Temperature Measurements

1. **OBJECTIVES:**

This experiment includes the construction, calibration, and use of a thermocouple. The time response is determined and validated. A digital thermometer is also used to measure temperature.

2. **EQUIPMENT:**

- Thermocouple Assembly Kit
- Thermocouple Amplifier Assembly
- Temperature indicator and probes
- Thermocouple Wire
- Recording Oscilloscope or A/D converter
- Boiling Water
- Ice water

3. **INTRODUCTION:**

Thermocouples are simple in construction, made by connecting or welding two dissimilar metals together and measuring the voltage between them. Once constructed, they are calibrated by measuring known temperatures. Boiling and freezing points of liquids are the most commonly used calibration temperatures.

Heating or cooling the probe is approximated by a first order rate equation [1].

\[
\frac{dT}{dt} = kT
\]  

(1)

Where: \( t \) is the time, \( T \) is the temperature difference between the thermocouple and its surroundings, and \( k \) is the constant for thermal-conductivity.

It should be apparent that the larger the conductivity, or \( k \), the faster the temperature will change.

Solving the rate equation, as explained in section 5.15.1, yields [2], which shows an exponential relationship between the temperature difference and time.

\[
\theta = \frac{T - T_\infty}{T_o - T_\infty} = e^{\frac{t}{\tau}}
\]  

(2)
Where: \( \theta \) is the non-dimensional relative temperature, \( T \) is the current probe temperature, \( T_0 \) is the initial probe temperature (temperature at \( t=0 \)), \( T_\infty \) is the temperature of the surrounds, which is the probe temperature at \( t=\infty \), and \( \tau \) is the time constant.

The non-dimensional temperature \( \theta \) was created to represent the current relative temperature. Simply explained, it is the current difference in temperatures over the final difference in temperatures. From this, it follows that for any system, heating or cooling, \( \theta \) will start at 1 \((t=0)\) and go to 0 \((t=\infty)\).

Conduction and convection are represented by \( \tau \), which is known as the time constant. From [2], it can be seen that as \( \tau \) decreases, the rate of cooling increases. For the case of a probe in water, [3] gives an approximation of the time constant.

\[
\tau = \frac{m \cdot c}{h \cdot A}
\]  

(3)

Where: \( m \) is the mass of the probe being heated, \( c \) is the specific heat of the probe, \( h \) is the convection coefficient between the fluid and probe, and \( A \) is the Surface area of the probe.

Note:

This idealization does not fully represent the physical system seen in the lab. There are different materials in the construction of the probe, so \( c \) is not a constant. Heat must also travel from the outer sleeve of the probe to the material junction, so conduction is also involved. Finally, the entire probe cannot be put in the water, so heat will be entering the lower part of the probe and being lost through the upper part.

4. PROCEDURE:

1. Select a thermocouple type to construct. Materials are available for K, T, J and E type thermocouples. Construct the thermocouple using the method demonstrated by your TA.

2. Connect the thermocouple to the data acquisition system. Use the boiling and ice water to calibrate the thermocouple. Save the data to a floppy disk for analysis. The file format is set up for importing to Excel as a comma-delimited file.

3. Measure temperature variation with time of the thermocouple. Take at least 3 cooling measurements and 3 heating measurements. Make sure the probe temperature has adequate time to stabilize between measurements. This can be combined with step 2 if desired.

4. Take calibration measurements for the pre-manufactured surface probe using the boiling and ice water. Time constant calculations are not necessary for this.

5. REPORT REQUIREMENTS:

5.1 Theory

1. Explain and compare the Seebeck, Peltier, and Thomson effects.

2. Describe the type of thermocouple made by your group. This should include usable temperature range, color, materials, and anything else specific to your thermocouple.

3. Explain first order dynamic response (textbook p.179 – 182) and how this can be used with an exponential curve fitting on Excel for the calculation of time constant

5.2 Results and Analysis

1. Give the calibration curves and equations (use the linear curve fit on EXCEL) for the thermocouple and pre-manufactured probe.

2. Graph the heating and cooling curves of the thermocouple. If temperatures are used, they must be corrected with the calibration equation.

3. Calculate the time constants for the thermocouple using the exponential curve fit on EXCEL. Compare the heating and cooling curves with the exponential curve fit. How good is this curve fit? How well do the heating and cooling curves match? Explain any differences.

(Hint: In order to get the time constant, you should plot the temperature vs. the normalized temperature, $\theta$. Also time shifting method and tail cutting method you have learned in the class should be used)

4. Quantify and compare the uncertainty of the pre-manufactured probe and your own thermocouple.

(last update: August 21, 2001)