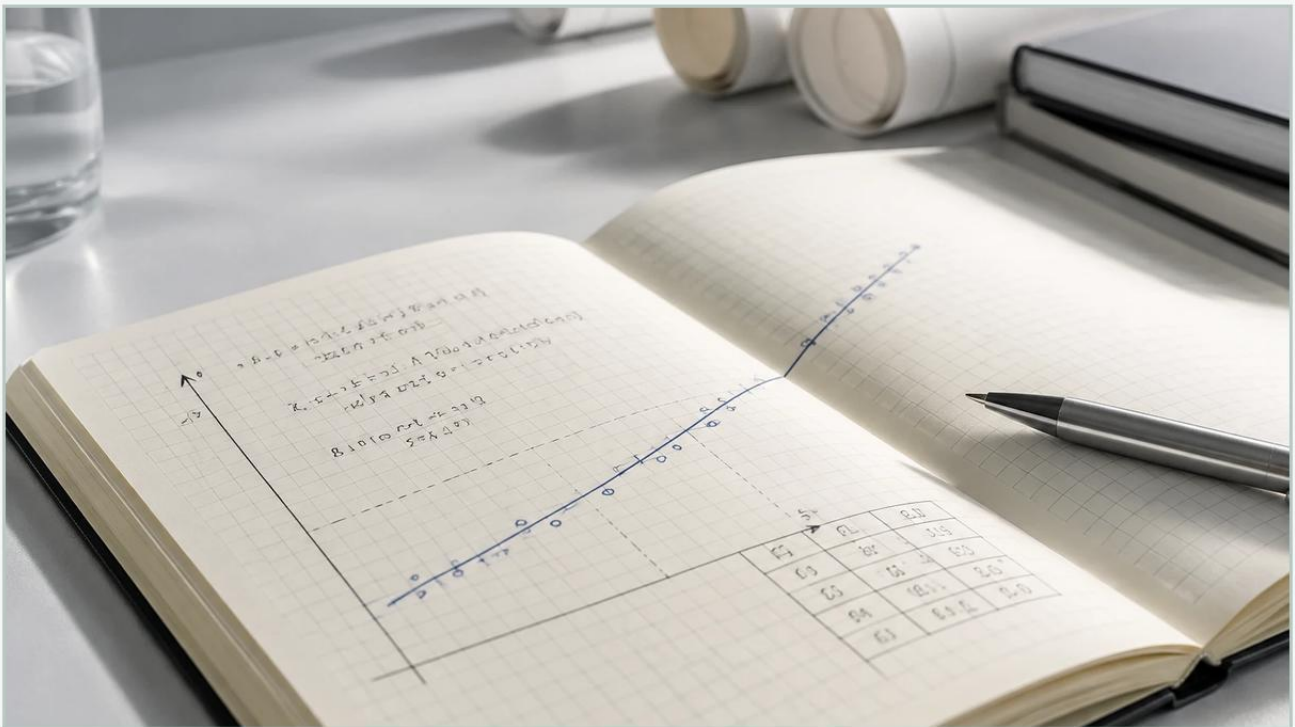


Callendar Van Dusen Equation

A practical guide to callendar van dusen equation, covering the reader intent, the relationship to callendar van dusen equation, key evaluation criteria, common risks, and the information the intended project audience should confirm before taking the next step.



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In the realm of industrial process control and automation, precision is the cornerstone of safety and efficiency. Among the various sensors used to monitor environmental and process conditions, Resistance Temperature Detectors (RTDs) are favored for their stability and accuracy. However, to translate the raw electrical resistance of a platinum sensor into a precise temperature reading, engineers rely on a specific mathematical framework: the Callendar Van Dusen equation. This equation is fundamental for characterizing platinum RTDs, which are frequently integrated into complex level measurement systems to provide temperature compensation and ensure data integrity.

| Introduction to RTD Temperature Measurement

Resistance Temperature Detectors (RTDs) operate on the principle that the electrical resistance of a metal changes in a predictable manner with temperature. Platinum is the preferred material for high-precision industrial RTDs (such as the common Pt100 or Pt1000) due to its chemical inertness, wide temperature range, and highly linear resistance-to-temperature relationship.

While the relationship is largely linear, it is not perfectly so. For basic industrial applications, a simple linear coefficient (the Alpha value) might suffice. However, as temperature ranges widen or accuracy requirements become more stringent—such as in chemical processing or cryogenic storage—a more sophisticated model is required. The Callendar Van Dusen equation provides this model, allowing for the correction of non-linearities across a broad spectrum of temperatures, typically from -200°C to 850°C.

In industrial automation, these sensors are rarely used in isolation. They are often embedded within or paired with instruments found on our Main Page, such as hydrostatic level transmitters or ultrasonic sensors, where temperature fluctuations directly impact the density of the medium or the speed of signal propagation.

| Understanding the Callendar Van Dusen Equation

The Callendar Van Dusen equation was developed through the combined work of British physicist Hugh Longbourne Callendar in 1887 and later refined by Milton S. Van Dusen in 1925. Callendar originally established the equation for temperatures above 0°C, while Van Dusen added a fourth term to account for the non-linear behavior of platinum at sub-zero (cryogenic) temperatures.

The equation is expressed in two forms depending on the temperature range being measured.

For Temperatures Above 0°C

For the range of 0°C to 850°C, the equation is a second-order polynomial:

$$R_t = R_0 [1 + At + Bt^2]$$

For Temperatures Below 0°C

For the range of -200°C to 0°C, an additional term is added to account for the increased curvature of the resistance-temperature plot:

$$R_t = R_0 [1 + At + Bt^2 + C(t - 100)t^3]$$

Where:

R_t : The resistance at temperature t (in Celsius).

R_0 : The resistance at 0°C (e.g., 100 Ω for a Pt100 sensor).

A, B, C : Coefficients derived from the specific calibration of the platinum wire.

| The Coefficients: Alpha, Delta, and Beta

In practical engineering, the $A, B,$ and C coefficients are often derived from three other parameters: Alpha (α), Delta (δ), and Beta (β). These parameters describe the physical characteristics of the platinum used in the sensor.

1. Alpha (α): This is the temperature coefficient of resistance (TCR). It represents the average change in resistance per degree Celsius between 0°C and 100°C. The most common standard is the DIN/IEC 60751, which specifies an Alpha of 0.00385055 $\Omega/\Omega/^{\circ}\text{C}$.
2. Delta (δ): This describes the deviation from linearity at higher temperatures. It is typically determined by measuring the resistance at a third point, such as the freezing point of zinc (419.53°C).
3. Beta (β): This is the Van Dusen constant, used only for temperatures below 0°C. It corrects the curve at cryogenic levels and is determined by testing at a point like the boiling point of oxygen (-182.96°C).

The mathematical relationship between these parameters and the A , B , C coefficients is as follows:

$$A = \alpha \left(1 + \frac{\delta}{100} \right)$$

$$B = -\alpha \frac{\delta}{10000}$$

$$C = -\alpha \frac{\beta}{100,000,000} \text{ (only for } t < 0^{\circ}\text{C)}$$

| Role in Industrial Level Measurement

Precise temperature data via the Callendar Van Dusen equation is vital for the accuracy of various level measurement technologies. Level measurement is rarely just about distance; it is about mass, volume, and pressure, all of which are temperature-dependent.

Hydrostatic Level Transmitters

Hydrostatic level sensors measure the pressure exerted by a liquid column. However, pressure is a function of both height and density ($P = \rho gh$). Since the density (ρ) of liquids changes with temperature, a hydrostatic sensor must know the exact temperature of the fluid to calculate the true level. Using a high-precision RTD characterized by the CVD equation allows the transmitter's electronics to perform real-time density correction.

Ultrasonic and Radar Level Meters

In ultrasonic level measurement, the sensor calculates distance based on the time-of-flight of a sound wave. The speed of sound in air or gas varies significantly with temperature. An integrated RTD provides the necessary temperature input to the processing unit. While radar (microwave) sensors are less affected by temperature than ultrasonic ones, extreme temperature fluctuations can still affect the dielectric constant of the vapor space or the physical dimensions of the tank, requiring temperature compensation for the highest level of accuracy.

Selection and Calibration Criteria

When selecting an RTD for an industrial application, engineers must choose between using "standard" coefficients or "sensor-specific" coefficients. Most industrial RTDs follow the IEC 60751 standard curve. However, for critical B2B applications where sub-degree accuracy is required, a process called "sensor characterization" is used.

Accuracy Classes

RTDs are categorized into classes based on their tolerance. The following table outlines the common standards:

Accuracy Class	Tolerance at 0°C	Temperature Range	Application Suitability
Class AA (1/10 DIN)	±0.10°C	0°C to 150°C	Laboratory and high-precision calibration
Class A	±0.15°C	-30°C to 300°C	Critical chemical and pharmaceutical processes
Class B	±0.30°C	-50°C to 500°C	General industrial level and flow monitoring
Class C	±0.60°C	-106°C to 600°C	Non-critical environmental monitoring

Calibration and Characterization

If an application requires higher accuracy than Class A, the specific RTD can be calibrated at several fixed temperature points. The resulting resistance values are then used to solve for the unique A , B , and C coefficients of that specific sensor. These unique Callendar Van Dusen constants are then programmed into the transmitter or PLC (Programmable Logic Controller) to virtually eliminate sensor interchangeability errors.

Practical Installation and Limitations

To maintain the accuracy provided by the Callendar Van Dusen equation, several installation factors must be considered:

1. **Lead Wire Resistance:** The resistance of the wires connecting the RTD to the transmitter can introduce significant errors. In industrial settings, 3-wire or 4-wire configurations are mandatory to compensate for or eliminate lead wire resistance.
2. **Self-Heating:** To measure resistance, a small current must be passed through the RTD. This current generates heat (I^2R), which can artificially raise the sensor's temperature. High-quality transmitters limit the excitation current (typically to <1 mA) to minimize this effect.
3. **Immersion Depth:** If the sensor is not sufficiently immersed in the process medium, heat conduction along the sensor sheath (stem effect) can lead to inaccurate readings.
4. **Response Time:** RTDs generally have a slower response time than thermocouples. In fast-moving processes or where level changes rapidly alongside temperature, the thermal lag must be accounted for in the control logic.

Limitations of the CVD Equation

While the Callendar Van Dusen equation is the industry standard, it is an empirical fit. At extremely high temperatures (above 660°C) or extremely low temperatures (below -200°C), the equation's accuracy begins to degrade. For cryogenic applications below the boiling point of oxygen, the ITS-90 (International Temperature Scale of 1990) standard provides a more complex but more accurate set of reference functions.

Frequently Asked Questions (FAQs)

1. Can I use the Callendar Van Dusen equation for thermocouples?

No. The CVD equation is specifically designed for the resistance-temperature relationship of platinum RTDs. Thermocouples operate on the Seebeck effect (voltage generation) and use different polynomial sets for linearization.

2. What is the difference between Pt100 and Pt1000 in the context of the CVD equation?

The coefficients (A , B , C) remain the same for both, as they describe the properties of the platinum material. The only difference is the R_0 value (100 Ω vs. 1000 Ω). Pt1000 sensors are often preferred in 2-wire applications because the lead wire resistance has a proportionally smaller impact on the total resistance.

3. How often should RTDs be re-calibrated?

In stable industrial environments, RTDs are known for their long-term stability. However, mechanical shock, vibration, or thermal cycling can cause the platinum wire to strain, shifting the CVD constants. Annual calibration is standard for most B2B process industries.

4. Where can I find instruments that support CVD characterization?

Modern digital transmitters and signal conditioners are designed to accept custom coefficients. For a range of industrial-grade measurement solutions that utilize these technologies, you can explore the product offerings on our [Main Page](#).

By understanding and correctly applying the Callendar Van Dusen equation, engineers ensure that their temperature and level measurement systems operate with the highest possible precision, reducing waste and enhancing safety in complex industrial environments.