that the return condensate may be polluted by process liquid leaking into the steam tubes.

If this occurs, the return condensate must be prevented from returning directly to the boiler.

Figure 11.2 shows a typical control process circuit.

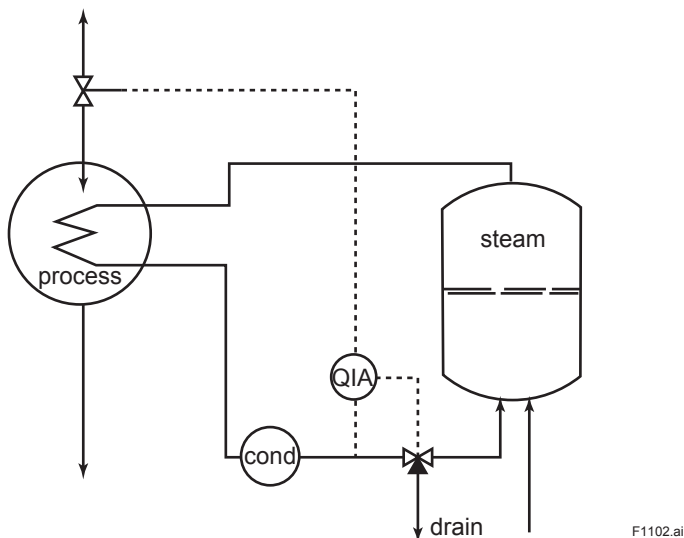


Figure 11.2 Return condensate

If the conductivity value of the condensate passes a preset-value, a valve in the return pipe to the boiler is closed and a blow-down valve is opened.

This protection allows optimum quality of the condensate and process liquid leaks are avoided.

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## 11.4 Blow-off Control of Cooling Towers or Open Cooling Systems

In a cooling system which includes an open cooler (e.g. cooling towers), the concentration of solids steadily increases due to evaporation losses. This is described as "increased thickening".

An increase in solids in the water also leads to greater deposits in the piping system. The cooling capacity then suffers all the resultant consequences (over-heating, increased cooling, water consumption, etc.). To prevent the cooling water from becoming too thick, it is periodically drained.

The use of conductivity measurement to the degree of thickening can be measured and, if necessary, recorded.

When a preset conductivity value is exceeded, a blow-off valve is opened and the water is replaced by unpolluted water, through a make-up valve.

## 11.5 Conductivity Measurement as a Measurement or Control of Concentration

Many industrial processes use conductivity measurement to determine and control the concentration of dissolved solutions. In such applications it must be realized that all dissolved solutions contribute to the conductivity value to a greater or lesser degree.

Some examples are:

- The control of sulphuric acid concentration.

The control of sulphuric acid concentration during manufacturing (see Figure 11.3).

The concentration of sulphuric acid is usually between 60 and 99 % wt. (see Figure 11.4).

The relation between conductivity and concentration in this range is such that an increase of concentration gives a decrease of conductivity.

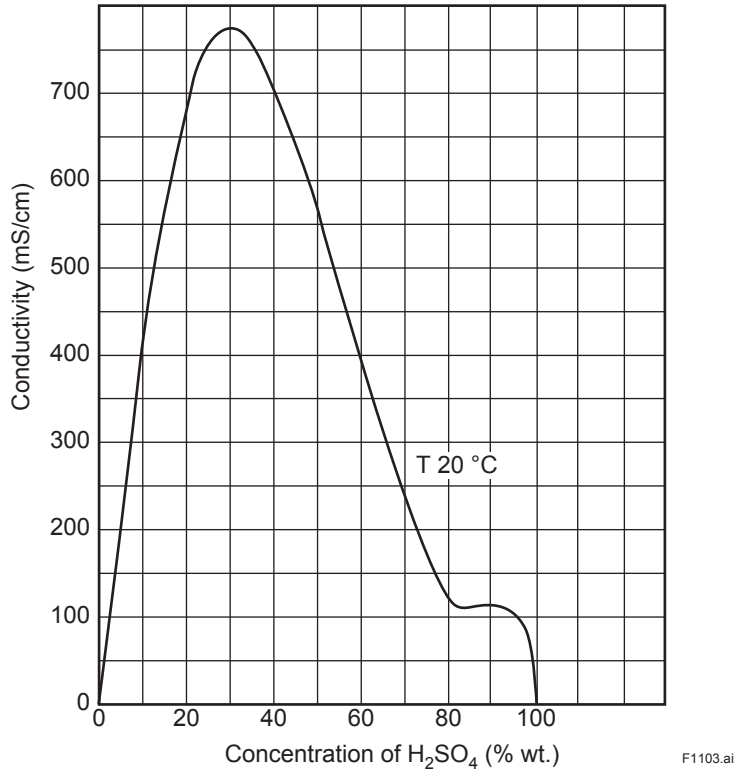


Figure 11.3 Conductivity of different sulphuric acid concentrations at 20°C.

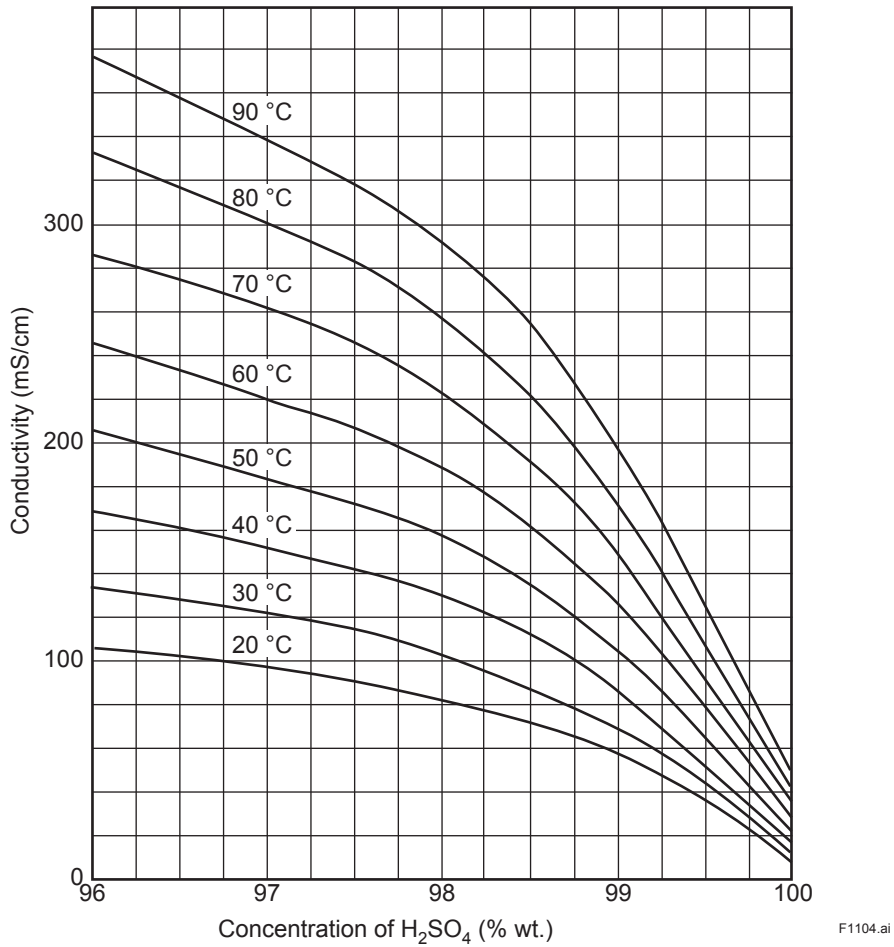


Figure 11.4 Conductivity of sulphuric acid with concentrations between 96 and 100 % wt.

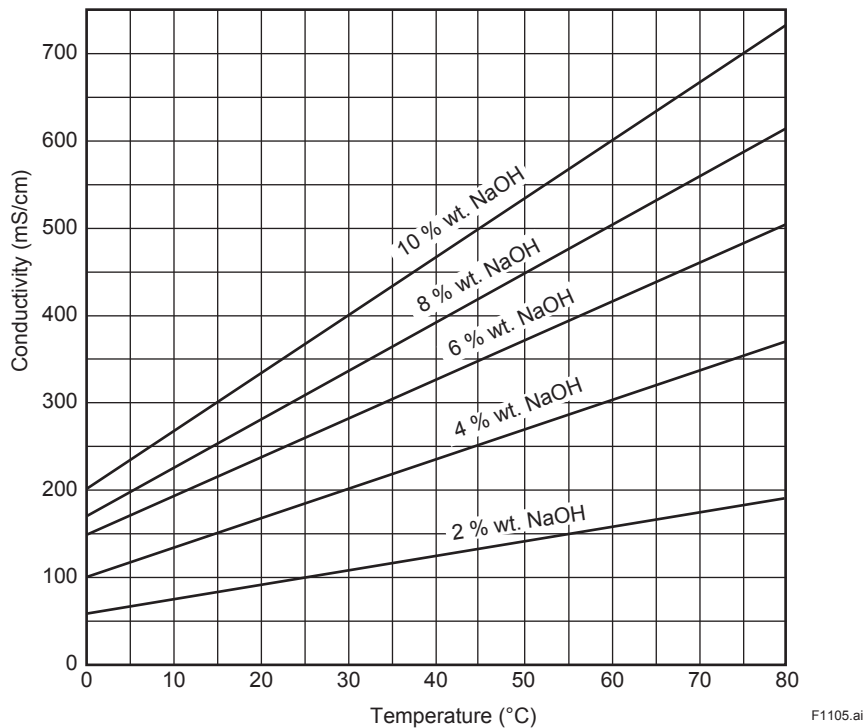


Figure 11.5 Conductivity of some NaOH concentrations at different temperatures.

- The measurement of alkaline concentration.

In a demineralising plant, the an-ions exchanges are regenerated with alkaline. That means the an-ions bound to the exchange resins are loosened by rinsing through with a concentrated alkaline solution. It is important that the alkali is used in the correct concentration and consequently, it is necessary to adjust this after each regeneration.

Non-optimum regeneration of an ions exchanger results in reduced operating cycle time and poorer water quality.

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