<u>**Transient response of thermocouples**</u>

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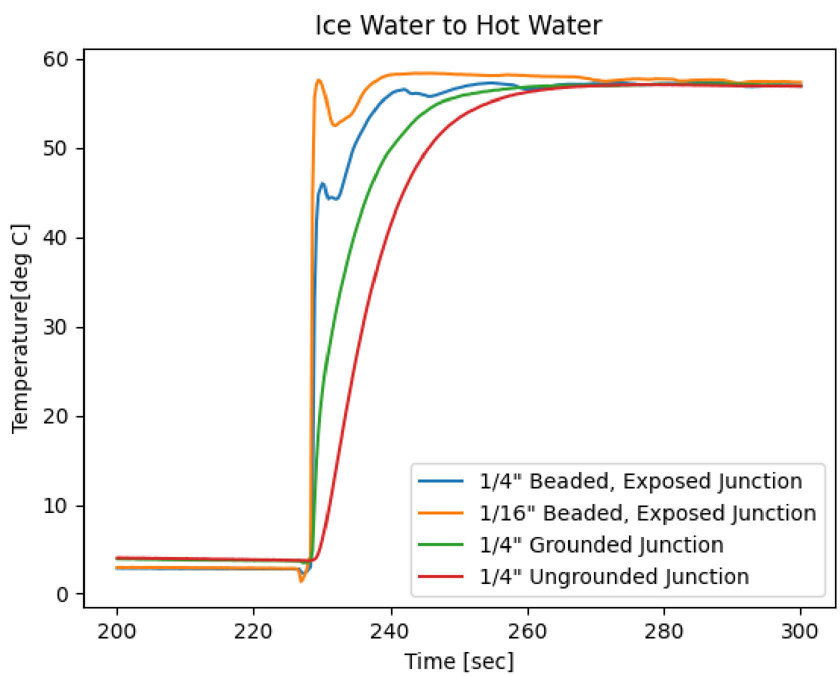
In this study, the transient response of four different thermocouple probes were investigated. The experiment involved immersing the junctions of these probes in water samples at various temperatures for three distinct tests. The objective was to compare their response times as they reached the new temperature. The four thermocouples used in the experiment were all Type K thermocouples with different specifications: a 1⁄4" diameter grounded junction, a 1⁄4" diameter ungrounded junction, a 1⁄4" diameter beaded exposed junction, and a 1⁄16" diameter beaded exposed junction. These thermocouples were mounted on a stand, allowing them to be simultaneously submerged in the water samples. The tests consisted of moving the thermocouples through different temperature transitions. These transitions included moving from hot water to ice water, from ice water to hot water, and from hot water to room temperature after drying the probes. Following the experimental setup and tests, the temperature versus time data obtained from the thermocouples was computed using the LabVIEW software. We then exported the data to a .txt file, converted it to an excel file, and used Python to analyze the data.

Upon analyzing the LabVIEW results, we were able to establish the sequence of temperature changes from fastest to slowest for the four thermocouple junctions. In the initial test, transitioning from hot water to ice water, the order of speed in temperature change was as follows: 1⁄16" beaded exposed junction exhibited the fastest response, followed by the 1⁄4" beaded exposed junction, the 1⁄4" diameter grounded junction, and finally, the 1⁄4" ungrounded junction. When moving from ice water to hot water and from hot water to room temperature air after the probes had been dried off with paper towels, the order remained consistent. In all these tests, the exposed junctions consistently demonstrated a quicker response compared to the shielded junctions.

The thermocouples responded in the expected order based on the time constants, τ_{Omega}. The 1⁄16" beaded exposed junction was the fastest since it has the smallest time constant value $\tau_{\text{Omega}} = 0.15$, meaning it has the quickest response to changes in temperatures. On the other hand, the 1⁄4" ungrounded junction has a time constant $\tau_{\text{Omega}} = 2.25$, resulting in a significantly slower response time to temperature change.

Figure 7 - Ice Water to Hot Water



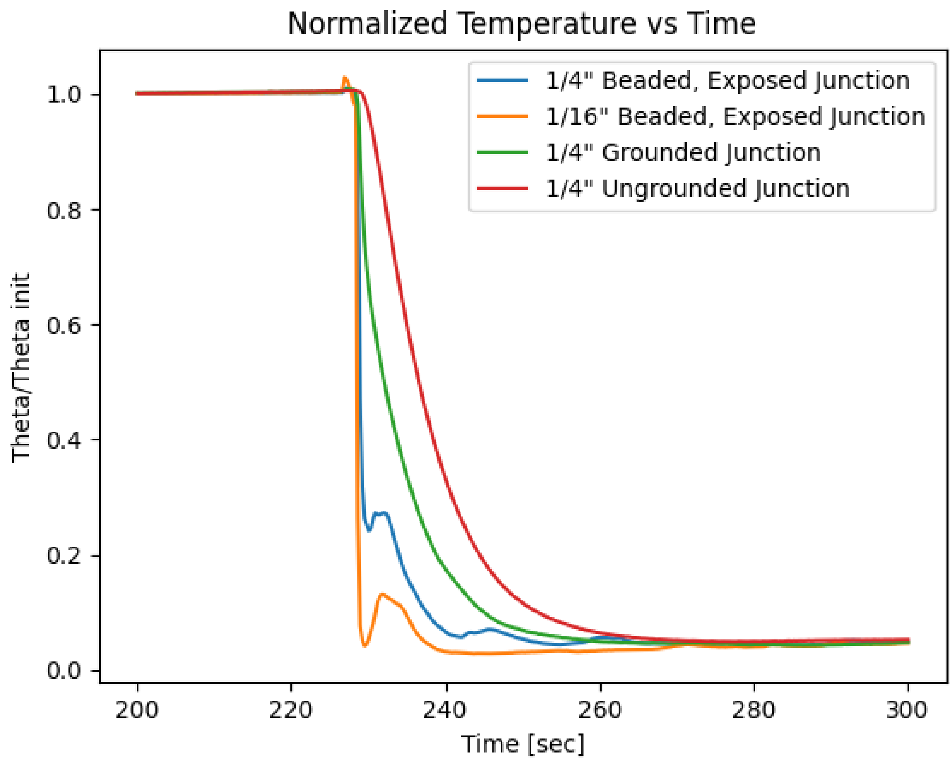
By zooming in on a specific time frame, we can see in more detail that the 1⁄16" beaded exposed junction thermocouple is able to transition from the ice water temperature to the hot water temperature extremely quickly. It is followed by the 1⁄4" beaded exposed junction, then the 1⁄4" grounded junction, and lastly, the 1⁄4" ungrounded junction in response time. When we transitioned from hot water to cold water, we had the same results, with the 1⁄16" beaded exposed junction thermocouple being the fastest to respond.

Due to variance and inconsistent steady state and initial temperature readings, we needed a way to analyze the data more accurately. We utilized a normalized temperature response using the following equation:

$$\frac{\theta}{\theta_i} = \frac{T(t) - T_\infty}{T_i - T_\infty}$$

Using Python, we were able to manipulate the y axis values following the equation above. In doing so, we created the following graph:

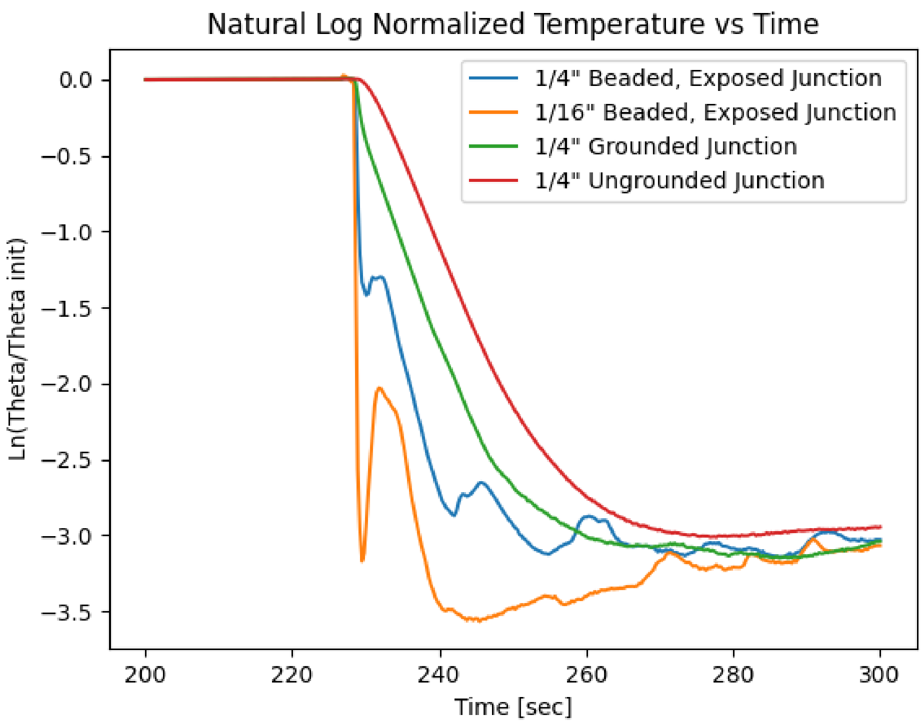
Figure 8 - Normalized Temperature v Time



Since this graph is now normalized for values between 0 and 1, we are able to better understand the response of each of the thermocouples. A value around 1 indicates the starting point, whereas a value near 0 indicates the end point. The order of junctions from fastest to slowest aligns with the temperature versus time graph, ranging from ice water to hot water. Notably, quicker junction responses correspond to steeper slopes on the graph. This is visually evident as the slopes change from sharp straight lines to gradual curves, reflecting the transition from faster to slower responses.

To further analyze the data more accurately and account for variance, we created a log normalized temperature response by taking the log base e of the normalized temperature and plotting it vs time. As a result, we were able to create the following graph:

Figure 9 - Natural Log Normalized Temperature v Time



When examining the natural log normalized temperature vs. time graph, the key observations are the slopes of the linear segments associated with each junction. A smaller slope signifies a slower temperature change, whereas a larger slope indicates a faster change in temperature. This distinction is evident in the graph, where the 1⁄16" beaded exposed and 1⁄4" beaded exposed junctions reach the final temperature more quickly due to their steeper slopes. On the other hand, the remaining two junctions exhibit smaller slopes and consequently take a longer time to reach the final temperature. This pattern aligns with the previously discussed sequence of fastest to slowest temperature changes, ranging from ice water to hot water.

The thermal time constant, τ_{Omega}, represents the time it takes for the temperature to reach 63.2% of steady state temperature. The equation below is used to calculate the thermal time constant:

$$\tau = \frac{\rho V c}{h_c A}$$

As shown in the equation, τ is directly related to the density, volume, specific heat, surface area, and the surface heat transfer coefficient of the measured medium. From this, we can deduce that a thermocouple with a smaller diameter, like the 1/16" thermocouple, will have a much faster response than the other ¼" thermocouples.

From an experimental approach, we can use the negative inverse slope of the linear section of our created log normalized graphs to calculate the thermal time constant, $\tau_{Calculated}$. The following equations represent the relationship between our graphed values and the thermal time constant:

$$ln\left(\frac{\theta}{\theta_i}\right) = \frac{-1}{\tau}t$$

We were able to use the equations above to calculate the thermal time constant, $\tau_{Calculated}$, and compare them to the expected values, τ_{Omega}, in the table below:

Table 3 - Probe Constants

Probe type	$\boldsymbol{\tau}$ **Calculated**	$\boldsymbol{\tau}$ **Omega**
1/4" D, ungrounded junction	9.26	2.25
1/4" D, grounded junction	8.03	1.00
1/4" D, beaded exposed junction	1.10	0.25
1/16" D, beaded exposed junction	0.36	0.15

It is important to note that we only use the initial region when calculating the thermal time constant, since that time constant corresponds to the transient at 63.2% of the final temperature that is being measured.