

# TECH NOTE

## Callendar-Van Dusen Equation and RTD Temperature Sensors

### OVERVIEW

This technical note discusses characteristics of resistance temperature detectors (RTD), the Callendar-Van Dusen equation, and compares RTDs with thermistors.

### CALLENDAR-VAN DUSEN

RTDs are used to measure temperature by correlating the resistance of the RTD with temperature. This correlation between the resistance and temperature of the RTD is described by the Callendar-Van Dusen equation.

For Temperature:  $-200^{\circ}\text{C} \leq t \leq 0^{\circ}\text{C}$ ,

$$R_T = R_0[1 + AT + BT^2 + (t - 100)CT^3] \quad (1)$$

Where:  $R^T$  = Resistance at Temperature,  $T$

$R_0$  = Resistance at  $0^{\circ}\text{C}$

$T$  = Temperature in  $^{\circ}\text{C}$

Equation (1) is the complete version of the Callendar-Van Dusen equation. A, B and C are known as the Callendar-Van Dusen constants, defined by the following equations:

$$A = \alpha + \frac{\alpha\delta}{100}$$

$$B = \frac{-\alpha\delta}{100^2}$$

$$C = \frac{-\alpha\beta}{100^4}$$

Alpha, beta and delta are constants that are found with the following equations:

$$\alpha = \frac{R_{100} - R_0}{100 + R_0}$$

$$\beta = \text{constant if } t < 0^{\circ}\text{C, else zero}$$

$$\delta = \frac{R_0[1+\alpha(260)] - R_{200}}{4.16R_0\alpha}$$

Beta is found empirically and is constant at temperatures less than  $0^{\circ}\text{C}$ ; for temperatures greater than  $0^{\circ}\text{C}$ , beta is zero. As can be seen from the equation for C, if beta is found to be zero when temperatures are above  $0^{\circ}\text{C}$  then C is zero. When C is zero the complete version of the Callendar-Van Dusen equation can be simplified.

For Temperature:  $0^{\circ}\text{C} \leq t \leq 661^{\circ}\text{C}$ ,

$$R_T = R_0(1 + AT + BT^2) \quad (2)$$

Equation (1) is typically used for temperatures below  $0^{\circ}\text{C}$ , whereas equation (2) is used for temperatures above  $0^{\circ}\text{C}$ . When equation (2) is used for temperatures below  $0^{\circ}\text{C}$  there is some error associated with the calculated resistance. As seen in Figure 1, the error due to the use of Equation (2) grows exponentially. Below  $-100^{\circ}\text{C}$  the error is too significant to justify using equation (2) in place of equation (1).



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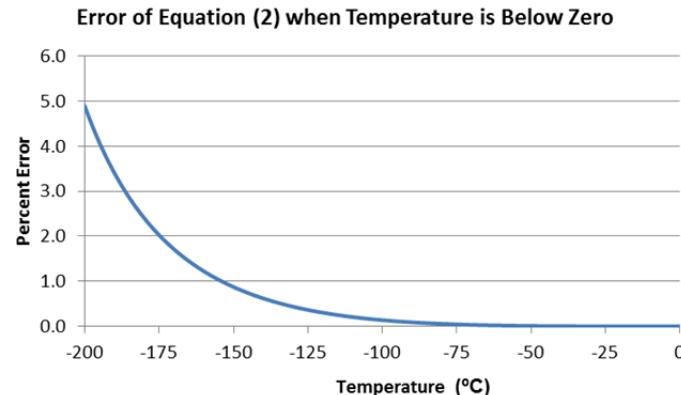


FIGURE 1: Callendar-Van Dusen Equation Comparison; Error Caused by Using Equation (2) for Temperatures Below Zero

## RTDs and THERMISTORS

The Callendar-Van Dusen equation that is detailed above is for platinum RTDs. RTDs come in various pure metals such as: platinum, nickel, and iron. Platinum is the most commonly used material for RTDs because of its wide temperature range, accuracy, stability and linearity. Platinum RTDs have positive temperature coefficients, meaning their resistance increases with increases in temperature. The typical sensitivity for platinum RTDs is  $0.4\Omega/\text{°C}$ . Sensitivity is the change in resistance for every  $1\text{°C}$  change in temperature. This low sensitivity is well suited for a RTDs' wide temperature range.

When compared to other temperature sensitive devices, such as thermistors, RTDs have better performance. Thermistors can have positive or negative temperature coefficients. A typical  $10k\Omega$  thermistor sensitivity is  $-1699\Omega/\text{°C}$  at  $0\text{°C}$ . This higher sensitivity and the thermistors' smaller temperature range give the thermistor a non-linearity which is not favorable over wider temperature ranges, which can be seen in Figure 2.

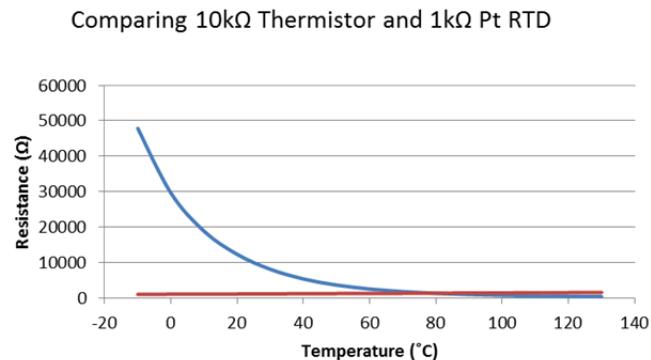


FIGURE 2: Comparing  $10k\Omega$  Thermistor and  $1k\Omega$  Pt RTD;  $10k\Omega$  Thermistor Blue Line,  $1k\Omega$  Pt RTD Red Line

## CONCLUSION

Selecting either a RTD or a thermistor is entirely dependent upon the experiment and needed results. If the experiment calls for a wide temperature range, a RTD is the best component to use. The low sensitivity and the wide temperature range will provide the best results. On the other hand, if the temperature range is narrow then a thermistor will provide greater sensitivity to temperature change. Thermistors should be selected for the temperature range they will be used for. Using a  $10k\Omega$  thermistor near  $25\text{°C}$  is an optimal choice, but using the same  $10k\Omega$  thermistor near  $0\text{°C}$  may not be optimal due to very high sensitivity. A better choice may be a  $3k\Omega$  thermistor that has a resistance close to  $10k\Omega$  near  $0\text{°C}$  and a more reasonable sensitivity. A major disadvantage of platinum RTDs is the cost, which is typically in the tens of dollars. Thermistors, however, typically cost less than a dollar. This cost tradeoff is why thermistors are more commonly used in the industry than platinum RTDs.