Title

A Transducer

Technical Field

The invention concerns an integrated transducer for measuring a plurality of environmental parameters of effluent.

Background of the Invention

Industrial and municipal wastewater must be treated to comply with the minimum environmental standards before discharge into a sewer or watercourse. These standards are intended to protect the sewerage infrastructure, workers maintaining the sewerage system and aquatic marine life. Also, these standards prevent adverse effects on treatment processes at downstream sewage treatment works.

Stricter environmental laws, in particular, water anti-pollution laws, increases the importance of monitoring multiple environmental parameters of effluent during the treatment and before discharge of the effluent. Therefore, there is a need for an instrument to measure these parameters conveniently and efficiently.

Summary of the Invention

In a first preferred aspect, there is provided an integrated transducer for measuring a plurality of environmental parameters of effluent, the transducer comprising:

a plurality of input ports to connect to a combination of measurement probes for measuring the environmental parameters, the environmental parameters being at least two selected from the group consisting of: temperature, pH, concentration of anions, conductivity, total dissolved solids (TDS), oxidation/reduction potential (ORP), concentration of dissolved oxygen (DO), salinity, and concentration of metallic ions;

a processor to process the measured environmental parameters according to predefined rules; and

a display to display the processed environmental parameters.

An input may be provided for setting the operational parameters of the measurement probes. The input may be a keypad or touchscreen integrated with the display. The environmental parameters to be measured may be selectable via the input.

The measurement probes may include at least one of: a platinum resistance thermometer, pH probe, oxidation/reduction potential (ORP) electrode, ion selective (ISE) electrode, conductivity electrode, dissolved oxygen (DO) electrode and an anode stripping voltammetry (ASV) system.

The predefined rules may comprise one or more of:

- measuring the resistance obtained by the platinum resistance thermometer to determine the temperature of the effluent;
- compensating the measured pH value with the temperature of the effluent;
- compensating the measured concentration of anions with the temperature of the effluent;
- compensating the measured oxidation/reduction potential (ORP) with the temperature of the effluent; or
- compensating the measured dissolved oxygen (DO) with the temperature of the effluent.

The temperature compensation may be performed automatically or manually by an operator.

An output port to connect with another device for outputting the measured parameters may be provided. The another device may be a desktop computer or printer.

A database may be provided to store total dissolved solid (TDS) values for each effluent source. The TDS value (ppm) for the effluent source may be calculated using a predetermined piecewise function directly from the measured conductivity.

The measurement probes may be placed in different analytical chambers or cells at the same time.

The measurements of the pH probe, oxidation/reduction potential (ORP) electrode, and ion selective (ISE) electrode may be shown in three modes on the display, the three modes including pH (pX) value, potential in mV and ion concentrations in ppm or mol/L.

The measurements of the conductivity electrode may be shown in three modes on the display, including conductivity, total dissolved solids (TDS) and salinity.

The measurements of the DO electrode may be shown in two modes on the display, including percentage of saturated dissolved oxygen and absolute concentration of dissolved oxygen.

The measurements of the anode stripping voltammeter (ASV) system may be shown in concentrations of metallic ions such as Zinc (Zn^{2+}), Copper (Cu^{2+}), Lead (Pb^{2+}), or Cadmium (Cd^{2+}).

The measurements of the conductivity sensor may be used to obtain salt-compensation of DO.

An adjustable calibration strategy may be provided for measuring the pH, ORP, and the concentrations of anions by applying the least square method.

The measurement of total dissolved solids (TDS) may be obtained by converting the measured conductivity by performing a lookup on the database.

The anode stripping voltammetry (ASV) system may be calibrated by peak searching and area integration.

The processor may process at least sixteen environmental parameters at the same time.

The salinity of the effluent may be obtained by converting the measured conductivity.

Advantageously, the transducer of the present invention enables the measurement of multiple environmental parameters of effluent in a single integrated device to be conducted in a user-friendly and efficient manner.

Brief Description of the Drawings

An example of the invention will now be described with reference to the accompanying drawings, in which:

Figure 1 is a plan view of the front panel of an integrated transducer according to the preferred embodiment of the invention;

Figure 2 is a schematic diagram of the transducer;

Figure 3 is a schematic view of the major functional elements of the microprocessor shown in Figure 2 and connection to other components of the transducer;

Figure 4 is a graph illustrating the calibration of the transducer for three pH values at two different temperatures;

Figure 5-1 and Figure 5-2 are graphs illustrating data of the conductivity and TDS value of the effluent;

Figure 6 is a graph illustrating one example of the method of applying voltages in anodic stripping voltammetry;

Figure 7 is a graph illustrating one example of curves showing sample currents of anodic stripping voltammetry; and

Figure 8 is a process flow diagram of the search algorithm for searching the peak in the voltammogram.

Detailed Description of the Drawings

Referring to Figure 1, there is provided an integrated electro-mechanical transducer 1 for environmental multi-parameter monitoring of effluent. A front view of the transducer 1 is shown. The transducer 1 is covered by a case 2 except for a panel containing a keypad 3, liquid crystal display (LCD) 23, a series of input jacks for connection with measurement probes/electrodes and other accessories. The keypad 3 includes sixteen keys: eleven are number keys, and five are function keys. The transducer 1 has eight jacks (4 to 11) to connect to: a pH electrode (not

shown), oxidation/reduction potential (ORP) electrode (not shown) and ion selective electrodes (ISE) (not shown). The transducer 1 has another three jacks 12, 13, 14 to connect to temperature probes (not shown), and one jack 15 to connect to a Dissolved Oxygen (DO) electrode (not shown) at the top of the case 2.

At the right side of the case, the transducer 1 has one jack 16 for connecting with a conductivity electrode (not shown), and three jacks (17 to 19) to connect to working, reference and counter electrodes of an anodic stripping voltammetry (ASV) system (not shown). The working, reference and counter electrodes of the ASV system enable measurement of the concentration of metallic ions such as heavy metals. Also at the right side of the case 2, the transducer 1 has a digital output port 20 to communicate with a computer or other computing device using the RS232 communication protocol.

An on/off button 21 on the front panel of the case 2 to activate or deactivate the transducer 1 is provided. Also on the front panel of the case 2, a contrast knob 22 to adjust the display contrast of the LCD 23 is provided.

Referring to Figure 2, a schematic of the functional components of the transducer 1 is illustrated. The pH, oxidation/reduction potential (ORP), and ion selective electrodes (ISE) are connected via the jacks 4 to 11 to the transducer 1. The analog voltage input 24 (8 channels) of the pH, ORP or ISE measurement probes are connected via an analog amplifier circuit 25 to a strobing circuit 55. The temperature probe is connected via the jacks 12 to 14 to the transducer 1. The analog input 27 (3 channels) of the temperature probe is connected to an analog amplifier circuit 28 to a strobing circuit 55. The DO electrode is connected via the jack 15 to the transducer 1. The analog current input 32 produced by the DO electrode under the polarizing voltage signal 31 of the polarizing voltage circuit 30 is connected to current to voltage circuit 33 for conversion to a voltage signal 34. The voltage signal 34 is then connected to an analog amplifier circuit 35 to a strobing circuit 55. The conductivity electrode is connected via the jack 16 to the transducer 1. The analog current input 39 produced by conductivity electrode

under the alternating voltage 38 of the oscillation generator circuit 37 is connected to a current to voltage circuit 40 for conversion to a voltage signal 41. The voltage signal 41 is then connected to an analog amplifier circuit 44 to the strobing circuit 55. An amplification gain of analog amplifier circuit 44 is controlled by the signal 43 of the controllable gain 42, which receives a control signal 61 from the microprocessor 59. The working electrode, reference electrode and counter electrode of the ASV system are connected via the jacks (17 to 19) to the transducer 1. The analog current input 48 produced by the electrodes under a deposition and stripping voltage circuit 47, is connected to a current to voltage circuit 49 to convert to a voltage signal 50. The voltage signal 50 is then connected via an analog amplifier circuit 53 to the strobing circuit 55. The deposition and stripping voltage circuit 46 receives a control signal 63 from the microprocessor 59. The amplification gain of analog amplifier circuit 53 is controlled by the signal 52 of the controllable gain 51, which receives the control signal 62 from the microprocessor 59.

The voltage inputs 26, 29, 36, 45 and 54 connected to the strobing circuit 55 are directed to an Analog to Digital (A/D) converter 57. The A/D converter 57 converts analog input 56 into a digital signal 58, one by one in a correct order. The digital signal 58 is input into a microprocessor 59 contained on a circuit board within the case 2 of the transducer 1. Keypad input 66 represents the connection of the various keys of keypad 3 to the microprocessor 59. Output 65 from microprocessor 59 to LCD display 23 is representative of various control lines that connect microprocessor 59 to the individual liquid crystal display elements of the components of display 23. Output 64 from microprocessor 59 is representative of various control lines that connect microprocessor 59 to the serial communication port of the computer using communication protocol RS232.

Referring to Figure 3, a schematic of the microprocessor 59 and its major logic elements and the connecting elements is illustrated. There are two types of inputs to the microprocessor 59: the digitized input 58 and the keypad input 66. There are five types of outputs from the microprocessor 59: the display outputs 65 to LCD 23, the serial digital output 64 to RS232 serial communication port 20, the channel selector output 60, the gain select output 61, 62, and the deposition and stripping voltage output 63. The channel selector output 60 controls the strobing circuit 55 to determine whether A/D Converter 57 is connected to pH/ORP/ISE jacks 4, 5, 6, 7,

8, 9, 10, 11 or to temperature jacks 12, 13, 14 or to DO jack 15 or to conductivity jack 16 or to heavy metal jacks 17, 18, 19. The gain select outputs 61, 62 control the gains of the amplifiers 44, 53. The deposition and stripping voltage output 63 control the deposition and stripping voltage 46 of anodic stripping voltammetry.

The two types of inputs and five types of outputs connect via the I/O interface 67 to an arithmetic logic unit (ALU) 71 of microprocessor 59. Additional inputs to ALU 71 are timer circuits 70 for indicating increments at which ALU 71 performs certain functions. The microprocessor 59 also contains read only memory (ROM) 69 in which various program routines and constants are permanently stored and recalled by ALU 71 in a controlled fashion. Random access memory (RAM) 68 is provided which contains various values obtained by ALU 71 from I/O 67 or from computations on those values, or stored values already in RAM 68, or values from ROM 69 or values from other various sources.

The transducer 1 measures the multiple environmental parameters of the sample solution, such as pH, ORP, temperature, conductivity, DO, concentration of some anions and metallic ions. When the transducer 1 is activated, all the measurable environmental parameters are displayed via the LCD 23. The operator presses a key to select the environmental parameters to be measured.

The principle and operational procedure for the measurable parameters in the transducer 1 uses the least square method. This method is performed by the microprocessor 59 to monitor different parameters for precise measurements.

The least square method is based on a pair of variables denoted as x_i and y_i, where x is an independent (known) variable and y is measured value (dependent variable). The line passing through the points (x_i, y_i) is described by the following equation:

$$\hat{y} = a + bx \qquad (1)$$

where: $\hat{y}$ is the estimated value of y for given x, a is the intercept of the line, and b is the gradient of the line.

The values of both *a* and *b* are calculated as follows:

$$b = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sum_{i=1}^{N}(x_i - \bar{x})^2}$$

$$a = \bar{y} - b\bar{x} \qquad (2)$$

$$r = \frac{\sum_{i=1}^{N}(x_i - \bar{x})(y_i - \bar{y})}{\sqrt{(\sum_{i=1}^{N}(x_i - \bar{x})^2)(\sum_{i=1}^{N}(y_i - \bar{y})^2)}}$$

where

$$\bar{x} = \frac{1}{N}\sum_{i=1}^{N} x_i$$

$$\bar{y} = \frac{1}{N}\sum_{i=1}^{N} y_i \qquad (3)$$

N is the number of measured points (x_i, y_i).

r is the correlation coefficient between *y* and *x*. The closer $|r|$ approaches 1, the more linear dependant the relationship between *y* and *x* is.

TEMPEARTURE MEASUREMENT

A platinum resistance thermometer Pt100 is connected to the transducer 1 via the jack 12 and 14. The platinum resistance thermometer measures the temperature of the sample solution. The relationship between temperature and resistance of platinum resistance thermometers is approximately linear over a small temperature range. The transducer 1 adopts the International Temperature Standard 90 (ITS-90) to determine the relationship between resistance and temperature:

$$R_t = R_0(1 + a \bullet t + b \bullet t^2) \qquad (4)$$

where R_t , R_0 is the resistance at temperature t °C and 0 °C respectively. For Pt100, R_0 is equal to 100 ohms. $a = 3.9083 \times 10^{-3}, b = -5.775 \times 10^{-7}$.

After measuring the resistance of Pt100 at the temperature, the transducer 1 determines the temperature value t (°C) according to the following equation:

$$t = \frac{a + \sqrt{a^2 + 4a(\frac{R_t}{R_0} - 1)}}{2b} \quad (5)$$

pH MEASUREMENT

The pH probe is connected to the transducer 1 via the jack 4 to 7. The pH probe measures the pH value of the sample solution. To commence measuring, the operator selects the pH measurement via the measurement menu of the LCD 23. The transducer 1 carries out a single or multiple point calibration in pH measurement. The temperature effect on pH measurement is compensated automatically if the temperature probe is connected to the transducer 1. The main functions of pH measurement, including monitoring, calibration and temperature compensation, are displayed in the menu of pH measurement. The operator presses a key to select the correspondent function before performing the operation.

The pH measurement is carried out electrochemically using a combined pH electrode with a glass electrode and silver-silver chloride reference.

The pH of the sample solution is measured by immersing the pH probe in the sample solution. Then, millivolts of potential are produced between the reference electrode and the glass electrode. Next, the transducer 1 measures the potential. The transducer 1 converts the measured potential to pH units using Nernst's equation:

$$E = E_o - \frac{RT}{nF}\ln[H^+] = E_o - \frac{2.303RT}{nF}\log_{10}[H^+] = E_o + \frac{2.303RT}{nF}pH \quad (6)$$

where E (mV) is electrode potential; E_o (mV) is the standard cell potential; R is the ideal gas constant and equal to 8314 J/(mole• K); T is the temperature in degree

Kelvin; F is the Faraday constant and equal to 96485 C/mole; and n is the charge of the ion and $n = 1$ for pH probe.

Equation 6 is rewritten as follows:

$$E = E_o + \frac{2.303R * 298.15}{F} \bullet \frac{t + 273.15}{298.15} pH = E_o + k_o \bullet \frac{t + 273.15}{298.15} pH = E_o + k \bullet pH \quad (7)$$

where t is the temperature in degrees Centigrade, k_o (59.16mV) is the constant and equal to k at 25 °C. The constant E_o and k in Equation 7 is obtained through the calibration of the pH measurement.

As shown in Equation 6, the pH value of the sample solution is a function of its temperature.

Referring to Figure 4, the temperature effect on the pH-millivolt curve is illustrated graphically. Three pH standard solutions and their corresponding potential differences (shown by "+" and "o" symbols respectively) at two different temperatures (T_1 and T_2) are shown. The lines to fit the pH-millivolt relationship at different temperatures are also drawn to indicate that the temperature plays an important role in the pH measurement. According to Equation 6, the gradient of the plot of pH versus millivolts is directly proportional to the absolute temperature in degrees Kelvin. Thus, the gradient of the plot in measurement temperature t_m, which is different from calibration temperature t_c, is determined and the transducer 1 compensates for the effect of temperature on the pH measurement.

The calibration of pH measurement is carried out as follows:

1. Press the key to select the calibration method, one-point, two-point or multi-point calibration.

2. Place pH and temperature probes in one standard solution with value pH_i, press the key to input the pH value of the standard solution, and wait until the measurement E_i of the standard solution stabilizes.

3. If more than one point needs to be calibrated, change to another standard solution with the same temperature, and repeat step 2 until the calibration points are completed.

4. According to the selected calibration points, the microprocessor 59 performs any one of multi-point calibration, single point calibration or two point calibration.

Multi-point calibration:

When a series of calibration pH_{cl} values are input into the microprocessor 59, the average temperature $\bar{t}_c$ is obtained from the individual calibration temperature measurement. Replacing *y* with *E* and *x* with *pH* in Equation 1 to 3, obtains E_o and *k* in Equation 7 as well as *r*.

The information about the condition of pH probe indicates the state and availability of the probe.

For example, an alarm is displayed if the obtained $k \le 85\% \bullet \frac{\bar{t}_c + 273.15}{298.15} \bullet 59.16$

and/or $|r| \le 0.9$.

If the sample solution is measured at the same temperature as used for calibration, then, $E_{om} = E_o$ and $k_m = k$, and the sample pH_m value is obtained by the following equation:

$$pH_m = \frac{E_m - E_o}{k} \qquad (8)$$

If the sample solution is measured at a different temperature t_m, the temperature compensation is based on the following equation:

$$k_m = k \bullet \frac{t_m + 273.15}{\bar{t}_c + 273.15} \qquad (9)$$

where k_m are the gradients of Nernst's equation in measurement temperature t_m.

$$E_{om} = E_o + k \bullet \frac{\bar{t}_c - t_m}{t_c + 273.15} \bullet 7 \quad (10)$$

where E_{om} is the standard cell potential at the measurement temperature t_m.

and then the sample pH_m value is obtained by the following equation:

$$pH_m = \frac{E_m - E_{om}}{k_m} \quad (11)$$

Single point calibration:

The calibration and measurement potentials E_c and E_m at the calibration and measurement temperature t_c and t_m, are obtained by the transducer 1. The calibration pH_c value is input into the microprocessor 59 during calibration. From Equation 7, the sample pH_m value with temperature compensation is obtained by the following equation:

$$pH_m = \frac{t_c + 273.15}{t_m + 273.15} \bullet pH_c + \frac{298.15}{t_m + 273.15} \bullet \frac{E_m - E_c}{59.16} \quad (12)$$

Two point calibration:

During calibration, two calibration values, pH_{c1} and pH_{c2}, are input into the microprocessor 59. The calibration potentials E_{c1} and E_{c2} at the calibration temperatures t_{c1} and t_{c2} as well as measurement potential E_m at the measurement temperature t_m are obtained by the transducer 1. From Equation 7, the sample pH_m value with temperature compensation is obtained by the following equation:

$$pH_m = \frac{\bar{t}_c + 273.15}{t_m + 273.15} \bullet \frac{E_m - E_{c1}}{E_{c2} - E_{c1}} \bullet pH_{c2} - \frac{\bar{t}_c + 273.15}{t_m + 273.15} \bullet \frac{E_m - E_{c2}}{E_{c2} - E_{c1}} \bullet pH_{c1} \quad (13)$$

where $\bar{t}_c$ is the average temperature of calibration solution.

The transducer 1 carries out temperature compensation of the pH measurement automatically or manually, depending on the selection of the operator. When the operator selects the mode of automatic temperature compensation (ATC), the temperature probe is connected to the transducer 1 through jacks 12 to 14 and placed into the identical solution during pH measurement. If the temperature probe is faulty or is not connected, the transducer 1 raised an alarm and adopts a default value such as 25°C, to compensate for the temperature effect during pH measurement.

When the operator selects the mode of manual temperature compensation in pH measurement, the transducer 1 reminds the operator via LCD 23 to input the temperature value of the solution to the transducer 1. The temperature may be measured by other instruments. If the operator does not input the temperature value or inputs an unreasonable value for the temperature, for example, higher than 100°C or lower than 0°C, the transducer 1 raises an alarm and adopts a default value, such as 25°C, to compensate for the temperature effect during pH measurement. Then, the transducer 1 replaces the measurement result of the temperature in the earlier described procedure of automatic temperature compensation with the input temperature value, and follows the same procedure as automatic temperature compensation. This completes the manual temperature compensation of pH measurement.

ANIONS MEASUREMENT

The ion selective electrodes (ISE) are connected to the transducer 1 through jacks 8 to 11. This enables the transducer 1 to measure the concentrations of some anions including: chloride (Cl^-), fluoride (F^-), cyanide (CN^-) and sulfide (S^{2-}), simultaneously. The names and calibration concentration (mol/L or ppm) of the tested anions are input into the microprocessor 59. The working principle of ISE for measuring the concentration of some anions is similar to the pH probe for measuring the pH value of the sample solution. According to Nernst's Equation, the

ISE X produces a potential difference proportional to a logarithm function of the concentration of a specific anion X (mol/L or ppm), and is:

$$E = E_o - \frac{RT}{nF}\ln X = E_o - \frac{2.303RT}{nF}\log_{10} X = E_o + \frac{2.303RT}{nF} pX = E_o + \frac{K}{n} pX \quad (14)$$

where $pX = -\log_{10} X$, and n is the charge of the ion.

Equation 14 is a similar function to Equation 7 by replacing pH with pX. The transducer 1 measures pX values in sample solutions with calibration and temperature compensation suing the same principles and procedures as those for the pH probe.

The transducer 1 has two modes to display the measurement result of the concentration of some anions: one for the unit of mol/L, and the other for the unit of ppm.

The transducer 1 calculates the concentration of the anions based on the following equation:

$$pX_m = \frac{E_m - E_{om}}{k_m / n}$$
$$C_x = 10^{-pX_m} \quad (15)$$

where C_x is the concentration of anion X with mol/L or ppm unit, which is dependent on the unit of original input at the calibration stage.

CONDUCTIVITY MEASUREMENT

The conductivity electrode is connected to the transducer 1 via the jack 16. The conductivity electrode measures conductivity of the sample solution. The operator selects the conductivity measurement in the measurement menu of the LCD 23. The transducer 1 selects the measurement range automatically and does not require frequent calibration of the conductivity measurement. The result of the conductivity measurement is converted to the value of total dissolved solids (TDS) and salinity by the microprocessor 59.

Conductivity

The conductivity electrode has two plane metal probes coated with platinum black. The conductivity electrode is immersed in the sample solution. Next, the transducer 1 applies a sinusoidal alternating voltage with an amplitude of order 1V and a frequency of order 1 kHz to the electrode. The current is then measured through the two probes. The transducer 1 converts the current to a conductivity value using following equation:

$$\sigma = K \bullet I \tag{16}$$

where σ (Scm^{-1}) is the conductivity of the solution; K ($Scm^{-1}A^{-1}$) is the proportional constant; and I (A) is the measured current through the two probes.

The transducer 1 switches the measurement range automatically during a conductivity measurement. The range of conductivity encountered in common aqueous solutions is very broad, for example, from lower than 1 μScm^{-1} of distilled water at room temperature to about 1 Scm^{-1} of 30% sulfuric acid. In order to measure the conductivity for a wide range, the transducer 1 provides an intelligent function to adjust the gain of the amplifier automatically. Figure 2 shows the controllable gain 42 of analog amplifier circuit 44 for the measurement of conductivity. During the measurement of conductivity, the microprocessor 59 adjusts the value of the controllable gain 42 until the amplitude of the amplified signal 43 meets the requirement of A/D converter 57. For example, in the measurement of the sample solution of low conductivity, the current signal 39 produced by conductivity electrode and the corresponding voltage signal 41 is very weak, so the controlled gain 42 is set to a high value. Otherwise, in the measurement of the sample solution of high conductivity, the current signal 39 produced by conductivity electrode and the corresponding voltage signal 41 is very strong, and the controlled gain 42 is set to a low value. By adjusting the gain 42 automatically, the transducer 1 measures the conductivity of the solution in a wide range without switching the measurement range manually. This provides intelligent operation for measuring conductivity.

When the transducer 1 is first used or a new conductivity electrode is connected to the transducer 1, the operator is required to calibrate the conductivity measurement as follows:

1. Immerse the conductivity and temperature probe into a 0.01 M potassium chloride solution.

2. Measure the current through the conductivity probe, and the temperature *t* of the solution.

3. Consult the conductivity value of 0.01 M potassium chloride solution at the temperature *t* from the handbook of chemistry, and calculate the proportional constant *K* of the transducer 1 according to Equation 16 and then input the value and store it in the memory of the microprocessor 59.

After *K* is determined by calibration and recorded in the microprocessor 59, the conductivity value is directly obtained and displayed through the measurement of the current.

Total Dissolved Solids (TDS)

The transducer 1 is able to convert the conductivity measurement to obtain the total dissolved solids (TDS) of the sample solution. As the measured conductivity of a solution depends strongly on temperature and the TDS value does not change with temperature, it is necessary to standardize the conductivity value at a different temperature to a reference temperature, such as 25°C. The transducer 1 performs the standardization:

$$\sigma_{25} = \frac{\sigma}{[1+0.0191(t-25)]} \qquad (17)$$

where σ is the conductivity value at the temperature t, and σ_{25} is the conductivity value at 25°C.

If the temperature probe is faulty or not connected, the transducer 1 reminds the operator via a message shown on the LCD 23 to input the temperature value

manually. After the operator inputs the temperature value *t* of the solution, the transducer 1 performs the conversion according to Equation 17.

The effluent is always composed of various components and it is very difficult to identify the type of the effluent in this situation. To address this difficulty, the transducer 1 builds a database to store the conductivity and TDS value of the effluent from various sources. About 1400 data items are stored in the database. The relationship between the conductivity and the TDS is obtained by performing nonlinear regression. The transducer 1 applies the following function in nonlinear regression:

$$\text{Ln } y = a + b\bullet(\text{Lnx}) + c\bullet(\text{Lnx})^2 + d\bullet(\text{Lnx})^3 + e\bullet(\text{Lnx})^4 + f\bullet(\text{Lnx})^5 + g\bullet(\text{Lnx})^6$$

$$y = h + i\bullet(\text{Lnx}) + j\bullet(\text{Lnx})^2 + k\bullet(\text{Lnx})^3 + l\bullet(\text{Lnx})^4 + m\bullet(\text{Lnx})^5 + n\bullet(\text{Lnx})^6 \quad (19)$$

where x and y is the conductivity value (mS/cm) and the TDS value (ppm) of the effluent respectively, and *a*, *b*, c, d, e, f, g, h, l, j, k, l, m, and *n* are the parameters of regression.

Referring to Figure 5-1 and Figure 5-2, typical data of the conductivity and TDS value of the effluent are illustrated. Figure 5-1 shows the regression result of Equation 18, while Figure 5-2 shows the regression result of Equation 19. Figures 5-1 and 5-2 approximately represent the relationship between the conductivity and TDS of the effluent.

When the operator selects from the menu, to measure the TDS of the effluent, the transducer 1 performs the regression automatically, calculates the TDS value based on Equation 18 or 19, displays the TDS value and updates the parameters of regression.

Salinity

The transducer 1 converts the conductivity measurement to the salinity of the solution. Salinity measurements are closely related to conductivity measurement, and are used in marine, estuarine and brackish water studies. The unit of salinity is parts per thousand ($^0/_{00}$). As the relationship between conductivity and salinity is approximately linear, the transducer 1 estimates the salinity value of the solution based on the following equation.

$$S = 0.68 \bullet \sigma_{25} \tag{20}$$

where S is the salinity of the solution and the unit is $^0/_{00}$, and σ_{25} is the conductivity of the solution at 25 °C and the unit is mS/cm.

DISSOLVED OXYGEN (DO) MEASUREMENT

The dissolved oxygen (DO) measurement is carried out electrochemically using a Clark-type DO electrode, with a platinum cathode and a silver/silver chloride reference anode in KCl electrolyte separated from the sample solution by a gas-permeable plastic membrane.

The DO probe for performing a DO measurement is connected to the transducer 1 via the jack 15. Next, the DO probe is immersed in the sample solution. Then, the transducer 1 applies a fixed polarizing voltage (component 30 of the transducer) around 800 mV to the platinum electrode, and the DO electrode produces a current that is proportional to the concentration of DO in the sample solution. The theoretical relationship between the concentration of DO and the current produced by DO sensor is:

$$I = I_0 + \beta \bullet C_{DO} \tag{21}$$

where C_{DO} (mg/L) is the concentration of DO, I (A) is the measured current through the probe, I_0 (A) is the current through the probe when concentration of DO is equal to zero, and β is the proportional factor.

The calibration of the DO measurement is as follows:

1. Place DO and temperature probes in a saturated solution of sodium hypo-sulfite, whose concentration of DO is equal to zero, and then the current signal I_o produced by DO electrode is measured by the transducer 1.

2. Remove DO and temperature probes from the saturated solution of sodium hypo-sulfite, and rinse them with water.

3. Place DO and temperature probes in the tap water. Stir the solution continuously for about half an hour to saturate the solution with the oxygen in atmosphere. Then the transducer 1 measures the current signal produced I_s by DO electrode, the temperature of the solution t of the solution.

4. Calculate the proportional constant β as the following equation:

$$\beta = \frac{I_s - I_o}{C_s} \tag{22}$$

where C_s is the saturation concentration of DO in the tap water and is calculated by the following empirical formula:

$$C_s = \frac{461.7}{30.7 + t} \tag{23}$$

where C_s (mg/L) is the saturation value of DO concentration in the water, t (°C) is the temperature of the water.

Then, Equation 22 is converted into the following equation:

$$\beta = (I_s - I_o)\frac{30.7 + t}{461.7} \tag{24}$$

The transducer 1 carries out temperature and salinity compensation in the procedure of DO measurement, automatically or manually. When the operator selects automatic temperature and salinity compensation, the temperature and conductivity probes are connected to the transducer 1 via the jack 12 to 14 and 16 respectively. The DO electrode is placed into the identical solution to measure the temperature t and salinity S of the solution during a DO measurement.

In this situation, the DO concentration of the unknown solution C_{DO} is calculated as follows:

$$C_{DO} = \frac{I - I_o}{I_s - I_o} \bullet \frac{461.7}{30.7 + t} \tag{25}$$

where I is the current signal produced by DO electrode immersed in the unknown solution.

The transducer 1 converts the DO measurement of the concentration in milligram per litre to the percentage of the saturation value according to the following equation:

$$DO\% = \frac{C_{DO}}{C_s^*} \times 100\% \tag{26}$$

where C_s^* is the saturation concentration of DO in the solution of the temperature t and salinity S, and is calculated as the following:

$$C_s^* = \frac{461.7 - 2.53S}{30.7 + t} \tag{27}$$

where C_s (mg/L) is the saturation value of DO concentration, and t (°C) and S ($^0/_{00}$) are the temperature and the salinity of the measured solution.

Then Equation 26 is converted into the following equation:

$$DO\% = \frac{I - I_o}{I_s - I_o} \times \frac{461.7}{461.7 - 2.53S} \times 100\% \tag{28}$$

When the operator selects manual compensation, the transducer 1 reminds the operator to input the temperature and salinity value of the solution, when necessary, in the procedure of calibration and measurement, and then follow the same program as the automatic compensation to calculate the DO concentration of the unknown solution.

HEAVY METAL MEASUREMENT

The transducer 1 performs anodic stripping voltammetry (ASV) to measure the concentration of some metallic ions, such as Cu^{2+}, Pb^{2+}, Cd^{2+} and Zn^{2+} etc. simultaneously or individually. The ASV system has three electrodes. The three electrodes are a working electrode, a reference electrode and a counter electrode. The working electrode is usually made of micro-mercury, gold, glass carbon and platinum, and is connected to the transducer 1 via the jack 17. The reference electrode is usually made of silver-silver chloride electrode, and is connected to the transducer 1 via the jack 18. The counter electrode is usually made of platinum, and is connected to the transducer 1 via the jack 19. The ASV system has two circuits: a polarizing circuit 46 that applies the deposition and stripping potential to the stripping cell in the direct current mode, and a measuring circuit 49 to monitor the cell current. The measurement of ASV includes two steps, a deposition step and a stripping step.

Referring to Figure 6, a typical process of applying voltages between the working electrode and the reference electrode in the ASV system is illustrated. During the deposition step, a deposition potential is applied between the working electrode and the counter electrode for a specific period of time. The metallic ions in the solution are deposited onto the surface of the working electrode. The deposition concentrates the metal ions from the solution onto the electrode in metallic form. During the stripping step, the potential applied between the working electrode and the reference electrode is scanned from the deposition voltage to a preset voltage. Current flowing between the working electrode and the counter electrodes is measured, and the resultant voltammogram (current-potential plot) is recorded. The voltammogram provides the analytical information of interest.

Referring to Figure 7, a typical voltammogram from the measurement of ASV is illustrated. Current peaks appear at potentials corresponding to the oxidation of metals as they are oxidized (stripped) from the electrode back into the solution. Peak potentials identify the metals in the sample solution. The stripping current is proportional to the concentration of that metal on the electrode. Therefore the stripping current is proportional to its concentration in the sample solution. The relationship between the peak area of the stripping current and the concentration of metallic ions is:

$$A = \varepsilon \bullet C \tag{29}$$

where A is the peak area of stripping current, C is the concentration of metallic ions, and ε is the proportional factor.

To measure metallic ions, the transducer 1 provides flexible strategies selectable through the keypad 3 by the operator. The selectable operational parameters are:

1. Deposition potential: -1500 mV to 1500 mV
2. Final potential: +1500 to -1500 mV
3. Deposition time: 0 to 3600 seconds
4. Potential scan rate at the stripping step: 0 - 200 mV/second

All the parameters are able to be manually set. The transducer 1 also provides an intelligent setting of most of operational parameters automatically after the type and concentration of the metallic ions to be measured are determined by the operator.

The deposition and final scan potentials used for the measurement of some metallic ions are related to the type of metallic ions, and listed in the following table:

Table 1 - Deposition potential of some metallic ions

Metal	Deposition potential (V)
Copper	-0.6

Lead	-0.9
Cadmium	-1.1
Zinc	-1.2

When more than one metallic ion requires measurement, the lowest value of the deposition potentials of the corresponding metals is set as the deposition potential of the measurement.

As the peak potential is dependent of the type of the metal, the transducer 1 only searches the peak of stripping current around the standard potential of the specific metal-metallic ion couple, shortens the time of searching peak, and reduces the possible mistakes in distinguishing peaks from noises.

In order to identify the peak in the voltammogram correctly, the transducer 1 performs data smoothing to filter the noise as follows:

$$\bar{i}_1 = i_1$$

$$\bar{i}_2 = \frac{\sum_{k=1}^{3} i_k}{3}$$

$$\bar{i}_j = \frac{\sum_{k=-2}^{2} i_{j+k}}{5} \quad when \quad j = 3,4...n-2 \qquad (30)$$

$$\bar{i}_{n-1} = \frac{\sum_{k=0}^{2} i_{n-k}}{3}$$

$$\bar{i}_n = i_n$$

Referring to Figure 8, after performing data smoothing, the transducer 1 uses a search algorithm to search the beginning potential (kb) of the peak, its related current (i_{kb}) and the end potential (ke) of the peak, and the related current (i_{ke}) in the voltammogram. The transducer 1 calculates the peak area by the following algorithm:

When $i_{ke} > i_{kb}$, the peak area is calculated as the following algorithm:

$$A = \sum_{k=kb}^{k=ke} \frac{i_k + i_{k+1}}{2} \Delta V - \frac{1}{2}(i_{ke} - i_{kb})(V_{ke} - V_{kb}) - i_{kb}(V_{ke} - V_{kb}) \quad (31)$$

When $i_{ke}<i_{kb}$, the peak area is calculated as the following algorithm:

$$A = \sum_{k=kb}^{k=ke} \frac{i_k + i_{k+1}}{2} \Delta V - \frac{1}{2}(i_{kb} - i_{ke})(V_{ke} - V_{kb}) - i_{ke}(V_{ke} - V_{kb}) \quad (32)$$

where ΔV is the interval of voltage scanning.

Before measuring the concentration of heavy metals of unknown solution, the transducer 1 requires calibration with a series of standard solutions. The calibration of the transducer 1 is carried out as follows.

1. Press the key to select the calibration method, one-point, two-point or multiple point calibration.

2. Prepare the cell with the stirrer and the three electrodes as described earlier, and then add a standard solution to the cell. Begin the ASV measurement described earlier, and wait until the peak area (A_i) of the standard solution (C_i) is calculated.

3. Remove the three electrodes from the standard solution, and rinse them with water.

4. Change to another standard solution, and repeat the steps 2 and 3 until the calibration points are completed.

5. Replacing *y* with *A* and *x* with *C* in Equations 1 to 3, the microprocessor 59 completes the calibration according to the above algorithms of multiple point calibration or single calibration, calculates the proportional factor ε, and updates the proportional factor for the following measurement of the concentration of metallic ions.

After calibration, the three electrodes are immersed in the unknown solution with same temperature as standard solution used for calibration. The transducer 1 performs the measurement of ASV with the same operational parameters as those of calibration procedure. Peak area A_x is measured, and then the concentration of the unknown solution is calculated as follows:

$$C_x = \frac{A_x}{\varepsilon} \qquad (33)$$

If the transducer 1 does not find a peak in the voltammogram, the concentration of the measured solution is set to zero.

The present invention may be used in laboratory analysis or industrial applications such as effluent discharge of industrial or municipal wastewater.

It will be appreciated by persons skilled in the art that numerous variations and/or modifications may be made to the invention as shown in the specific embodiments without departing from the scope or spirit of the invention as broadly described. The present embodiments are, therefore, to be considered in all respects illustrative and not restrictive.

WE CLAIM:

1. An integrated transducer for measuring a plurality of environmental parameters of effluent, the transducer comprising:

a plurality of input ports to connect to a combination of measurement probes for measuring the environmental parameters, the environmental parameters being at least two selected from the group consisting of: temperature, pH, concentration of anions, conductivity, total dissolved solids (TDS), oxidation/reduction potential (ORP), concentration of dissolved oxygen (DO), salinity, and concentration of metallic ions;

a processor to process the measured environmental parameters according to predefined rules;

an input for setting the operational parameters of the measurement probes; and

a display to display the processed environmental parameters;

wherein the predefined rules include compensating the measured pH value with the temperature of the effluent; compensating the measured concentration of anions with the temperature of the effluent; compensating the measured oxidation/reduction potential (ORP) with the temperature of the effluent; and compensating the measured dissolved oxygen (DO) with the temperature of the effluent.

2. The transducer according to claim 1, wherein the input is a keypad.

3. The transducer according to claim 1, wherein the input is a touchscreen integrated with the display.

4. The transducer according to claim 1, wherein the measurement probes include at least one of: a platinum resistance thermometer, pH probe, oxidation/reduction potential (ORP) electrode, ion selective (ISE) electrode, conductivity electrode, dissolved oxygen (DO) electrode or an anode stripping voltammetry (ASV) system.

5. The transducer according to claim 1, wherein the environmental parameters to be measured are selectable via the input.

6. The transducer according to claim 4, wherein the predefined rules include measuring the resistance obtained by the platinum resistance thermometer to determine the temperature of the effluent.

7. The transducer according to claim 1, wherein the temperature compensation is performed automatically or manually by an operator.

8. The transducer according to claim 1, further comprising an output port to connect with another device for outputting the measured parameters.

9. The transducer according to claim 8, wherein the another device is a desktop computer or printer.

10. The transducer according to claim 1, further comprising a database to store total dissolved solid (TDS) values for each effluent source.

11. The transducer according to claim 10, wherein the TDS value (ppm) for the effluent source is calculated using a predetermined piecewise function directly from the measured conductivity.

12. The transducer according to claim 1, wherein the measurement probes are placed in different analytical chambers or cells at the same time.

13. The transducer according to claim 1, wherein the display is a liquid crystal display.

14. The transducer according to claim 4, wherein the measurements of the pH probe, oxidation/reduction potential (ORP) electrode, and ion selective (ISE) electrode are shown in three modes on the display, the three modes including pH (pX) value, potential in mV and ion concentrations in ppm or mol/L.

15. The transducer according to claim 4, wherein the measurements of the conductivity electrode is shown in three modes on the display, including conductivity, total dissolved solids (TDS) and salinity.

16. The transducer according to claim 4, wherein the measurements of the DO electrode is shown in two modes on the display, including percentage of saturated dissolved oxygen and absolute concentration of dissolved oxygen.

17. The transducer according to claim 4, wherein the measurements of the anode stripping voltammeter (ASV) system is shown in concentrations of metallic ions such as Zinc (Zn^{2+}), Copper (Cu^{2+}), Lead (Pb^{2+}), or Cadmium (Cd^{2+}).

18. The transducer according to claim 1, wherein the measurements of the conductivity sensor is used to obtain salt-compensation of DO.

19. The transducer according to claim 1, further comprising an adjustable calibration strategy for measuring the pH, ORP, and the concentrations of anions by applying the least square method.

20. The transducer according to claim 10, wherein the measurement of total dissolved solids (TDS) is obtained by converting the measured conductivity by performing a lookup on the database.

21. The transducer according to claim 4, wherein the anode stripping voltammetry (ASV) system is calibrated by peak searching and area integration.

22. The transducer according to claim 1, wherein the processor processes at least sixteen environmental parameters at the same time.

23. The transducer according to claim 1, wherein the salinity of the effluent is obtained by converting the measured conductivity.