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Technical Note

Aqua TROLL® 200 Measurement Methodology

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Introduction

The Aqua TROLL® 200 water quality instrument measures and records conductivity, level, and temperature. It is also capable of calculating and recording useful derived parameters such as salinity and water density.

This technical note provides an overview of the instrument's measurement techniques and the equations used to calculate its derived parameters.

Actual Conductivity

The Aqua TROLL 200's primary conductivity measurement is its actual conductivity parameter (the term "actual conductivity" is used here to distinguish the parameter from "specific conductivity" since the general term "conductivity" is often used to refer to both types of conductivity interchangeably).

Actual conductivity is a measure of the ability of an aqueous solution to carry an electric current. In water, an electric current is carried by ions since electrons do not pass through water by themselves. Thus actual conductivity is dependent on the concentration of ions in the solution. The measurement responds to all ionic content in the solution and cannot distinguish particular conductive substances in the presence of others. Actual conductivity is temperature dependent. As water becomes less viscous at high temperatures, ions move more easily.

The Aqua TROLL 200 measures actual conductivity by applying a controlled excitation voltage across electrodes in the solution and measuring the resulting electric current that flows between them. An internal factory calibration is then applied to convert the measured electric current into the actual conductivity of the solution.

In order to prevent altering the solution by major ionic movement or electrochemical reactions at the electrodes, an alternating current is used. By using an alternating current, the polarity of the applied excitation voltage changes frequently enough that ions do not significantly move between, or react with, the electrodes. The instrument controls both the magnitude of the applied voltage and its frequency to optimize performance over its operating range.

The conductivity cell utilizes six titanium electrodes, three on each side of the cell. The two outer electrodes on each side are drive electrodes. The center electrodes on each side are sense electrodes. The drive electrodes apply the excitation voltage symmetrically about the sense electrodes. Because the drive electrodes carry current, they are subject to fouling and must be compensated to maintain an accurately controlled drive voltage. The sense electrodes are used to make high impedance voltage measurements. Since the high impedance measurements draw negligible current, the sense electrodes are much less susceptible to fouling. A control loop within the Aqua TROLL 200 continually adjusts the voltage applied to the drive electrodes to keep the voltage measured at the sense electrodes, and thus the voltage applied across the cell, constant. To prevent interference from other electrical sources that may be present in the solution, both the drive and the sense electrodes are electrically isolated from the instrument's external power and communication signals.

Factory calibration of the actual conductivity parameter consists of making measurements in several precision conductivity solutions spread over the operating range of the instrument. The factory calibration takes into account the physical geometry of the instrument's conductivity cell and normalizes the cell constant to a value of one across its entire operating range. The Aqua TROLL 200 is capable of meeting its published accuracy specifications without requiring additional calibration by the user.

Provision is made for the user to calibrate the actual conductivity parameter by adjusting the cell constant. The instrument should only require a user calibration if its measurement cell has undergone physical change (deposits on the cell walls or on the electrodes that cannot be removed, physical damage to the cell walls or electrodes, etc.). The user may also need to calibrate the instrument to conform to a standard operating procedure. The user calibration takes the following form:

$$AC = K \times AC_f + K_0$$

Where:

AC = reported actual conductivity

K = cell constant (default = 1)

K_0 = cell offset (default = 0)

AC_f = factory calibrated actual conductivity

When K and K_0 are set or restored to their default values, the factory calibrated actual conductivity is reported.

A simple one-point calibration is performed by measuring a precision conductivity standard using the default factory calibration, then calculating a new cell constant as follows.

$$K = \text{Standard Value} / \text{Measured Value}$$

The cell offset K_0 is only used when two standards are measured to determine a straight line calibration, or three or more standards are measured to determine a best-fit straight line. K is then the slope of the line and K_0 is the offset.

The internal unit of measure for actual conductivity is microsiemens per centimeter (µS/cm). All derived parameter equations use this internal unit of measure. Changing the reported units of the parameter does not affect internal calculations.

Temperature

The Aqua TROLL 200 measures the solution temperature using a precision thermistor encapsulated in a titanium button. The temperature parameter is factory calibrated by taking several temperature measurements over the operating range of the instrument and curve fitting these to measurements taken at the same time by a precision reference thermometer. The temperature parameter will meet its published accuracy specifications without requiring additional calibration by the user. No provision is made for user calibration of this parameter.

The internal unit of measure for temperature is degrees Celsius (°C). All derived parameter equations use this internal unit of measure. Changing the reported units of temperature does not affect internal calculations.

Specific Conductivity

Specific conductivity is a means of expressing what the actual conductivity of a solution would be at a standard reference temperature. It can be a useful way of observing changes in the conductivity of a solution independent of changes in temperature.

The Aqua TROLL 200 derives specific conductivity from its actual conductivity and temperature measurements using the following general equation.

$$SC = \frac{AC\,(\beta_0 + \beta_1 T + \beta_2 T^2 + \ldots + \beta_7 T^7)}{(1 + \alpha(T - T_{ref}))}$$

When the instrument's factory default coefficients for the general equation are used, specific conductivity is calculated per Standard Methods 2510B as shown below.

$$SC = \frac{AC}{(1 + 0.0191\,(T - 25))}$$

By leaving coefficient $\beta_0 = 1$ and coefficients β_1 through $\beta_7 = 0$, α can be set to temperature compensate different types of solutions and T_{ref} can be set to different reference temperatures.

By setting $\alpha = 0$ and $T_{ref} = 0$, the equation becomes a general polynomial that can accommodate more sophisticated temperature compensation schemes.

Salinity

The Aqua TROLL 200 derives salinity from actual conductivity and temperature using Standard Methods 2520A with low range extensions. Results are reported in Practical Salinity Units (PSU) and are suited to applications ranging from 0 to 42 PSU.

$$S = a_0 + a_1 R_t^{1/2} + a_2 R_t + a_3 R_t^{3/2} + a_4 R_t^2 + a_5 R_t^{5/2}$$
$$+ f(T)(b_0 + b_1 R_t^{1/2} + b_2 R_t + b_3 R_t^{3/2} + b_4 R_t^2 + b_5 R_t^{5/2})$$
$$- a_0 / (1 + 1.5X + X^2)$$
$$- b_0\, f(T) / (1 + Y^{1/2} + Y^{3/2})$$

Where:

$R_t = AC / (r_0 + r_1 T + r_2 T^2 + r_3 T^3)$

$X = 400\, R_t$

$Y = 100\, R_t$

$f(T) = (T - 15) / (1 + 0.0162\,(T - 15))$

The polynomial in the denominator of the R_t term is a proprietary curve fit that is used to calculate what the actual conductivity of a 32.4356 g KCl / kg reference solution would be at the same temperature as the sample solution. The following table defines the constants for the salinity equations.

Constant	Value	Constant	Value
a_0	0.0080	b_0	0.0005
a_1	-0.1692	b_1	-0.0056
a_2	25.3851	b_2	-0.0066
a_3	14.0941	b_3	-0.0375
a_4	-7.0261	b_4	0.0636
a_5	2.7081	b_5	-0.0144
r_0	29752.63	r_2	3.429338
r_1	830.5102	r_3	-0.02193934

Total Dissolved Solids

The concentration of total dissolved solids (TDS) is derived from specific conductivity using a simple, user definable conversion factor.

$$TDS = CF_{TDS} * SC$$

The default unit of measure for TDS is parts per million (ppm). The relationship of conductivity to concentration is not standardized. A "natural water" mineral composition that includes bicarbonates has a typical conversion factor of 0.6 to 0.7 ppm TDS per µS/cm. The Aqua TROLL 200 uses a default conversion factor of 0.65 ppm TDS per µS/cm.

Resistivity

Resistivity is simply the inverse of actual conductivity.

$$R\ (\text{ohm-cm}) = 10^6 / AC\ (\mu S/cm)$$

Resistivity is often used to report measurement results instead of actual conductivity in high purity water applications.

Density of Water

The Aqua TROLL 200 calculates the density of water from its salinity (S) and temperature (T) parameters using the following equation per Standard Methods 2520C.

$$\rho(g/cm^3) = (\rho_0 + aS + bS^{3/2} + cS^2) / 1000$$

Where:

$$\rho_0 = 999.842594 + 0.06793952T - 0.00909529T^2 + 1.001685e\text{-}4T^3 - 1.120083e\text{-}6T^4 + 6.536332e\text{-}9T^5$$

$$a = 0.824493 - 0.004089T + 7.6438e\text{-}5T^2 - 8.2467e\text{-}7T^3 + 5.3875e\text{-}9T^4$$

$$b = -0.00572466 + 1.0227e\text{-}4T - 1.6546e\text{-}6T^2$$

$$c = 0.000483140$$

Pressure

Pressure is the primary measurement parameter used by the Aqua TROLL 200 to derive level measurements. The pressure due to the column of water above the instrument is measured using a precision, temperature compensated, silicon strain gauge encapsulated behind a titanium diaphragm.

Gauge pressure instruments measure pressure at the diaphragm relative to atmospheric pressure by venting the backside of the strain gauge to the atmosphere through the cable connector and cabling system. Gauge pressure units automatically remove the effects of atmospheric pressure changes above the surface of the water; however they require some care to insure that the vent system does not become fouled.

Absolute pressure instruments measure pressure at the diaphragm relative to a vacuum that is sealed behind the strain gauge. Absolute pressure systems do not require a venting system and can be deployed without a cable; however, they do not automatically correct for barometric changes. Level data must be barometrically corrected after data is retrieved, reducing overall system accuracy and potentially increasing system costs.

Factory calibration of the pressure parameter consists of making several precision pressure measurements over the pressure range of the instrument at each of several precision temperatures. This data is fit to a multivariable equation that is used to convert the electrical signal of the strain gauge to a temperature corrected pressure.

The internal unit of measure for pressure is pounds per square inch (PSI). All derived parameter equations use this internal unit of measure. Changing the reported units of the parameter does not affect internal calculations.

The largest component of pressure sensor drift is the pressure offset at zero pressure. The Aqua TROLL 200 provides the capability for the user to zero the pressure parameter.

Depth

The Aqua TROLL 200 converts the pressure of a column of water above the instrument (P) to the depth of the instrument below the water's surface (D) using the following equation.

$$D = 0.70307 * P / SG$$

Where SG is the user defined constant for the specific gravity of the water or fluid. The default unit of measure for depth is meters (m).

Level (Surface Elevation)

Pressure is converted to a surface elevation using the following equation.

$$L = L_r + 0.70307 (P_m - P_r) / SG$$

Where P_r is the pressure measured by the instrument when the level reference L_r is set. This technique automatically corrects for any zero pressure offset error that the instrument may have accumulated. It is not necessary for the user to zero the pressure parameter when using the instrument in this level mode.

In the surface elevation mode, an increase in pressure (an increase in the water column above the instrument) indicates an increase in water level. A decrease in pressure (a decrease in the water column above the instrument) indicates a decrease in the water level.

Level (Depth to Water)

The depth to water mode is particularly useful when measuring inside a well, where it is a common practice to measure the distance from the top of the well down to the water level. Pressure is converted to depth to water using the following equation.

$$L = L_r - 0.70307 (P_m – P_r) / SG$$

Where P_r is the pressure measured by the instrument when the level reference L_r is set. As with the surface elevation mode, this technique automatically corrects for any zero pressure offset error that the instrument may have accumulated. It is not necessary for the user to zero the pressure parameter when using the instrument in this level mode.

In the depth to water mode, a decrease in pressure (an decrease in the water column above the instrument) indicates an increase in the depth to water. An increase in pressure (an increase in the water column above the instrument) indicates a decrease in the depth to water.

Automatic Density Correction

The Aqua TROLL 200 provides the capability of automatically and continuously correcting its depth and level parameters for changes in water density due to changes in salinity. This can improve the accuracy of depth and level measurements in estuaries and coastal waters where tides and rainfall continuously affect the local salinity.

Automatic density correction is enabled by programming the local gravitational correction factor CF_g to a non-zero value. With each reading, the Aqua TROLL 200 will determine the current value for the specific gravity of the water using the following equation.

$$SG = \rho * CF_g$$

Where ρ is the water density parameter calculated from the measured conductivity and temperature. To calculate CF_g, first calculate the acceleration due to gravity at the local latitude (Φ) in degrees and the local elevation above sea level (H) in kilometers as follows.

$$g = 9.780356(1 + 0.0052885\sin^2(\Phi) – 0.0000059\sin^2(2\Phi)) – 0.003086H$$

The local gravitational correction factor is then calculated as the ratio of the local gravitational acceleration to the average gravitational acceleration on the earth.

$$CF_g = g / 9.80665$$

Note that if CF_g is set to zero, the instrument will revert to its default calculation of depth and level using the user specified constant for specific gravity.

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